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GEOLOGICAL SURVEY CIRCULAR 170

SEDIMENTATION AND CHEMICAL QUALITY OF WATER IN THE POWDER RIVER DRAINAGE BASIN WYOMING AND MONTANA

By C. H. Hembree, B. R. Colby, H. A. Swenson, and J. R. Davis

Prepared as part of a program of the
Department of the Interior for
Development of the
Missouri River Basin

UNITED STATES DEPARTMENT OF THE INTERIOR
Oscar L. Chapman, Secretary

GEOLOGICAL SURVEY
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SEDIMENTATION AND CHEMICAL QUALITY OF WATER IN THE POWDER RIVER DRAINAGE BASIN, WYOMING AND MONTANA

ABSTRACT

In the spring of 1946 the United States Geological Survey began a systematic investigation of fluvial sediments and dissolved minerals in streams of the Powder River drainage basin in Wyoming and Montana. This report gives the preliminary results that were obtained prior to October 1, 1950. As part of the investigation, eight sediment stations and seven chemical-quality stations were operated for periods of 4 months to about 4½ yr.

A reconnaissance study was made of the geology of the area and its effect on sedimentation and the chemical quality of the water. The rocks in the basin range in age from pre-Cambrian to Recent. Mesozoic and Tertiary rocks underlie the areas outside the mountains, which are also the areas of high sediment yield.

The topography of the Powder River drainage basin ranges in type from rugged mountains to semiarid plains. The mountainous areas are underlain by pre-Cambrian and Paleozoic rocks, which are very resistant to erosion. Most of the drainage basin is a part of the Great Plains province. Precipitation is low over the plains, and most of the runoff is in direct response to storms. Practically all streams rising in the plains are ephemeral or intermittent. Rocks underlying the plains areas are mostly erodible shales, siltstones, and sandstones; and the stream valleys have alluvial fills that are susceptible to erosion.

Average annual runoff varies from less than 1 in. over most of the plains area to more than 15 in. near the crest of the Bighorn Mountains. Most of the flow of the Powder River originates in the mountains. The mountain streams are clear and have steep gradients. Streams in the plains have low gradients and usually flow in sandy-bottomed, shifting channels.

Since April 4, 1946, records of suspended-sediment discharge have been obtained at Arvada, Wyo. Similar records have been obtained at the gaging station on the Middle Fork Powder River above Kaycee since April 22, 1949, and at six other gaging stations in the Powder River drainage basin since the spring of 1950. The average annual discharge of suspended sediment at the Arvada station for the period of record was about 5,500,000 tons, and the average annual water discharge was about 200,000 acre-ft, which is only two-thirds of the average annual discharge for the period of stream-flow records at Arvada. The concentrations and discharges of suspended sediment were low at gaging stations on Clear Creek near Arvada, Crazy Woman Creek near Arvada, and the Middle Fork Powder River above Kaycee. Most of the water that passes these stations comes from the mountains; much of this water is melted snow. Records of suspended-sediment discharge obtained at sediment stations during the water year 1949-50 are not representative because the water discharge for that year was nearly as low as the lowest annual discharge for the period that is covered by stream-flow records.

The study shows that the mountain areas have relatively high runoff and are minor sources of sediment. In contrast, the plains areas have low runoff and are major sources of sediment. The effects of fairly rapid erosion can be seen in most of the plains areas, but more rapid rates of erosion probably occur in badland areas, at gullies that are actively eroding, and on the outside edge of stream meanders. Erosion of alluvium from the valleys of main streams probably supplies much of the sediment that is transported by the Powder River.

The specific weight of a sediment deposit that might be formed from the suspended sediment of the Powder River at Arvada, Wyo., was computed to be 56 lb per cu ft when the deposit has not been compacted during a period of many years or under the weight of appreciable quantities of overlying deposits. This specific weight was based on the particle-size analyses of suspended-sediment samples from the Powder River at Arvada and on the relation between median particle size and specific weight of sediment deposits in reservoirs. From April 4, 1946, to September 30, 1950, the measured suspended-sediment discharge at Arvada was 26,146,000 tons. The initial volume of this quantity of suspended sediment after deposition at 56 lb per cu ft would be 21,420 acre-ft.

Three different equations were applied to compute discharge of sediment as bed load for the Powder River at Arvada. Results based on two of the equations were used to compute annual bed-load discharges of 190,000 tons and 160,000 tons at Arvada.

The chemical quality of the water in the Powder River drainage basin differs widely from one stream to another and is variable in each stream from headwaters to mouth. Geologic factors largely determine the nature and the amounts of dissolved solids that are transported by the Powder River and its tributaries. In mountainous regions that are underlain by igneous rocks of pre-Cambrian age the river water is dilute, and the mineral

content is composed mainly of calcium and carbonate; the concentration of dissolved solids for a water from this source is often less than 100 ppm. Where the Powder River drains an area of erodible shales and sandstones of Tertiary and Mesozoic age, the river water is much more concentrated, and the mineral content consists largely of sodium and sulfate. The concentration of soluble salts in this water sometimes exceeds 2,000 ppm. The chemical pattern of water in tributary streams varies from headwaters to mouth owing to geologic factors or to cultural influences, such as return irrigation flows.

The chemical analyses of over 100 water samples that were collected from three stations on the Powder River and from four stations on tributary streams during the period November 1945 to September 1950 show the quality of the water under varying conditions of flow. The periods of higher salt concentrations corresponded approximately with intervals of low water discharge, whereas days of lower salt concentrations were associated with days of high runoff. A basin salinity study of low flows established a salinity-discharge relationship for important streams in the basin.

As a source of irrigation supplies, the main stem waters at Arvada are rated, on the average, as permissible, as defined by Wilcox's classification of irrigation waters. Of 27 samples of water that were collected at Arvada during discharges of 1.5 to 2,110 cfs, 1 was rated as good, 17 as permissible, and 9 as doubtful for irrigation. The waters in tributary streams, in general, are of better quality.

The main stem waters contain objectionable amounts of dissolved minerals for ordinary domestic uses, whereas the tributary waters are, as a rule, of more satisfactory quality.

INTRODUCTION

Purpose and Scope of Investigation

The investigation of sedimentation and of the chemical quality of surface waters in the Powder River drainage basin was undertaken as a part of the program of the Department of the Interior for development of the Missouri River basin. The over-all plan for the basin includes the development of irrigation and hydroelectric power and the storage and regulation of flood waters. One of the requirements for successful planning of economically feasible projects in the basin is reliable information on fluvial sediments and on the chemical quality of the water.

The study of sedimentation in the Powder River drainage basin was begun to determine the quantity of sediment that is transported by the Powder River and its major tributaries, the probable specific weight of the sediment deposit as initially laid down in a reservoir, and the probable sources of sediment. This progress report summarizes the results to September 30, 1950.

On April 4, 1946, the Geological Survey installed a sediment station on the Powder River at Arvada, Wyo. Since that time seven additional sediment stations have been established on the Powder River and tributaries. The stations and the dates on which the collection of samples was begun are as follows:

South Fork Powder River near Kaycee, Wyo.	May 17, 1950
Powder River at Sussex, Wyo.	March 3, 1950
Powder River at Arvada, Wyo.	April 4, 1946
Powder River near Locate, Mont.	March 3, 1950
Middle Fork Powder River above Kaycee, Wyo.	April 22, 1949
Middle Fork Powder River near Kaycee, Wyo.	March 3, 1950
Crazy Woman Creek near Arvada, Wyo.	March 2, 1950
Clear Creek near Arvada, Wyo.	March 2, 1950

The records of suspended-sediment discharge for the Powder River at Arvada, Wyo., were supplemented by computed rates of sediment that is discharged as bed load.

Sediment discharge data collected at these stations for a sufficient period of time will give a measure of the probable quantity of sediment that will be transported by the streams over a long-term period. Size analyses of suspended-sediment samples, together with analyses of bed-material samples, will furnish data for computing the probable initial specific weight of the suspended sediment after deposition in a reservoir.

The network of sediment stations is arranged so that a comparison of the sediment loads measured at the stations will show the general areas where sediment yield is high. Preliminary field studies have been made to select the specific areas and the types of erosion that contribute most of the sediment to the Powder River. More intensive studies should be made before engineering works that are designed to reduce sediment yield are started.

In this study of the chemical quality of waters in the Powder River drainage basin the following four items were considered: the geochemistry of the basin waters, the quality of the water in relation to stream discharge, the rating or classification of these waters for irrigation, and the use of the waters for domestic needs. Of these items, the classification of the basin waters as to their suitability for irrigation was given the most attention inasmuch as this information has a direct bearing on further agricultural development of the basin.

Seven sampling stations for chemical-quality studies were established on the Powder River and key tributaries in the period from 1945 to 1949 to determine the quality of water. Stations on the Powder River were operated at Sussex, Wyo., at Arvada, Wyo., and near Locate, Mont. Stations maintained on tributaries were the Middle Fork Powder River near Kaycee, Crazy Woman Creek near Arvada, Clear Creek near Buffalo, and Clear Creek near Arvada, all in Wyoming. The stations on the Powder River furnish information on the change in the quality of the water in the river from headwaters to the mouth. The station near Locate measures the quality of the water that leaves the basin. Tributary stations except Clear Creek near Buffalo were established at points near the mouths of these tributaries.

A salinity study was made September 10 to 14, 1949, to determine the chemical character of the water in the basin during a period of low flow.

The geologic studies made during the investigation provide a background of information that is essential to the understanding and interpretation of the base data, both on sediment and chemical quality. The material carried by the streams in solution, in suspension, and as bed load was originally derived from the rocks in the basin. The geologic studies, therefore, included a review of pertinent published reports and a reconnaissance of the basin to study the rocks and their relationship to the sediment and minerals that are carried in suspension and in solution by the streams.

Previous Investigations

In 1938 the Corps of Engineers, U. S. Army, started a study of suspended sediments in the Powder River and its tributaries. This study continued through 1944, and some of the results of the study are contained in Supplement VI of a report on the Yellowstone River and tributaries by the office of the Corps of Engineers (U. S. Army, 1946, pp. T6 and T12a) at Fort Peck, Mont. The sediment stations and their periods of operation are as follows:

Powder River at Arvada, Wyo.	May to June 1938
Powder River at Moorhead, Mont.	April 1938 to April 1946
Middle Fork Powder River near Kaycee, Wyo.	May 1938 to January 1940
South Fork Powder River near Kaycee, Wyo.	May 1938 to March 1940
Clear Creek at Buffalo, Wyo.	April 1938 to March 1939

Many reports on the geology of the Powder River basin have been published, but most of them have been concerned primarily with oil and gas resources. So far as is known, geology has not been used to help in solving the sedimentation and quality-of-water problems of the area.

Personnel and Acknowledgments

This investigation is one of several being made by the U. S. Geological Survey in cooperation with other agencies of the Department of the Interior. The investigation was conducted by the Water Resources Division of the Geological Survey, C. G. Paulsen, chief hydraulic engineer, and S. K. Love, Chief of the Quality of Water Branch, Washington, D. C., and was under the general supervision of P. C. Benedict, regional engineer, Lincoln, Nebr.

The analytical work on the chemical quality of surface waters was supervised by H. A. Swenson, assisted by personnel of the office at Lincoln, Nebr.

Records of suspended sediment were obtained by personnel of the office at Worland, Wyo., under the supervision of T. F. Hanly.

Unpublished records of water discharge were furnished by F. M. Bell, district engineer, Geological Survey, Denver, Colo., and Frank Stermitz, district engineer, Geological Survey, Helena, Mont.

POWDER RIVER DRAINAGE BASIN

Location and Extent

The Powder River and its tributaries drain an area of about 13,400 sq mi (Congressional documents, 1934, p. 26) in northeastern Wyoming and southeastern Montana. More than half of the drainage basin is in Wyoming. The Powder River drainage basin is bounded on the southwest by the Bighorn Mountains. The rest of the boundary is formed by low divides that separate the basin from the drainage basins of the Tongue, Little Missouri, Belle Fourche, Cheyenne, North Platte, and Bighorn Rivers.

The South Fork, largest tributary of the Powder River, rises in the Rattlesnake Range near Ervay, Wyo., and flows northeastward to its junction with the Middle Fork a few miles east of Kaycee, Wyo. The Powder River, formed by the junction of the South and Middle Forks, flows eastward to a point a short distance downstream from Sussex, Wyo., where it turns abruptly and flows northeastward into an alluvial valley bordered by badlands (fig. 1) to join the Yellowstone River near Terry, Mont. The Powder River, including the South Fork, is about 480 miles long (Congressional documents, 1934, p. 26).

The principal tributary streams entering the Powder River downstream from Sussex are Crazy Woman Creek, Clear Creek, the Little Powder River, and Mizpah Creek. (See fig. 2.) All these streams except the Little Powder River drain areas to the west of the Powder River.

Topography

The topography of the Powder River drainage basin ranges from rugged mountains to semiarid plains. (See fig. 3.) Mountains, plateaus, uplands, lowlands, badlands, and river terraces form the varied landscape of the basin.

Except for a very small area drained by the Tongue River, the east slope of the Bighorn Mountains in Johnson and Natrona Counties, Wyo., is drained by streams tributary to the Powder River. The altitude of the Bighorn Mountains ranges from about 9,000 ft on the south to 13,165 ft at the top of Cloud Peak near the northwest corner of Johnson County. Cloud Peak is the culmination of a rugged area of granite ridges and glacial cirques in the high central part of the Bighorn Mountains. Most of the cirques are now free of ice, but a few at the base of Cloud Peak still contain remnants of once large mountain glaciers. The erosive action of the mountain glaciers--large rivers of moving ice--is evident on most of the topographic features of the central area.

The south part of the Bighorn Mountains is an extensive plateau dissected by deep stream-cut canyons. The plateau, built on the sedimentary rocks that arch over the crest of the

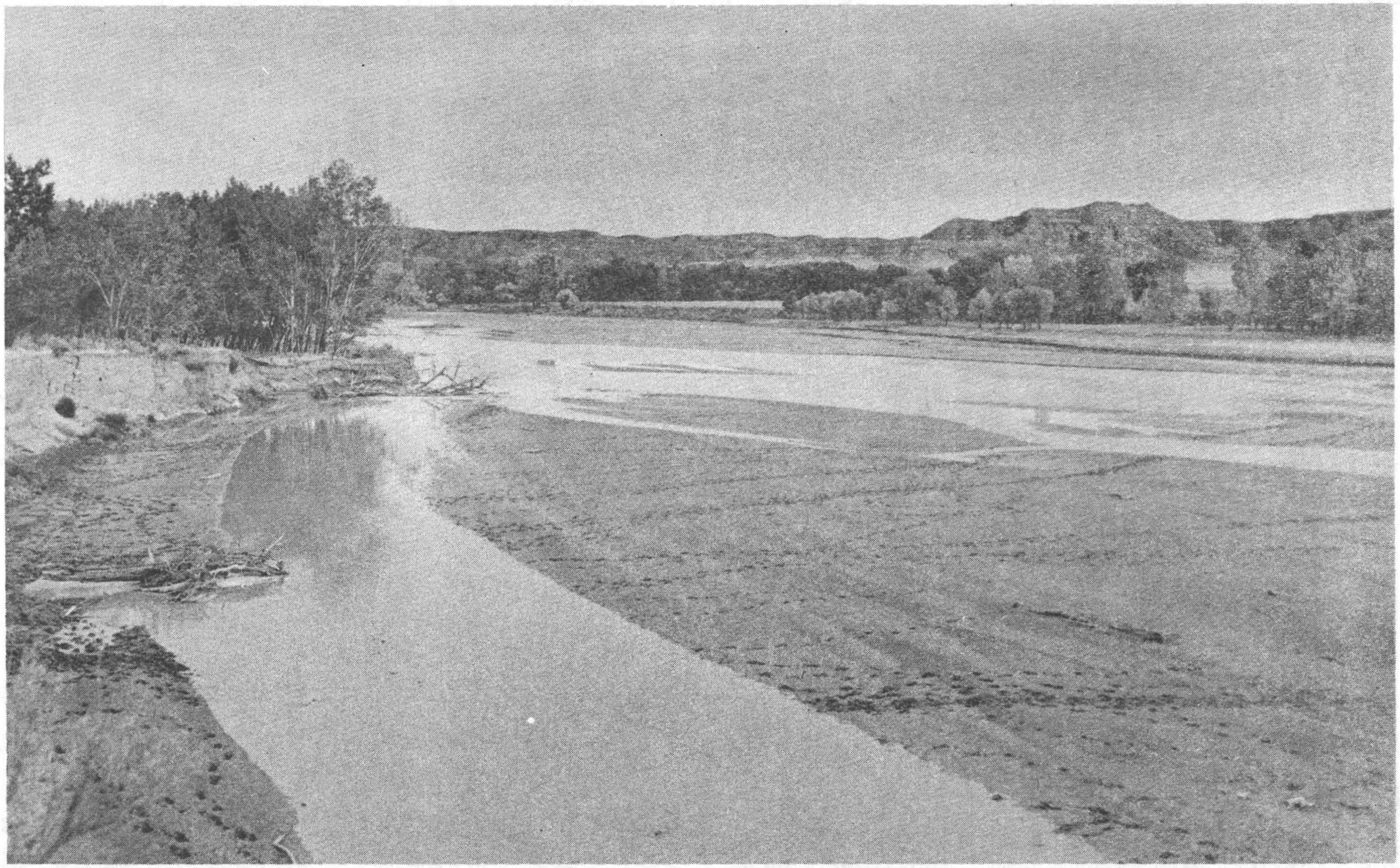


Figure 1.--Powder River 2 miles downstream from mouth of Crazy Woman Creek. This is a typical section of the river valley upstream from the mouth of Clear Creek. Note the flood plain and the higher terraces. At this point the flood plain is about 5 ft above the stream, and the next terrace is about 12 ft above the stream. A gravel-capped terrace can be seen through the opening in the trees on the right and about 50 ft above the stream. Note the cut banks and wide flat stream bed.

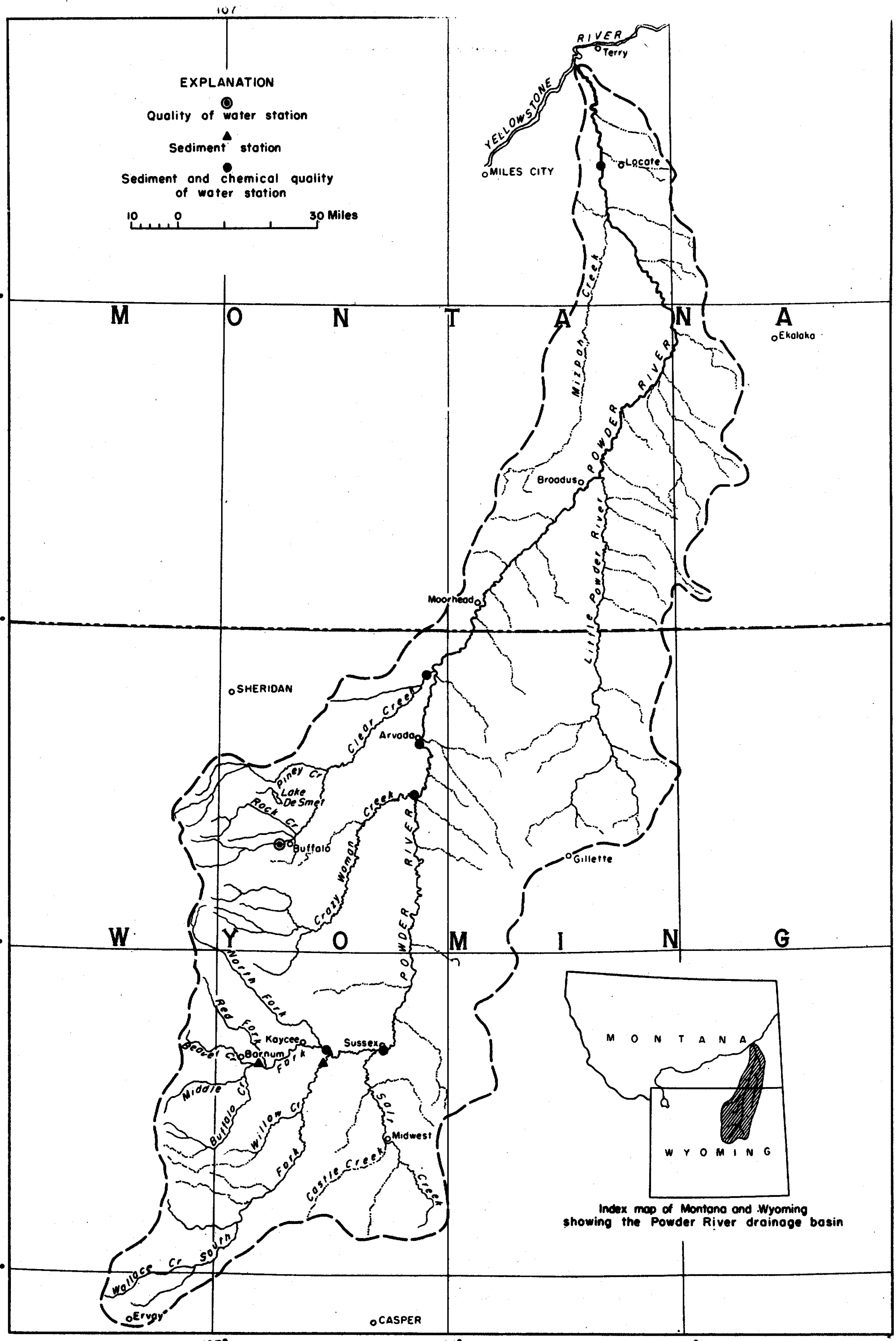
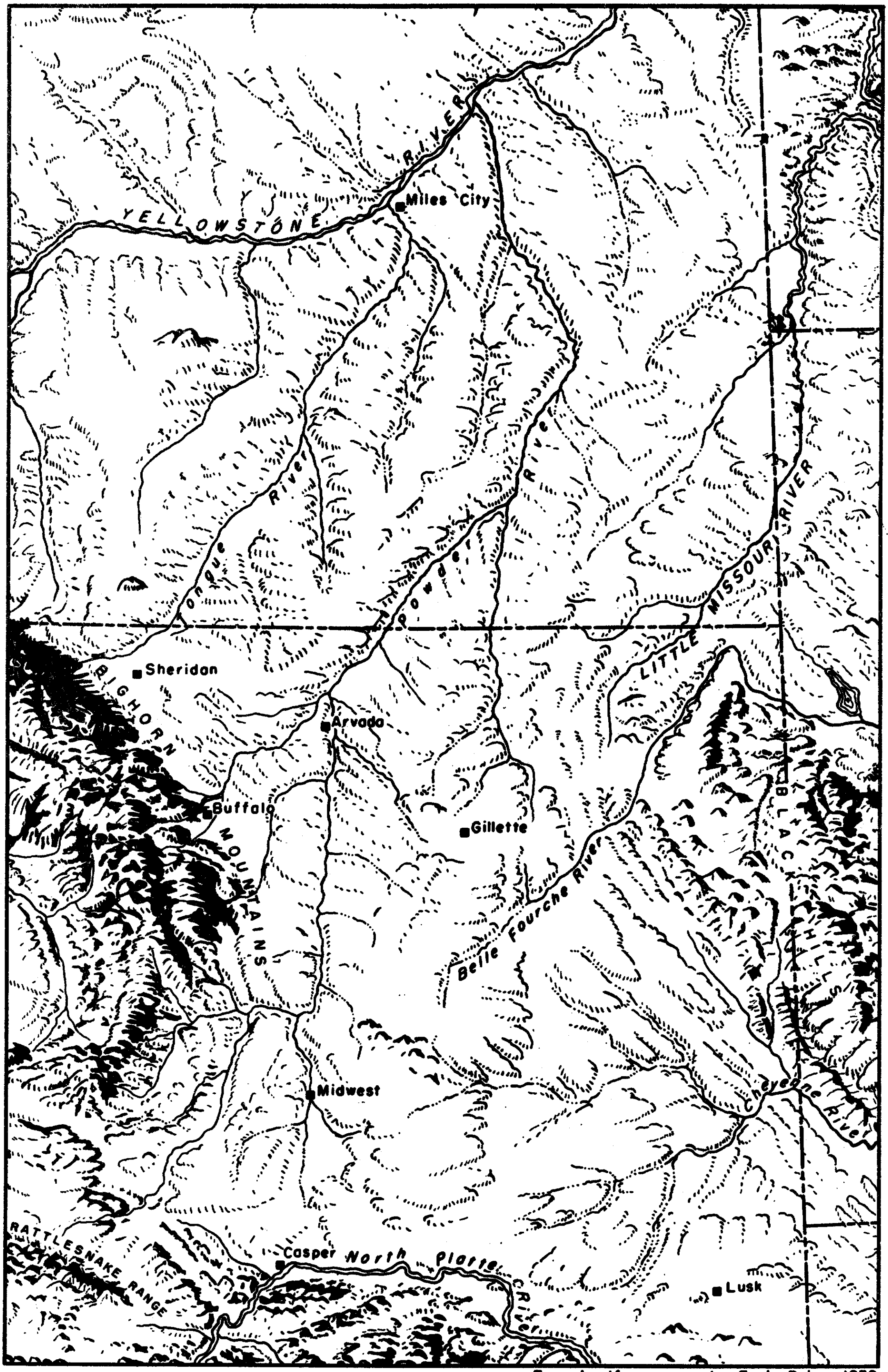


Figure 2.--Map of the Powder River drainage basin in Wyoming and Montana.



From landforms map by Erwin Raisz, 1939

10 0 50 Miles

Figure 3.--Map of the landforms of the Powder River drainage basin and surrounding areas.

mountains, is an area of forests and associated parks.

The front range, which stands about 2,000 ft above the plains and extends along the east side of the mountains, is a large hogback of plainward-dipping sedimentary rocks. The west side of the front range is a rather abrupt slope or cliff.

A westward-facing cliff of red rock, called the red wall, runs along the south and southeast flank of the Bighorn Mountains from a point north of Barnum southward to the head of Buffalo Creek. The red wall is a hogback of eastward-dipping red siltstone strata and, because of its color, is the most striking of the many hogbacks along the east side of the mountains.

The greater part of the Powder River drainage basin lies to the east of the mountains and is a part of the Great Plains province. In this area the rolling uplands are at a much higher elevation than the main streams. Parts of the uplands are level and receive sufficient precipitation for dry farming, but most of the uplands are used for grazing, owing to a lack of precipitation and to the sloping topography.

Probably the most distinctive type of topography in the drainage basin is the badlands, which form a border around the uplands and usually separate them from the lowlands along the rivers. However, at some places the badlands extend to the banks of the streams. Although they may be only narrow bands, in some places they are an almost impassable area of sharp ridges and steep canyons that extend several miles back from the streams.

Climate

The Powder River basin, owing to the range in altitude from about 2,300 ft to more than 13,000 ft, has wide local differences in temperature and precipitation. These differences in climate not only affect the amount of sediment that is transported by the streams but also partly determine the areas that will furnish most of the sediment to the streams.

As shown by figure 4, relatively heavy precipitation, most of which is snow, occurs in the high mountains. Climatological records are not available at high altitudes, but precipitation at some localities in the mountains probably exceeds 30 in. a year. The lines of average annual runoff in figure 4 give an indication of the increase in precipitation with altitude.

The climate of the lower mountain slopes and foothills is less humid, but the climate does vary in the foothill belt because of differences in altitude and topographic features. The foothill section, in general, is a transitional zone between the cold, humid climate of the high mountains and the relatively warmer and more arid climate of the plains.

The climate of the rest of the basin is, in general, one of less precipitation and of greater variation in temperatures. The plains section has a semiarid climate with an average precipitation less than 15 in. annually.

Soils and Vegetation

The soils of the Powder River drainage basin are represented by a large number of broad soil groups, which follow vegetational and climatic differences without regard to geological conditions (Thorp, 1939, p. 42). They are: soils of the humid mountains, soils of the subhumid foothills, and soils of the semiarid plains. Only small areas of soil were developed over many of the rock formations of the mountains. In the higher part of the mountains the soils, where they occur, are well-developed Podzols. The soils in the foothills and semiarid plains are mainly Chernozem and Chestnut soils, but possibly the soils of the more arid part of the plains may be grouped with the Brown soils (Dunnewald and others, 1939, p. 32). The Chernozems are mainly restricted to narrow areas in the foothills.

The soils of the older terraces and alluvial fans have a dark grayish-brown surface layer, a very heavy brown gumbo upper subsoil layer, and a thick accumulation of silty lime in the alluvial substratum. Alluvial gravel from many types of rocks is present at different depths.

The soils of the younger terraces and alluvial fans range in color from light grayish-brown to black, have little clay or gumbo in the upper subsoil layers, and have only a moderate accumulation of lime in the subsoil. In most areas these soils are underlain by a series of old buried soils, which are exposed in many places in high stream banks and road cuts.

The soils of the flood plains are composed of water-deposited silts, sands, clays, and gravels; all are more or less calcareous. Near the mountains the soils are dark or have a pink tinge, owing to organic material or fragments of parent rocks. The farther the soils lie from the mountains, the more uniform is their pale-gray color.

The soils of the uplands in the plains area are mostly shallow, and their color and texture are due to the character of the parent materials. The surface color of the soils is gray, grayish-brown, or reddish-brown. The surface soils are sandy, silty-clay, or clay loams.

In the open areas of the mountains the soils are dark brown and black, and the surface soils are usually about 1 ft thick. The color of the subsoil depends upon the parent rock. In the forested areas under a thin layer of partly decomposed pine needles, the soil is light grayish-brown loam to a depth of 3 or 4 in. Below this layer the soil is lighter-colored.

The native vegetation of the Powder River basin is as varied as the soils. Large areas in the mountains are covered by forests. The most common tree is the lodgepole pine, but the western yellow pine, limber pine, Engelmann spruce, alpine fir, red cedar, and aspen are common. Willows grow in some of the meadows along the streams. The open areas in the forests are covered with many kinds of pasture grasses.

The vegetation of the semiarid plains is a typical arid-land cover of grasses, sagebrush,

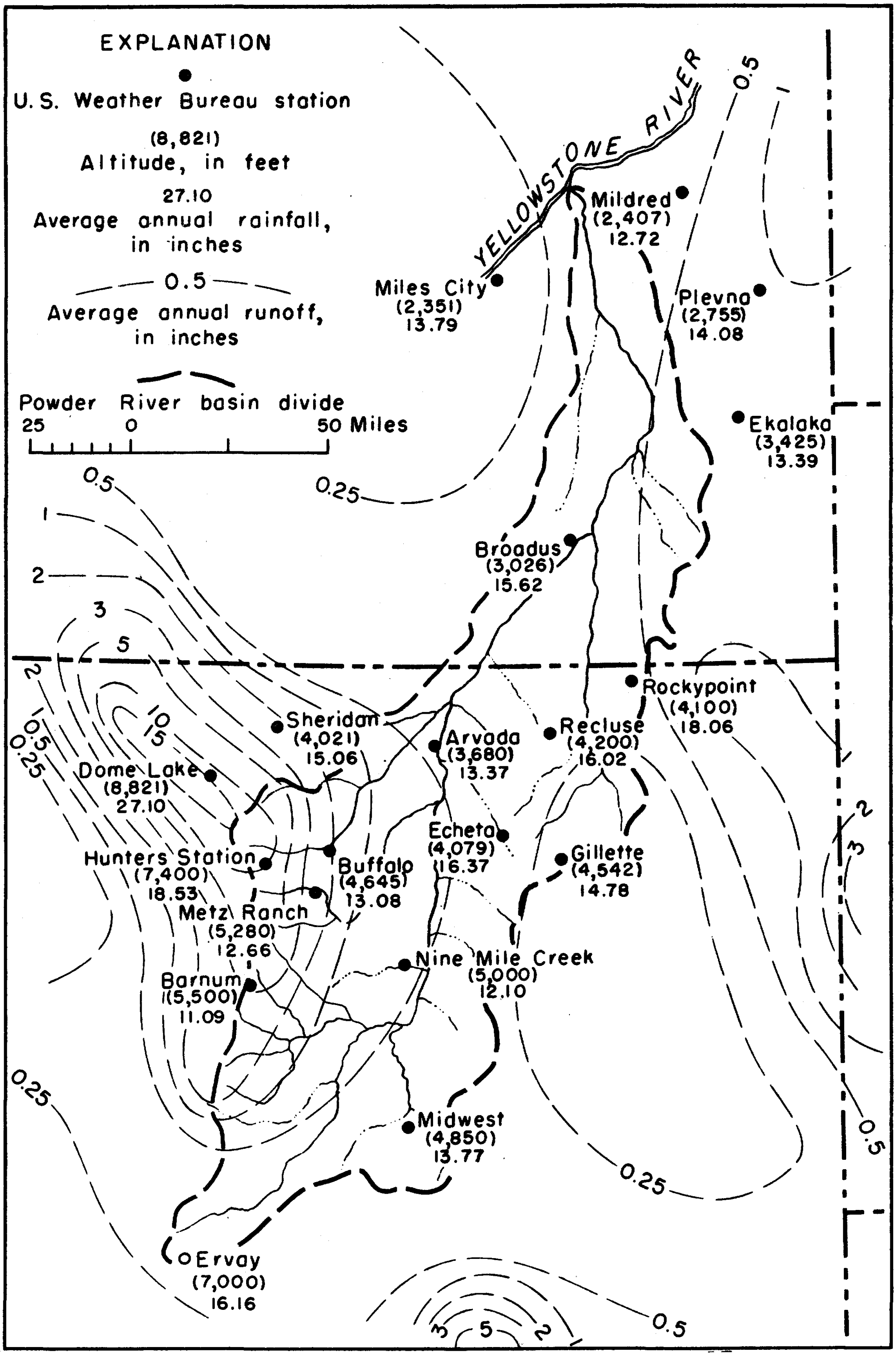


Figure 4.--Precipitation and runoff in the Powder River drainage basin. Lines of average annual runoff from U.S.G.S. Circular 37.

pricklypear, and rabbitbrush. The most common grasses are gramagrass, wheatgrass, junegrass, and buffalograss. Greasewood is common on salt-impregnated soils. Cottonwoods grow along some of the streams, especially the Powder River. Near the mountains where sufficient moisture is available, there are dense thickets of plum, chokecherry, haw, and other bushes.

GENERAL GEOLOGY OF THE POWDER RIVER DRAINAGE BASIN

Exposed Rocks

The rocks exposed in the Powder River drainage basin are granite and schist of pre-Cambrian age and a thick series of sedimentary strata that range in age from Cambrian to Recent. (See table 1.) Outcrops of pre-Cambrian and Paleozoic rocks are confined to areas in or near the mountains. The rocks of pre-Cambrian age are igneous and metamorphic and erode slowly. These of Paleozoic age are mostly limestones and sandstones that are relatively resistant to erosion.

Rocks of Mesozoic age crop out principally along the east flank of the Bighorn Mountains and over large areas in the southwest part of the basin (fig. 5). On the basis of different erosional characteristics, the sedimentary rocks of the Mesozoic era may be divided, in general, into three groups. The first group, comprised of the Triassic and Jurassic formations and the Cretaceous Cloverly formation, has a small area of outcrop and is not an important source of sediment even though some of the formations are highly erodible. The second group, made up of the Thermopolis and Mowry shales, the Frontier formation, and the Cody shale, is composed of a great thickness of alternating thin beds of sandstone and thick beds of highly erodible shale. The third group, comprised of the Mesaverde, Lewis (or Bearpaw), Foxhills, Lance (or Hell Creek) formations, is a series of interbedded sandstones and shales. Except for local areas, such as the headwaters of Salt Creek, this group is considered to be a minor source of sediment because of its relatively small area of outcrop, even though some of the beds of shale and sandstone erode rapidly.

Rocks of Cenozoic age cover the greater part of the plains section of the basin north of Sussex. (See fig. 5.) Those of Paleocene and Eocene age consist of sandstone, shale, siltstone, and some coal. Part of the terrain underlain by these rocks is rolling, and erosion appears to be at moderate rates. The unequal resistance to erosion of the fine-textured materials and the sandstones has caused the formation of steep broken topography along many of the interstream divides and of badlands along the streams. Small patches of rocks younger than Eocene and older than the Recent alluvial deposits occur in and adjacent to the mountains, but, because of the small area of outcrop, they are not significant as a source of sediment.

River Terraces

A knowledge of the history of river terraces in the Powder River drainage basin is essential to an understanding of the causes of past and present rates of erosion and deposition. Although some preliminary field work has been done, additional information still is needed before a satisfactory discussion of the river terraces can be prepared.

Table 1.--Summary of exposed rock formations in the Powder River drainage basin (Darton, 1906, pl. 47; Hares and others, 1946; Love, 1945; Thompson, 1949; Brown, 1949; Wegemann, 1918, p. 13; Reeside, 1944; Thomas, 1948, pp. 79-92; Love and Weitz, 1951)

Age		Formation and member		Remarks
Quaternary				Glacial deposits in the mountains. Terrace and flood-plain deposits of gravel, sand, and silt along the streams.
		Unconformity		
Tertiary	Oligocene	White River(?) formation and younger unnamed rocks.		Sands, volcanic ash, gravels, and boulders.
		Unconformity		
Tertiary	Eocene	Wasatch formation	Moncrief member Kingsbury member	Sandstone, drab-colored; drab-colored to variegated claystone and shale; and numerous coal beds. Moncrief member consisting of conglomerate of pre-Cambrian rock fragments, sandstone, and drab shale. Kingsbury member consisting of conglomerate of Paleozoic rock fragments, sandstone, and variegated claystone.
		Unconformity		
Tertiary	Paleocene	Fort Union formation	Tongue River member Lebo member Tullock member	Sandstone, light-colored, massive; drab-colored shale; and numerous coal beds. On the east side of the Powder River basin the Fort Union is, in places, divided into three members: the Tongue River member at the top, the Lebo member in the middle, and the Tullock member at the base.
		Unconformity		
Cretaceous		Lance formation Fox Hills sandstone Lewis shale	Hell Creek formation Fox Hills sandstone Bearpaw shale	Sequence of dark marine shales (Lewis, Bearpaw), followed by marine sandstone (Fox Hills), and then by nonmarine dark-colored claystone and shale and coal beds called Lance in Wyoming part of basin, except near Black Hills, and in Montana part of basin, where Hell Creek formation is used.

Table 1.--Summary of exposed rock formations in the Powder River drainage basin--Continued

Age		Formation and member		Remarks
Cretaceous		Mesaverde formation	Teapot sandstone member	Sandstone, alternating white to buff, massive, cross-bedded, coal-bearing, with a middle zone of marine shales. In northern part of basin Teapot member is not recognized.
			Parkman sandstone member	
		Cody shale		Sandstone, shaly; dark-gray marine shales; calcareous shale; thin limestones; and a few thin beds of bentonite.
			Shannon sandstone member	
		Frontier formation	Wall Creek sandstone member	Sandstone and shales, interbedded, gray and black. Thin sub-bituminous coal beds are present.
		Mowry and Thermopolis shales, undivided		Mowry shale, hard, black, siliceous, weathers silvery gray; underlain by soft black Thermopolis shale that has Muddy sandstone member 200 ft above base.
		Inyan Kara group and Cloverly, Morrison, and Unkpapa formations, undivided		Inyan Kara group includes Fall River sandstone at top, Fuson shale in middle, and Lakota sandstone at base along eastern margin of Powder River basin; Cloverly formation used along southern and western margins. Morrison formation consists of green to variegated claystone and thin limestones in Black Hills.
Jurassic		Sundance and Gypsum Spring formations, undivided		In descending order, green glauconitic shale, red sandstone and siltstone, gray sandstone, green shale, and lenticular white sandstone. At base is Gypsum Spring formation consisting of red siltstone and gypsum with some white dolomite and limestone beds.
		Unconformity		
Triassic		Chugwater formation	Popo Agie member	Claystone, ocher-colored; purple to red siltstone; and limestone conglomerates.
			Alcova limestone member	Limestone, thin, crinkly light-gray.
			Red Peak member	Siltstone, reddish.
		Unconformity(?)		Undivided Triassic and Permian rocks along the south and west margins of the Powder River basin.
Permian				
		Unconformity		
Carboniferous	Pennsylvanian	Tensleep sandstone and Amsden formation, undivided		Sandstone, thick; underlain by red shale and limestone and red to gray sandstone.
		Unconformity		
	Mississippian	Madison formation		Limestone and dolomite, massive, blue-gray, cherty. Locally includes dolomite and sandstone of Devonian(?) age.
		Unconformity		
Ordovician				Bighorn dolomite underlain by equivalents of Flathead sandstone and Gros Ventre and Gallatin formations along west margin of Powder River basin.
		Unconformity		
Cambrian				
		Unconformity		
Pre-Cambrian				Granite, schist, and gneiss.

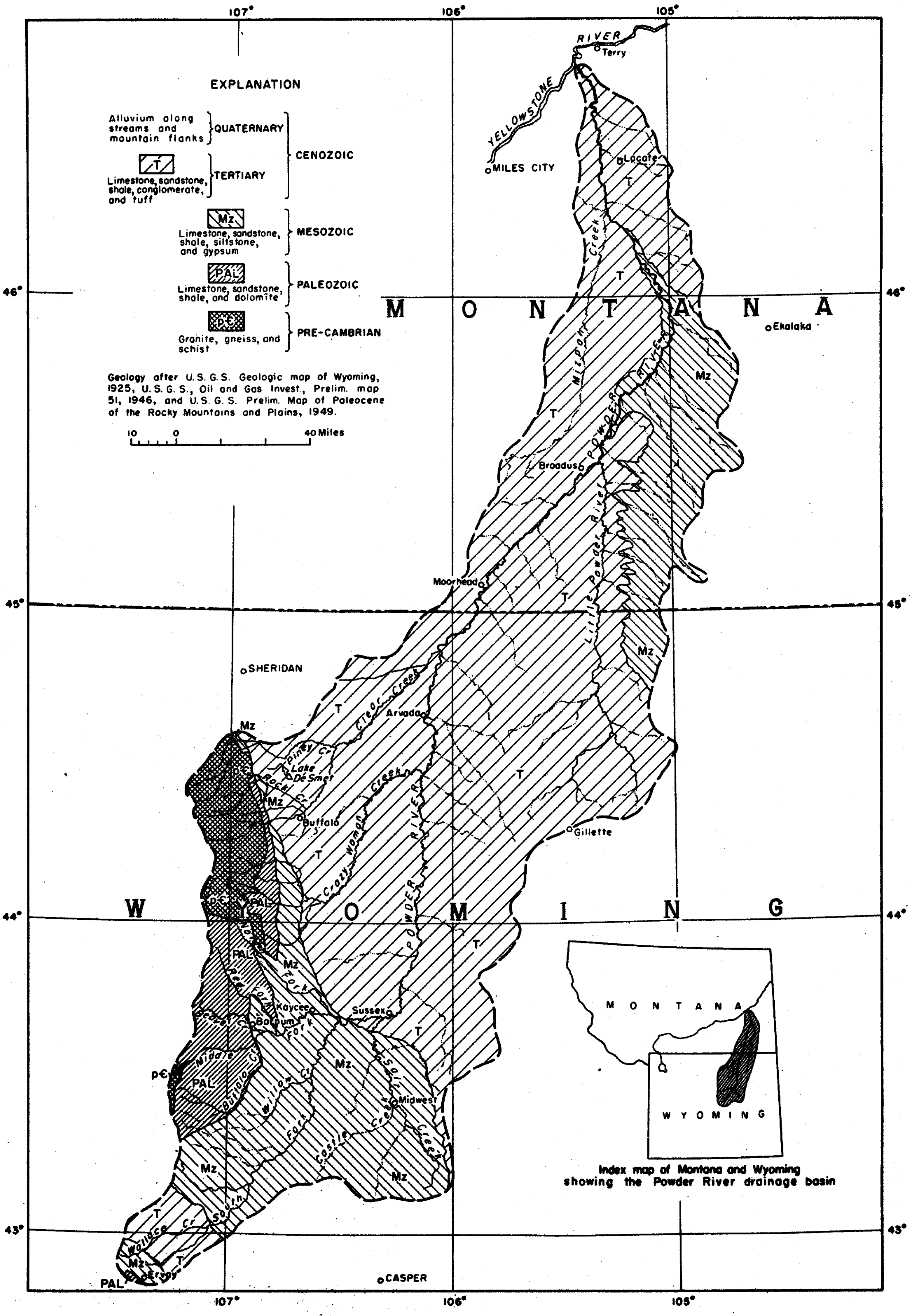


Figure 5.--Geologic map of the Powder River drainage basin in Wyoming and Montana.

PHYSICAL CHARACTERISTICS OF THE POWDER RIVER AND ITS TRIBUTARIES

The physical characteristics of a stream are controlled by many factors. Outstanding among the factors are types of rock material, climate, topography, and vegetation. Although the factors are interdependent, types of rock material and climate play the leading role in determining the characteristics of a stream; type and density of vegetation as well as minor topographic features are dependent upon them. In describing the characteristics of the streams, only types of material and topography associated with the streams will be discussed. Climate and vegetation have been described in previous parts of this report.

The approximate slopes, differences in altitude divided by lengths of channel, of the Powder River and its tributaries are listed in the following table:

Table 2.--Approximate average slopes of the Powder River and major tributaries

Rivers and selected reaches	Approximate slope in feet per mile
South Fork Powder River	10
Powder River from junction of the Middle and South Forks to mouth	7
Middle Fork Powder River	
From headwaters to mouth of Red Fork	110
From mouth of Red Fork to junction with the South Fork	9
Buffalo Creek	90
Beaver Creek	140
Red Fork	110
North Fork Powder River	
From headwaters to Mayoworth	110
From Mayoworth to mouth	30
Salt Creek from Midwest to mouth	10
Crazy Woman Creek	
From headwaters to junction of the North and Middle Forks	150
From junction of the North and Middle Forks to mouth	10
Clear Creek	
From headwaters to mouth of Rock Creek	220
From mouth of Rock Creek to junction with the Powder River	13
Little Powder River	7
Mizpah Creek	8

Powder River

The Powder River is formed by the junction of its Middle and South Forks, 2 miles downstream from the junction of the Middle and North Forks and 6 miles east of Kaycee, Wyo. Above their junction the three Forks drain an area of about 2,220 sq mi (Follansbee, 1923, p. 101). The Powder River, therefore, is from its inception a large river. However, it is merely an extension of the South Fork in that it has all the characteristics of that stream and practically none of the characteristics of the Middle Fork. The Powder River, then, begins as a wide, flat, meandering stream that flows on a sand-covered stream bed between predominantly low stream banks. Throughout most of its length, it is bordered by a wide, low flood plain and a series of terraces that blend into alluvial fans that extend down from the bordering hills. (See fig. 1.) At some points, where the river is cutting laterally into flood-plain deposits that predate the present flood plain, the low stream banks give way on one side to high banks.

Except for the alluvium of the flood plain and terraces, the valley of the Powder River is underlain, for the most part, by sandstones, siltstones, and shales of the Fort Union and Wasatch formations of Tertiary age. Similar badland topography is developed from both formations. However, badlands developed from the Wasatch formation are more extensive, but this is probably due to geographical location rather than to any major difference in the erodibility of the two formations.

Northward from Sussex the difference in altitude between the valley floor and the highlands increases and reaches a maximum about half way between Sussex and Arvada. Badland topography increases with the increase in relief and reaches maximum development along the river east of Buffalo. Here the badlands extend several miles back from the river, but they gradually become more subdued downstream.

During July, August, and September there is little or no flow in the Powder River between Sussex and the junction of Clear Creek. Consequently, during these months almost all sediment carried into the Powder River by tributaries upstream from Clear Creek is deposited in the channel. Part of this channel fill is moved downstream by spring floods and is replaced later by material transported from upstream. For many miles below its junction with the Powder River, the summer flow of Clear Creek, a stream which carries little sediment, flushes from the channel of the Powder River the finer sediments that are deposited during spring floods.

The flow of Powder River is maintained almost entirely by tributary streams from the Bighorn Mountains to the west. The Little Powder River is the only major tributary to the Powder River from the east.

South Fork Powder River

The South Fork Powder River rises in the Rattlesnake Range near Ervay, Wyo., in the extreme western part of Natrona County and flows northeastward to its junction with the Middle Fork, 6 miles east of Kaycee. East of the Rattlesnake Range the South Fork flows through an area of high rolling plains, which are deeply trenched by tributary streams. The headwaters of the tributary streams are separated by low divides from the headwaters of streams tributary to the Bighorn and North Platte Rivers. Wallace, Cave, and Willow Creeks are the major tributaries to the South Fork.

The South Fork flows across many kinds of rocks, but about three-fourths of its drainage area is underlain by shales of Cretaceous age.

For most of its length the South Fork flows in a wide valley that is flanked by low rounded hills. Leading down from the hills are valleys, which in the past were cut by streams and partly refilled with alluvium. Many of these valleys are now the sites of deep gullies, which carry large volumes of sediment-laden water into the South Fork during and following heavy rains.

Easily eroded material, sloping land, sparse vegetation, and rainfall of high intensity combine to make the South Fork one of the major contributors of sediment to the Powder River.

Middle Fork Powder River

The Middle Fork Powder River originates in the southern part of the Bighorn Mountains and flows northeastward to its junction with the South Fork east of Kaycee. All its major tributaries except Buffalo Creek rise in the mountains and have characteristics of mountain streams for most of their length. In the mountains they flow over stream beds of gravel or boulders and carry very small quantities of suspended sediment. At the foot of the mountains they leave the areas underlain by Paleozoic rocks and flow across areas underlain by the more erodible Mesozoic rocks where their gradient decreases and where they begin to acquire some of the characteristics of sediment-carrying streams. (See fig. 6.) Important perennial tributaries of the Middle Fork are Buffalo Creek, Beaver Creek, Red Fork, and the North Fork Powder River. In the spring and summer most of the flow of these streams is diverted for irrigation.

Salt Creek

Salt Creek and its principal tributaries rise to the south of the town of Midwest and drain an area underlain principally by Cretaceous shales. It flows in a general northwestward direction to join the Powder River near Sussex. It has a total drainage area of about 840 sq mi (Follansbee, 1923, p. 101). Along Salt Creek and some of its tributaries, especially in the lower reaches, there are broad alluvial flood plains and high cut banks, but the land back from these major streams is cut into extensive areas of badlands by a network of deep gullies. (See fig. 7.) During the summer the creek flows only in rainy weather. After heavy storms it becomes a large and heavily sediment-laden river. Salt Creek, like the South Fork Powder River, is potentially one of the largest sediment-contributing streams in the Powder River drainage basin.

Crazy Woman Creek

The tributary forks of Crazy Woman Creek rise in pre-Cambrian granites near Hazelton Peak. They flow to the east and leave the mountains in deep canyons cut in the Paleozoic and Mesozoic rocks that compose the front range. After leaving the mountains, the streams flow through an area of rolling hills carved in Cretaceous shales before entering areas underlain by Tertiary rocks. After entering the plains area, the three forks join and flow north and east to join the Powder River upstream from Arvada. Because most of the summer flow of the stream is used for irrigation, only a small part of it reaches the Powder River.

Clear Creek

Clear Creek and its principal tributaries, Rock and Piney Creeks, rise near Cloud Peak and flow eastward through an area underlain by granitic rocks and leave the mountains by way of canyons cut in relatively narrow outcrops of Paleozoic rocks. Downstream from Buffalo, Rock Creek joins Clear Creek, which is in turn joined by Piney Creek at Ucross. From the mountains to its junction with the Powder River, downstream from Arvada, Clear Creek flows on a heavy bed of gravels between low banks. Wide flats on each side of the stream are used extensively for the cultivation of irrigated crops. The flow of Clear Creek during the irrigation season is controlled and augmented by storage in several lakes in the mountains and in Lake De Smet, a large off-stream reservoir 10 miles north of Buffalo. Lake De Smet had no surface outlet and was high in dissolved solids until inlet and outlet canals were built about 1921 between the lake and Piney Creek near Kearney. In 1949 the dissolved solids concentration of the lake water had been reduced to about 800 ppm, and the lake is an excellent habitat for rainbow trout. The flow from the lake into Piney Creek is controlled by gates at the north end of the lake.

Little Powder River

The Little Powder River rises in the uplands near Gillette and flows almost due north to join the Powder River downstream from Broadus, Mont. Most of the area drained by it is underlain by the Fort Union formation of Tertiary age. Along the lower reaches of the river there are broad flats, but in some areas the land back from the stream is cut into badlands by gullies. The flow of the stream except during storms is usually not sufficient to carry large sediment loads. There are small diversions from the stream for irrigation, mostly of hay meadows.

Mizpah Creek

Mizpah Creek rises in the uplands to the west of Broadus and flows northeastward to join the Powder River at Mizpah, Mont. The total drainage area of the creek is small in comparison with its length, and for the greater part of the year it is a dry stream channel. During heavy storms it probably carries a large volume of sediment into the Powder River. Along the upper part of Mizpah Creek water is diverted by spreader dikes. The sediment carried by the water is deposited and is gradually building up the flood plain. This type of irrigation is also practiced on other minor tributaries of the Powder River.

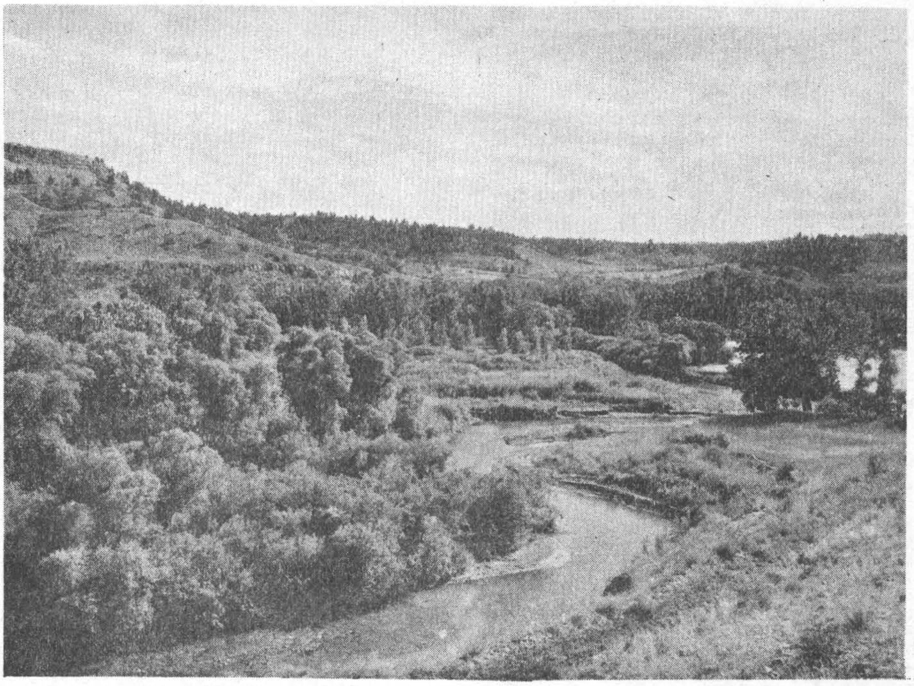


Figure 6.--Middle Fork Powder River above the junction of Red Fork. The river at this point still has some of the characteristics of a mountain stream, but evidence of the sediment transported during high flows is given by the raw stream banks.

Figure 7.--Sediment-filled reservoir on Salt Creek near the town of Midwest. Dredge keeps a cooling water pool open for the power plant. Note the gullies and badlands in the background.

EROSIONAL AND DEPOSITIONAL PROCESSES IN AN AREA NEAR THE MOUTH OF SALT CREEK

All the processes by which sediment may be moved from its place of origin to a temporary or final place of deposition are active in the Powder River basin.

Erosional or depositional features are better understood if the relation of the feature under study to the rest of the system is known. In order to study erosional and depositional processes in detail, a small area near the mouth of Salt Creek was selected. In this restricted area erosion is active in the form of gullying, sheet or rill erosion, bank cutting, and soil creep. Moreover, depositional forms that go hand in hand with erosion are well-exhibited.

Figure 8 is an aerial view of the terrain near the confluence of the Powder River and Salt Creek. The Powder River flows from right to left in the figure. A deep gully in the center of the area joins Salt Creek at coordinates 7.4,6.3. The divide of one of the headwater tributaries of this gully is a narrow ridge at coordinates 1.4,14.0. The ridge itself is a product of erosion of nearly horizontal shaly siltstones. To understand the processes by which sediment moves, is temporarily deposited, and is again moved, one should trace the sediment from its origin on the divide until it reaches Salt Creek.

The accumulation of fine rock debris at the foot of the steep slope that leads down from the top of the divide is the result of a combination of factors. The slope is too steep for weathered bedrock material to remain in place; nevertheless, weathering is an important part of the process of removing material from the bedrock slope. The freezing, thawing, wetting, and drying of the surface loosen a thin layer of material that is carried to the foot of the slope by gravity or water or by both.

Material has accumulated at the foot of the bare bedrock slope because of the change from a steeper to a gentler declivity. The gravitational force is sharply decreased, and the capacity of the water that flows from the steeper slope is insufficient to carry its load of sediment on the gentler gradient. Part of the sediment is deposited and an alluvial cone is built. Material will be added to the alluvial cone until the slope is increased enough to insure a velocity of flow great enough to transport the debris supplied by the bedrock slope.

Sheetwash aided by rain splash is the main cause of the downslope movement of sediment across the alluvial cone. However, there is also a mass movement of the material in the alluvial cone. This mass movement is soil creep, which is a type of mass transport at a speed so slow as to be imperceptible to the eye. Soil creep is caused by the force of gravity and is aided by water lubrication.

The sediment moving over the surface of the alluvial cone enters the gullies that are eating into the foot of the cone. (See fig. 8, coordinates 1.8,13.6.) These gullies are advancing headward by caving and slumping of the headwalls as a result of undercutting and by the weakening of the coherence of material at the base of the headcut by the wetting action of surface and ground water. The sediment entering the gully from the alluvial cone and eroded from the gully itself is carried downstream mainly because of the increased carrying capacity of the constricted flow.

Part of the sediment eroded from the headmost gully is transported to Salt Creek without deposition, but part of it is temporarily deposited in the reach between coordinates 2.9,12.8 and coordinates 7.2,12.3. (See fig. 8.) Deposition in this reach is caused by the reduction of the sediment-carrying capacity of the flow by decrease in slope, retardation of the flow by vegetation and by spreading, and reduction of flow by infiltration.

From the headcut at coordinates 6.2,12.3 (fig. 8) to Salt Creek the gully is being widened by bank cutting and by the action of water that enters the gully over the tops of the banks. (See figs. 9 and 10.) Along most of this reach, a balance exists between degradation and deposition, but at the extreme upper end the channel is being deepened, whereas at the lower end it is being aggraded. Field inspection and information furnished by a local resident indicate that the headcut of this gully has advanced headward about 380 ft in the last 30 yr. If this advance began at the present mouth of the gully and has progressed at a constant rate, the gully must have begun to develop more than 500 yr ago.

Relation of Local Base Level to Gully Formation

The mechanics of gully cutting are fairly well established, but the causes that start a gully are not well known. Land misuse has been advanced as one of the causes of gullying. This includes any use of the land that has destroyed the protective vegetative cover. Another cause that has been suggested is a slow climatic change. Either of these can cause gullying and probably are the most common causes, but a third cause of gullying has not received the attention it merits. This cause is the change in temporary base level at the mouth of a tributary valley.

Playfair's law of accordant junction implies that the gradients of main streams are gentler than those of tributaries that join them. Because main streams tend to attain grade early in the degradational part of the evolution of most geomorphic units, this is the relation generally observed.

Even though the gradients of the tributaries are as steep as or steeper than those of the main stream, the smaller volume of flow will at times prevent the tributary streams from maintaining accordance. Where a wet-weather, intermittent tributary joins a stream that has perennial flow, the difference in volume of flow in the main stream and in the tributary is great. During and immediately after rains, a discordance or hanging-valley type of waterfall may be formed at the junction of the wet-weather and perennial streams. If the wet-weather stream has a fairly large drainage area, the waterfall may advance an appreciable distance up the tributary valley. Between rains the perennial stream persistently deepens its valley while no erosion is occurring in the wet-weather stream. Discordant junctions resulting from

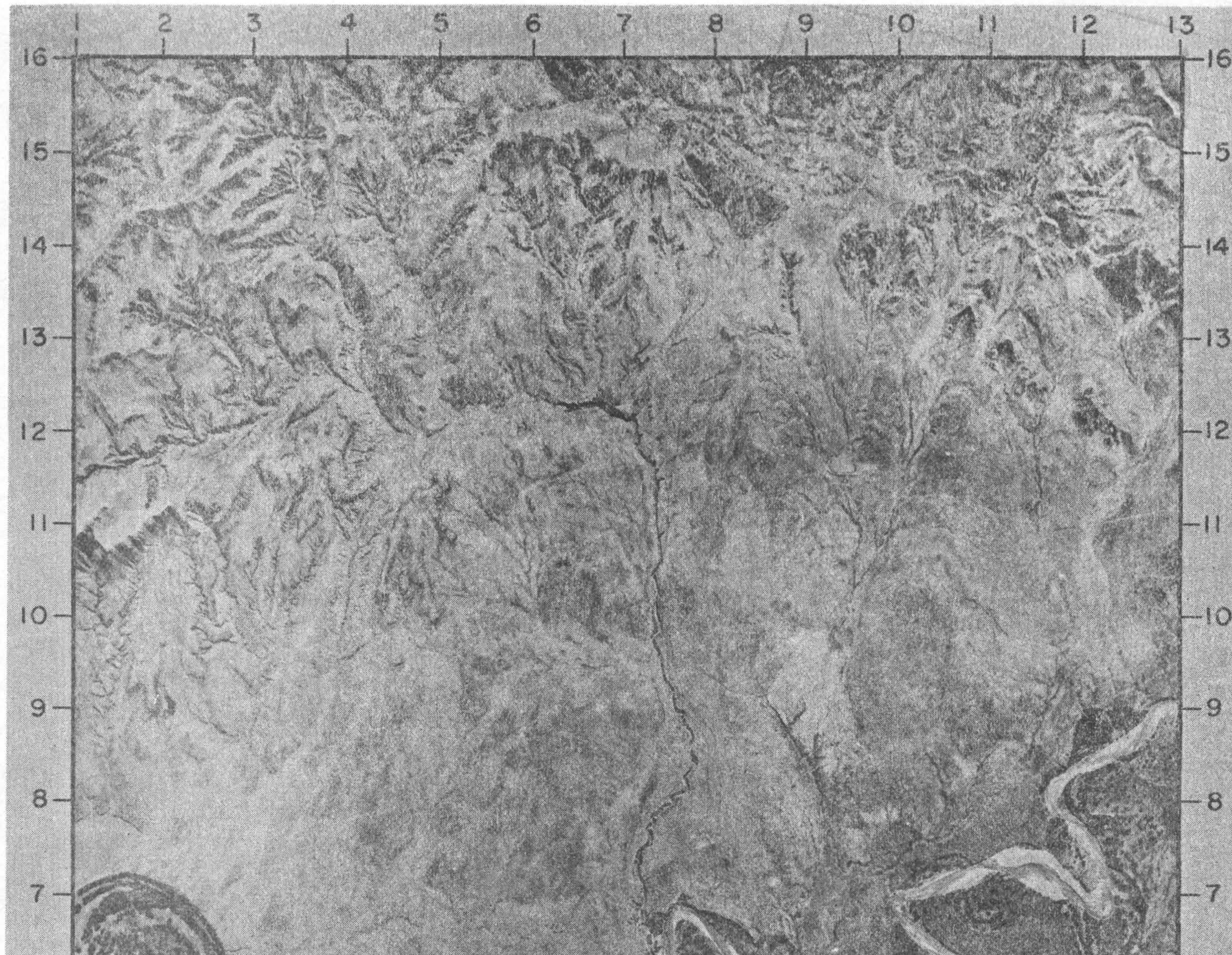


Figure 8.--Aerial photograph of area near mouth of Salt Creek. Photo by Fairchild Aerial Surveys, Inc., for Bureau of Reclamation.

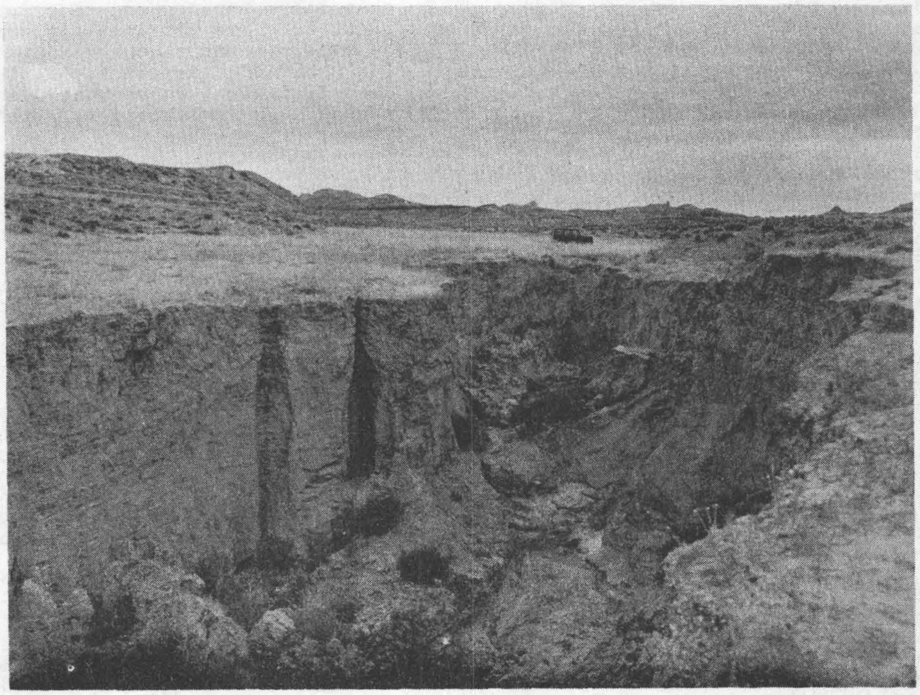


Figure 9.--Headcut of gully that joins Salt Creek near its mouth.

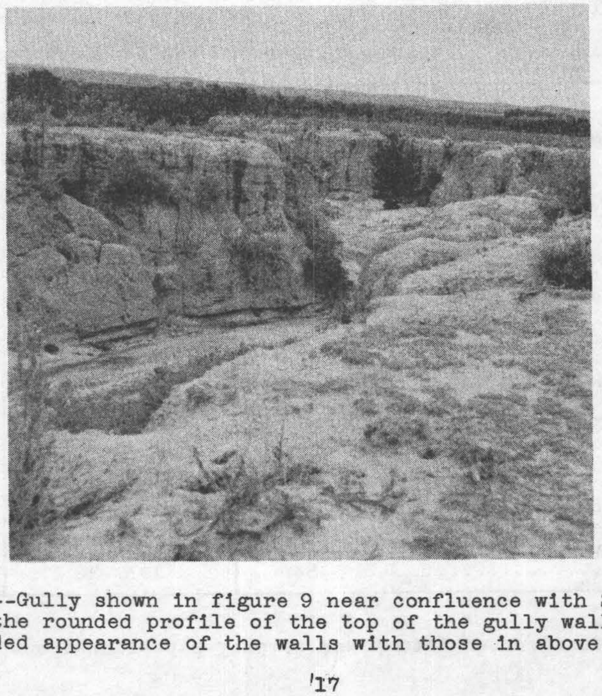


Figure 10.--Gully shown in figure 9 near confluence with Salt Creek. Compare the rounded profile of the top of the gully wall and the general eroded appearance of the walls with those in above photograph.

the above causes are common in arid and semiarid regions.

The gully that joins Salt Creek at coordinates 7.4,6.3 (fig. 8) probably was started by undercutting of its stream channel by a meander of Salt Creek. The evidence in the field and from figure 11 indicates that previous to interception of its channel by the meander bend the stream emptied into the Powder River or possibly Salt Creek at about coordinates 7.0,3.4. (See fig. 8.) An extension of the top or bank profile of the gully (fig. 11) would intercept the surface of the dissected alluvial fan at about coordinates 7.0,4.0. (See fig. 8.) The close parallelism of gradient between the present gully bottom and the top of the gully bank (fig. 11) is additional evidence that the gully was started by an abrupt change in the temporary base level.

RUNOFF

Stream-Flow Records

Although records of stream flow have been obtained by the U. S. Geological Survey at 29 gaging stations (fig. 12) in the Powder River drainage basin, most records are for short periods. The records were obtained primarily to determine water supply for irrigation. Winter records often are incomplete. There are unmeasured diversions upstream from most gaging stations. As a result, the runoff of the Powder River drainage basin is incompletely defined by the stream-flow records that are now available.

Figures of average discharge in cubic feet per second per square mile and the years for which the average was computed are listed in table 3 for each of 12 gaging stations. Drainage areas above the gaging stations are also given. The figures of average discharge are unadjusted for irrigation diversions, but records for Clear Creek near Buffalo do include an estimated diversion for electric power of about 7 cfs. Because figures of average discharge are based on records for different periods, they are not directly comparable so figures of average discharge during a 5-year period that ended September 30, 1950, are also listed. Table 3 shows that discharge per square mile varies widely within the Powder River drainage basin.

Distribution of Runoff

Figure 4 shows the approximate areal distribution of average annual runoff as based on stream-flow records prior to September 30, 1944 (Colby and Oltman, 1948, pl. 2). Average annual runoff from the entire Powder River drainage basin is a little less than 1 in. It is less than 0.5 in. over much of the basin. Along the crest of the Bighorn Mountains it is at least 15 in. and may be as high as 25 in. for small drainage areas at high altitudes. The large differences in runoff are partly due to differences in the amount and rates of precipitation; but land slopes, temperature, vegetal cover, and soil types also affect the distribution of runoff over the basin. In a general sense, the distribution of runoff in the basin is governed primarily by topography.

In the large areas of low runoff, most stream flow occurs during the late spring or during the summer and is caused by occasional rains of moderate to heavy intensity. Streams from these areas receive little ground-water discharge and are dry much of the time. Runoff from the areas of high runoff follows a different pattern. Stream flow is high during May, June, and July when the streams are fed by melting snow. During the remainder of the year the runoff is fairly uniform, and base flow of the streams in the mountains is well-maintained.

Figure 13 shows variations in annual discharge in acre-feet per square mile for Clear Creek near Buffalo and for the Powder River at Arvada. The annual discharge for Clear

Table 3.--Average discharge at gaging stations on the Powder River and its tributaries

Number on map (fig. 12)	Gaging station name	Drainage area (square miles)	Years for which average is computed	Average discharge (cfs per square mile)	Mean discharge Oct. 1, 1945, to Sept. 30, 1950 (cfs per square mile)
3	Powder River at (near) Arvada, Wyo..........................	6,050	1917-50	0.069	0.047
4	Powder River at Moorhead, Mont.	a 8,030	1939-50	.066	.069
6	Powder River near Locate, Mont.	a 12,900	1935-50	.059	.057
9	Middle Fork Powder River near Kaycee, Wyo.................	980	1939, 1941-50	.16	.16
12	North Fork Powder River near Mayoworth, Wyo...............	69	1943-50	.56	.52
17	Crazy Woman Creek near Arvada, Wyo.........................	956	1940-43	.066	....
18	Middle Fork Crazy Woman Creek near Greub, Wyo.............	82.7	1945-50	.24	.29
19	Clear Creek near Buffalo, Wyo..	120	1918-27, 1939-50	b .64	b .51
21	Clear Creek near Arvada, Wyo...	1,110	1940-50	.20	.19
23	Rock Creek near Buffalo, Wyo...	60.0	1946-50	.62	.62
26	Piney Creek at Kearney, Wyo....	106	1942-50	.95	.86
28	Little Powder River at Biddle, Mont.......................	a 1,540	1939-42	.016	....

a Approximate figure.
b Includes about 7 cfs diverted into power company pipe-line about 1½ miles upstream from gage.

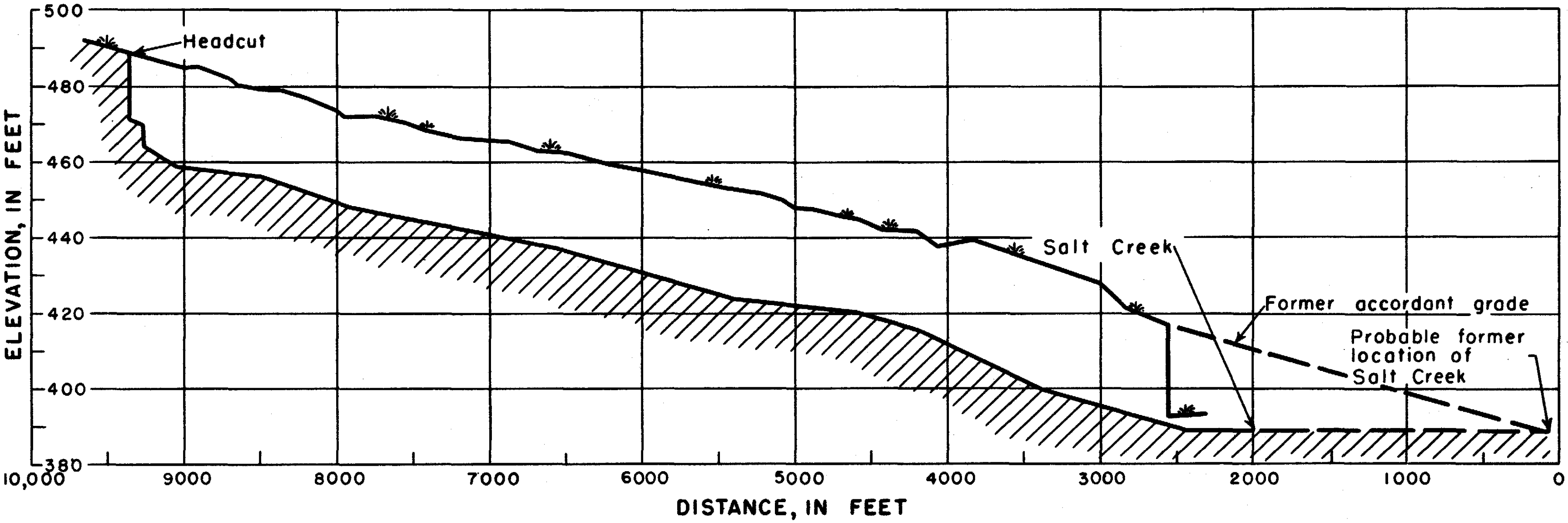


Figure 11.--Profile of gully channel and bank from confluence with Salt Creek to headcut.

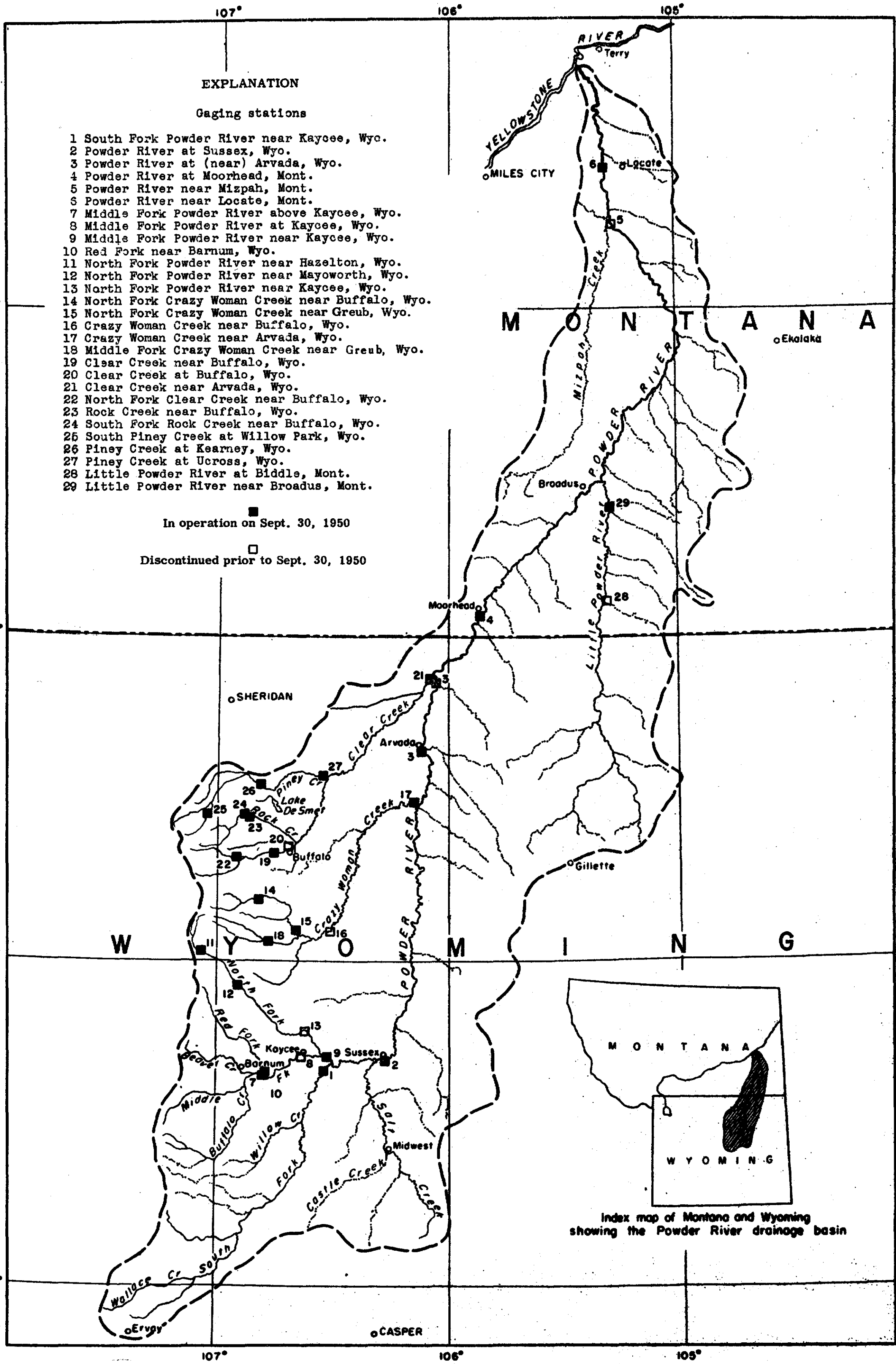


Figure 12.--Map showing locations of gaging stations in the Powder River drainage basin.

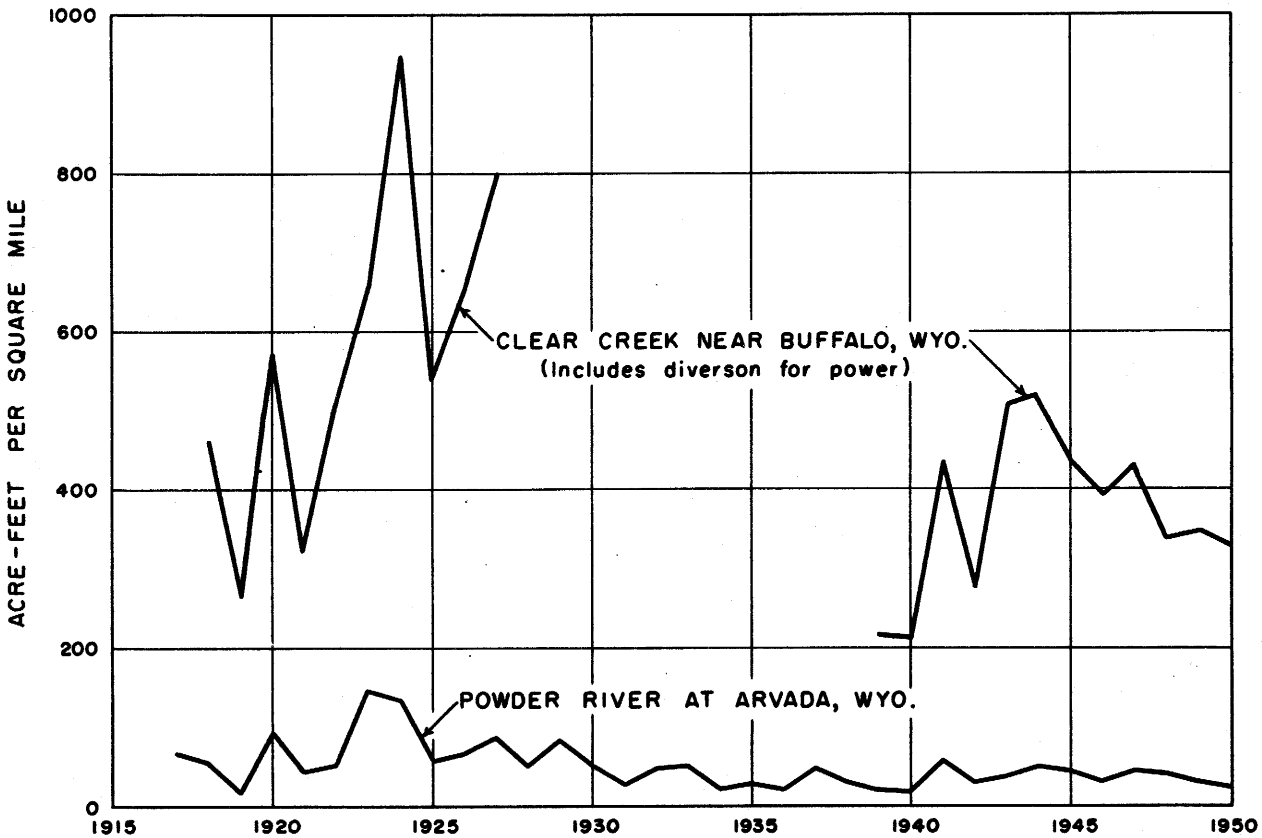


Figure 13.--Annual discharge, in acre-feet per square mile, for Clear Creek near Buffalo and the Powder River at (near) Arvada, Wyo.

Creek near Buffalo includes the estimated flow that is diverted around the gaging station and through a power plant. During the period for which stream-flow records are available, the trend of discharge has been downward.

The range in water discharge and the duration of different rates of flow are shown for the Powder River at Arvada (near Arvada prior to May 1919) by the duration curve on figure 14.

Diversions and Storage for Irrigation

The flow of the Powder River and its tributaries is appreciably controlled by storage and diversions for irrigation. Some idea of the effect of irrigation can be obtained from the number of acres that are irrigated. According to field observations and to reports of the Bureau of the Census (1942, pp. 329, 653, 654) 70,000 acres were irrigated by diversions from streams in the Powder River drainage basin during 1939, the last year for which information is published. About 10,000 acres were along Prairie Dog Creek in the Tongue River basin. Probably more than 35,000 acres were irrigated by diversions from Clear Creek and its tributaries. Nearly 10,000 acres were irrigated by diversions from the Middle Fork and its tributaries, and only a slightly smaller acreage was irrigated by diversions from streams in Crazy Woman Creek basin.

In the Powder River drainage basin only Lake De Smet, usable capacity 25,000 acre-ft (Harbeck, 1948, p. 71), has a usable capacity larger than 5,000 acre-ft. Kearney Lakes and Cloud Peak Reservoirs and several smaller reservoirs have a total usable capacity of about 10,000 acre-ft.

FLUVIAL SEDIMENT

Complete information on the sediment yield of a drainage basin would include rates and quantities of discharge of the sediment that is transported both in suspension and as bed load, the particle-size distribution of the suspended sediment and of the bed load, the mineral composition of the sediment, and the principal sources of the sediment. This progress report contains measured rates and quantities of suspended sediment and the results of particle-size analyses of suspended and deposited sediments. Computed rates of sediment discharge as bed load are also given for the Powder River at Arvada.

Definition of Terms

As the definitions of terms that relate to fluvial sediment are not completely standardized, some of the terms in this report are defined as follows:

Sediment is fragmental material that originates from weathering of rocks and is transported by, suspended in, or deposited by water or air, or is accumulated in beds by other natural agencies.

Fluvial sediment is sediment that is transported by, suspended in, or deposited by water.

Suspended sediment or suspended load is sediment that moves in suspension in water and is maintained in suspension by the upward components of turbulent currents or by colloidal suspension.

Bed load or sediment discharged as bed load includes both the sediment that moves along in essentially continuous contact with the stream bed (contact load) and the material that bounces along the bed in short skips or leaps (saltation load).

Sediment sample is a quantity of water-sediment mixture that is collected to represent the average concentration of suspended sediment, the average size distribution of suspended or deposited sediments, or the specific weight of deposited sediment.

Depth-integrated sediment sample is a sediment sample that is accumulated continuously in a sampler that moves vertically at a constant transit rate and that admits sediment-water mixture at a velocity about equal to the stream velocity at every point.

Sediment discharge is (a) rate at which dry weight of sediment passes a section of a stream or (b) quantity of sediment, as measured by dry weight or by volume, that is discharged in a given time.

Sediment rating curve is a curve of relation between water discharge and discharge of sediment. Usually the relation is between water discharge and suspended sediment, but it can be between water discharge and discharge of bed load or between water discharge and total sediment discharge (sum of sediment discharge in suspension and as bed load).

Specific weight of sediment deposit is weight of solids per unit volume of deposit in place.

The size classification used in this report is the classification recommended by the American Geophysical Union Subcommittee on sediment terminology (Lane and others, 1947, p. 937). According to this classification, clay-size particles have diameters between 0.0002 and 0.004 mm, silt-size particles have diameters between 0.004 and 0.062 mm, and sand-size particles have diameters between 0.062 and 2.0 mm.

According to Twenhofel and Tyler (1941, p. 110):
"The median, or median diameter, is the midpoint in the size distribution of a sediment of which one-half of the weight is composed of particles larger in diameter than the median and one-half of smaller diameter. The median diameter may be read directly from the cumulative curve by noting the diameter value at the point of intersection of the 50-percent line and the curve."

Water discharge is the discharge of natural water of a stream. The natural water contains both dissolved solids and suspended sediment.

Measurement of Suspended-Sediment Discharge

Discharge of suspended sediment is proportional to the product of water discharge and average concentration of suspended sediment.

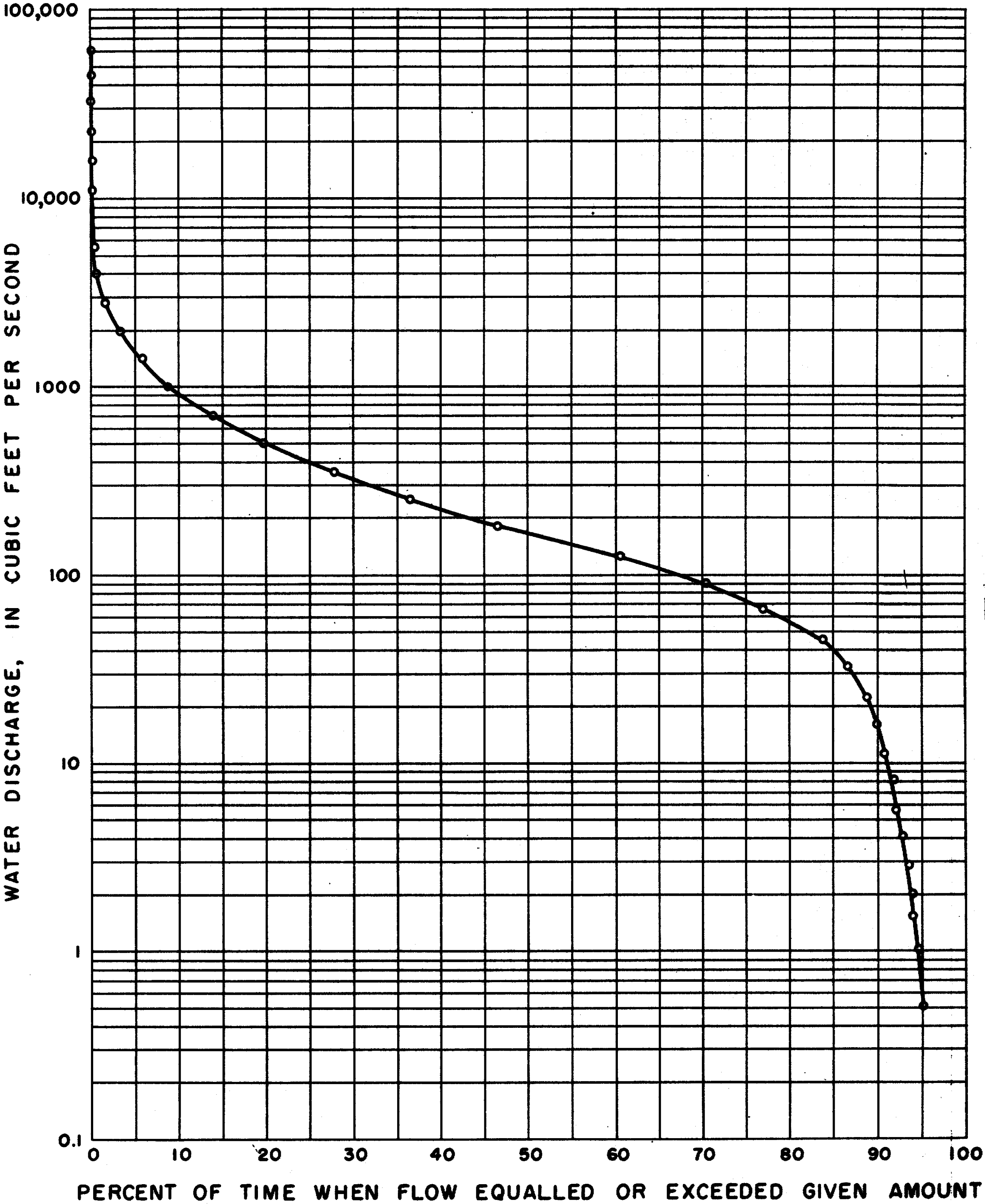


Figure 14.—Duration curve of stream flow for the Powder River at Arvada, from Oct. 1, 1917, to Sept. 30, 1950.

Procedures for gaging the flow of streams are fairly well standardized and are explained in Water-Supply Paper 888 (Corbett and others, 1943).

Concentration of suspended sediment in the Powder River basin was determined from depth-integrated sediment samples. These samples were collected either with the US DH-48 hand sampler or with the US D-43 sampler except when the temperature was below freezing at which times a modified Colorado River sampler was used.

At sediment-measuring stations, samples were usually collected by local observers at one vertical in the stream cross section, called the daily sampling station, once or twice a day except during periods of high or rapidly changing concentration or discharge when samples were taken more frequently. In addition, engineers periodically collected samples at the daily sampling station and at three to five verticals in the cross section of each stream. These verticals were spaced to represent equal quantities of water discharge. Concentrations of samples from the different verticals were averaged to get the concentration for the cross section. At some measuring stations, the concentration of samples that were collected at the daily sampling station varied consistently or erratically from the average concentration of the cross-section samples. At such stations, corrections were applied to adjust concentrations that were based on samples at the daily sampling station to concentrations for the cross section.

The suspended-sediment samples were weighed in the laboratory. After the sediment had settled, the supernatant water was drawn off. The residue was filtered or evaporated, and the sediment was dried and weighed. Corrections were applied for any appreciable quantity of dissolved solids that remained with the sediment after the water was evaporated.

Daily mean concentrations of suspended sediment were computed by plotting the concentration of samples from the daily sampling station on the gage-height graph, drawing a smooth curve through the plotted points, and picking the mean daily concentrations for the daily sampling station from this curve. If the concentration at the daily station usually differed appreciably from the average concentration for the cross section, a coefficient, either variable or else constant throughout the year, was applied to adjust the concentration at the daily sampling station to conform with the concentration for the cross section of the stream.

Discharge of suspended sediment in tons per day usually was computed by multiplying daily concentration in parts per million by mean daily water discharge in second-foot days and by 0.0027. The constant 0.0027 is correct only when the weight of a cubic foot of water-sediment mixture is about 62.5 lb. On days when both concentration and water discharge were changing rapidly, each day was subdivided, and sediment discharge was computed for parts of the day. For days when no samples were collected, the daily discharges of suspended sediment were estimated on the basis of water discharge, concentration for adjacent days, weather records, and records for other stations.

Suspended-Sediment Records

Since April 4, 1946, records of suspended-sediment discharge have been collected for the Powder River at Arvada, Wyo. Similar records have been obtained at the gaging station on the Middle Fork Powder River above Kaycee since April 22, 1949, and at six other gaging stations in the Powder River drainage basin since the spring of 1950. These records have been computed to September 30, 1950, and are summarized in table 4. Monthly and annual figures of suspended-sediment discharge are in tables 14 to 21. Locations of the stations are shown on figures 2 and 12. Records of suspended-sediment discharge at most stations were obtained only during the water year 1949-50, when stream flow was far below normal.

Suspended-sediment discharge fluctuates with changes in any one of several interrelated variables, which include water discharge, turbulence and temperature of the flowing water, and the availability of sediments of each size range. Resulting fluctuations in discharge of suspended sediment are large and rapid and have only a general relation to water discharge. (See figs. 15 to 22.) Except, perhaps, at very high discharges or overbank flows, the sediment discharge generally increases more rapidly than the water discharge because the concentration also tends to increase with water discharge. For this reason, discharge of suspended sediment is usually less than average during years of average water discharge, for an occasional year of high sediment discharge is likely to raise the average annual sediment discharge considerably above the median annual discharge. On streams, such as Salt Creek and the South Fork Powder River, on which most of the stream flow is caused directly by runoff from an occasional rain, the sediment discharge during one short period of storm runoff may exceed the average annual sediment discharge of the stream.

Table 4 shows that concentrations and discharges of suspended sediment were low at gaging stations on Clear Creek near Arvada, Crazy Woman Creek near Arvada, and the Middle Fork Powder River above Kaycee during the period of sediment records. Most of the water that passes these stations comes from the mountains.

Suspended-sediment discharge measured at the gaging station on the Powder River at Arvada during a 5-year period ending September 30, 1950, averaged about 5,500,000 tons per year. (See table 4.) This sediment discharge was transported by an annual water discharge of about 200,000 acre-ft, which is two-thirds of the average annual discharge for the period of stream-flow records. The average concentration by weight was 2 percent. As the drainage area upstream from Arvada is 6,050 sq mi, 200,000 acre-ft of water represents an average depth of 0.62 in. over the drainage area. The annual runoff during the 5-year period that ended September 30, 1950, would be about 0.7 in. after adjustment for net irrigation diversions.

Though little direct relationship exists between amount of runoff and quantity of sediment that is eroded, yet the maximum amount of erosion is effectively limited by the amount of runoff. In any area where the annual runoff averages less than 1 in., the average

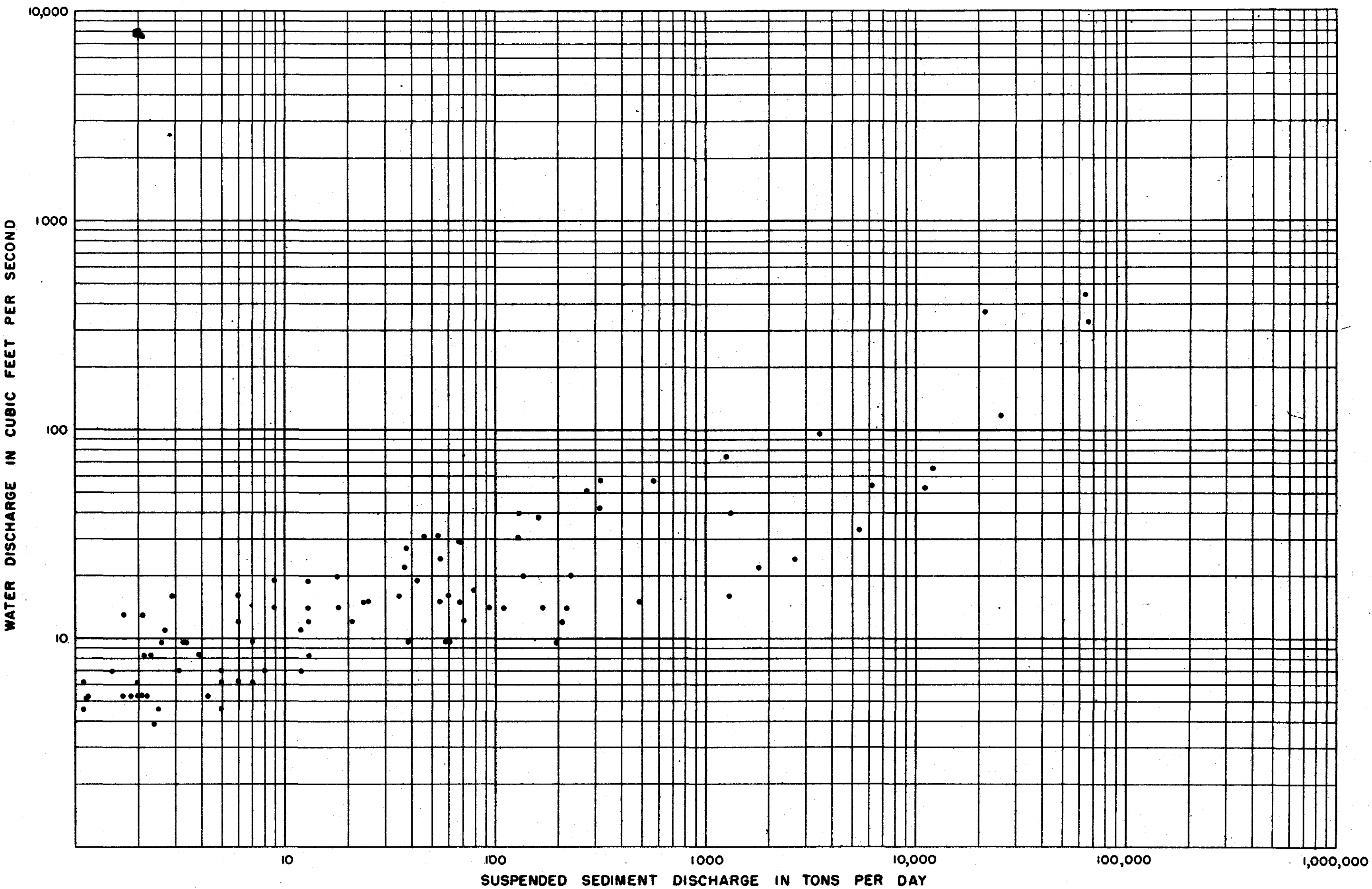


Figure 15.--Relation of suspended-sediment discharge to water discharge, South Fork Powder River near Kaycee, Wyo., May 17, 1950, to Sept. 30, 1950.

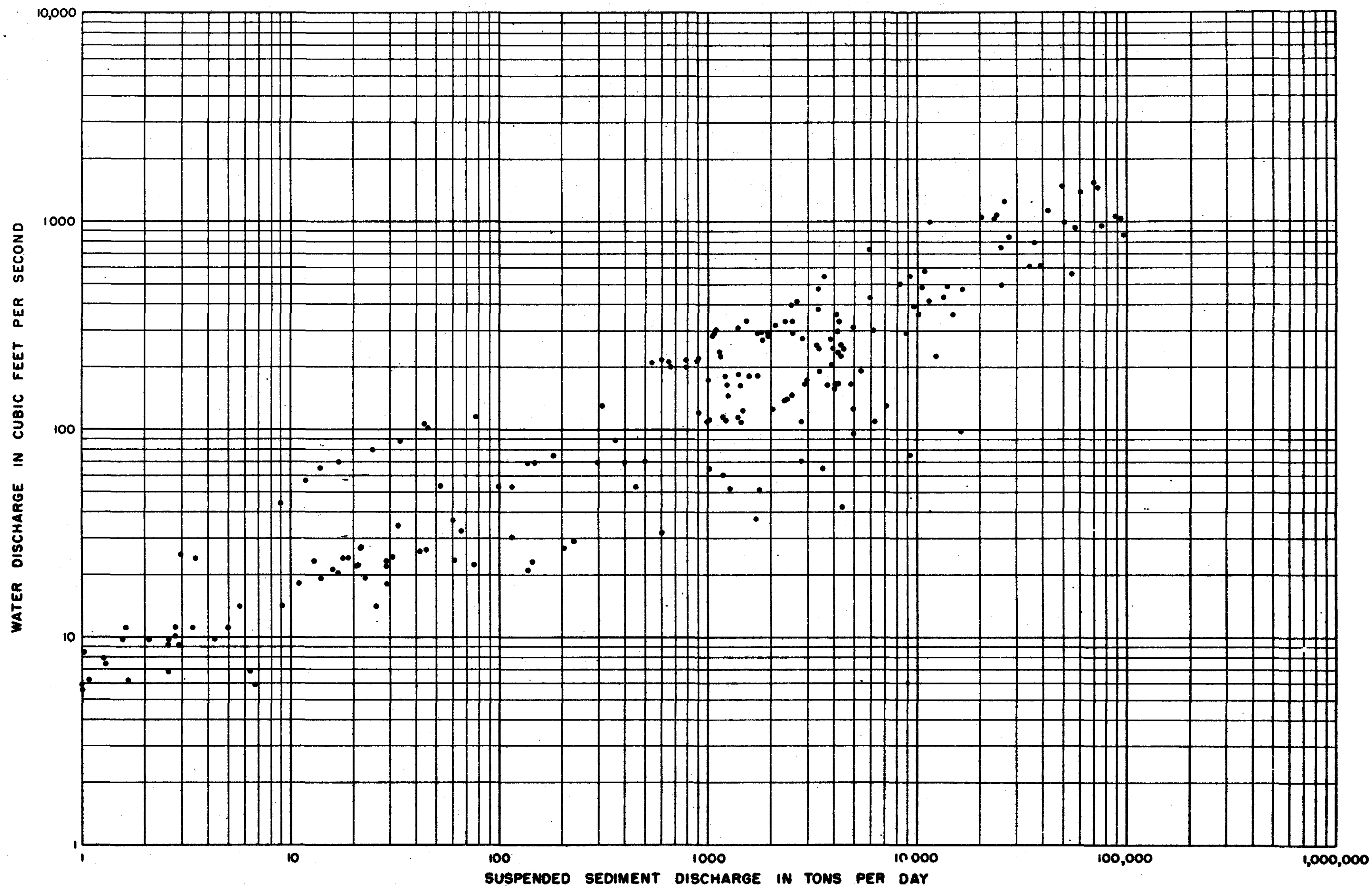


Figure 16.--Relation of suspended-sediment discharge to water discharge, Powder River at Sussex, Wyo., Mar. 1, 1950, to Sept. 30, 1950.

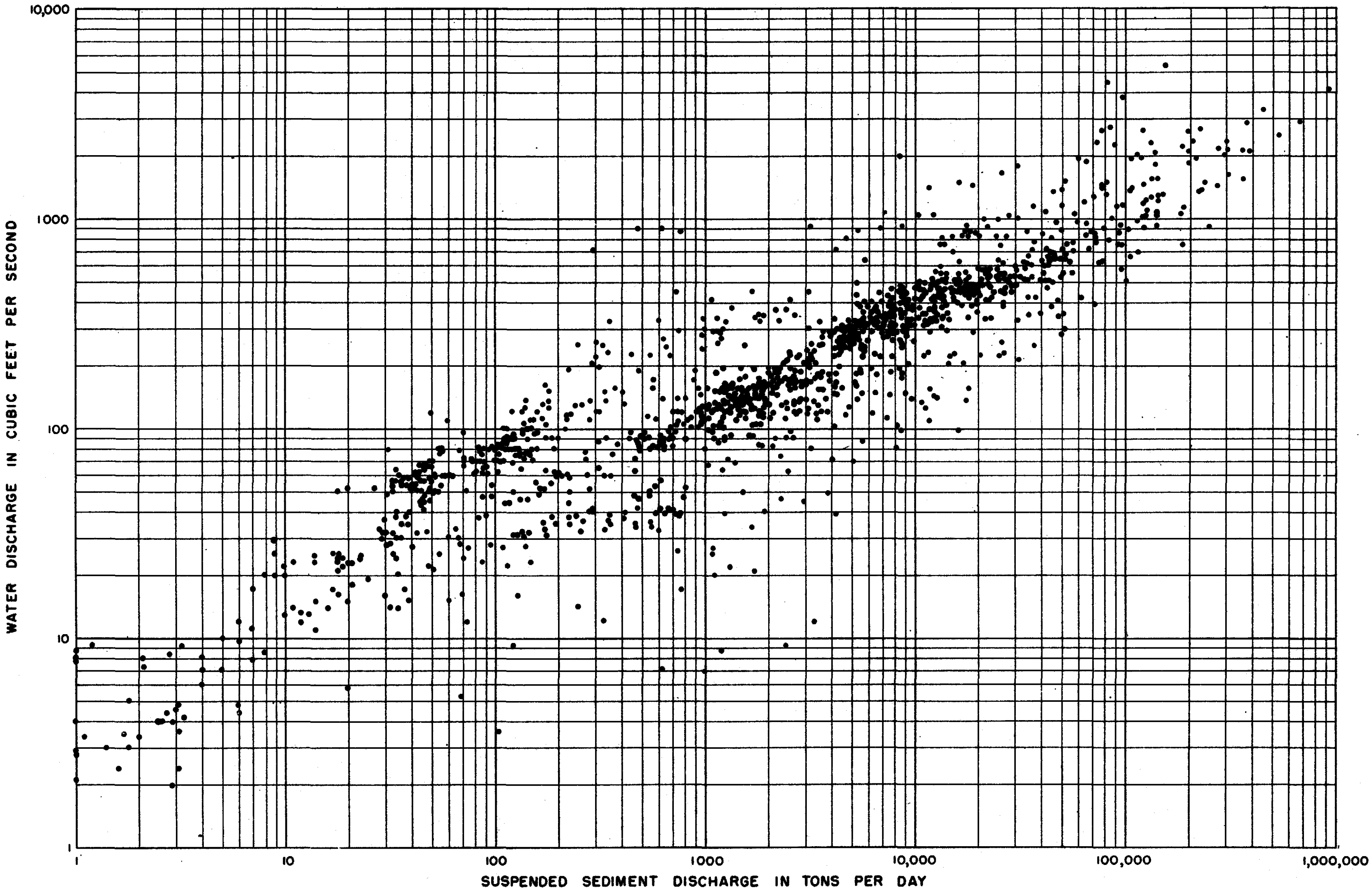


Figure 17.--Relation of suspended-sediment discharge to water discharge, Powder River at Arvada, Wyo., Apr. 4, 1946, to Sept. 30, 1950.

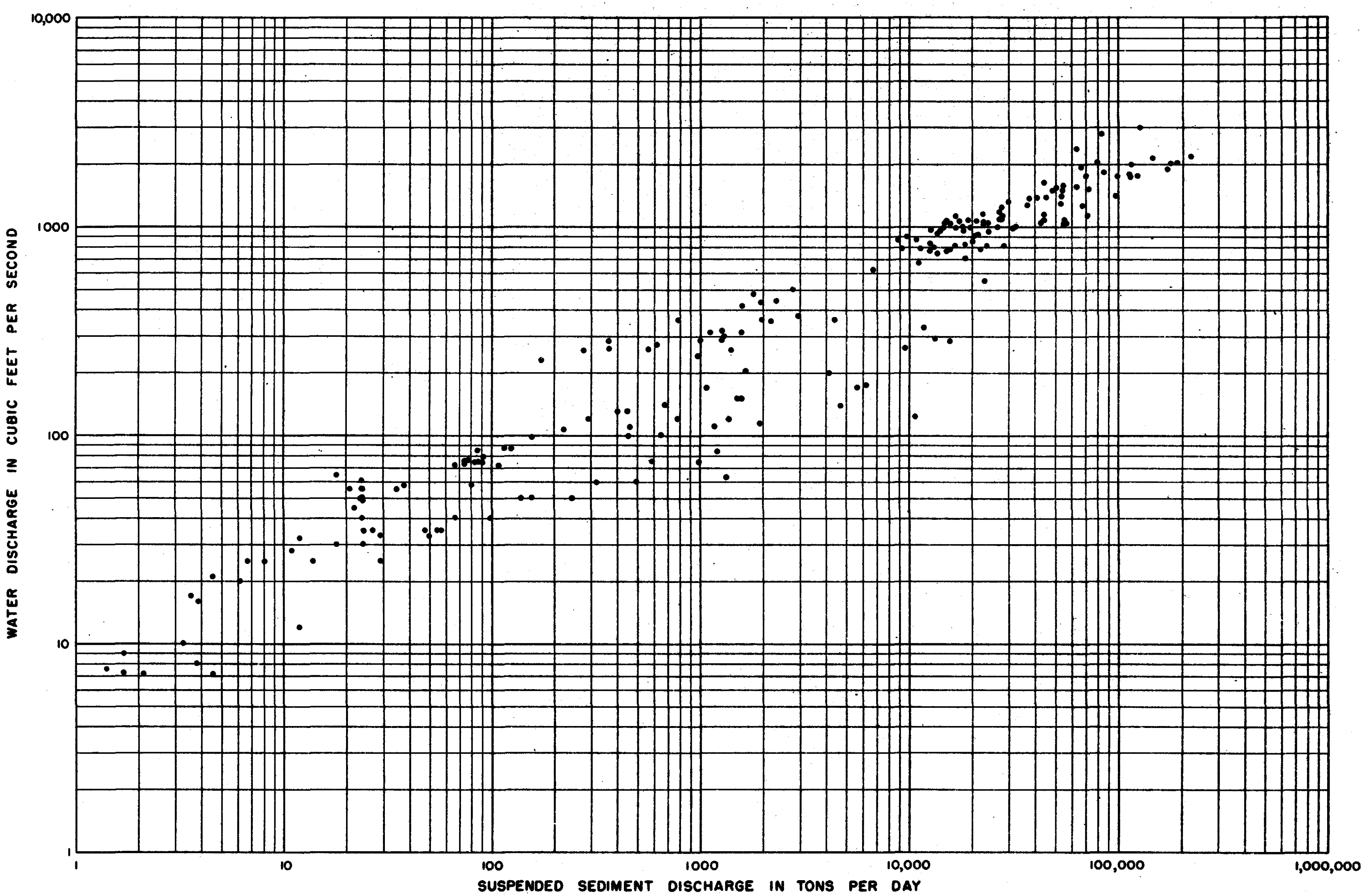


Figure 18.--Relation of suspended-sediment discharge to water discharge, Powder River near Locate, Mont., Mar. 1, 1950, to Sept. 30, 1950.

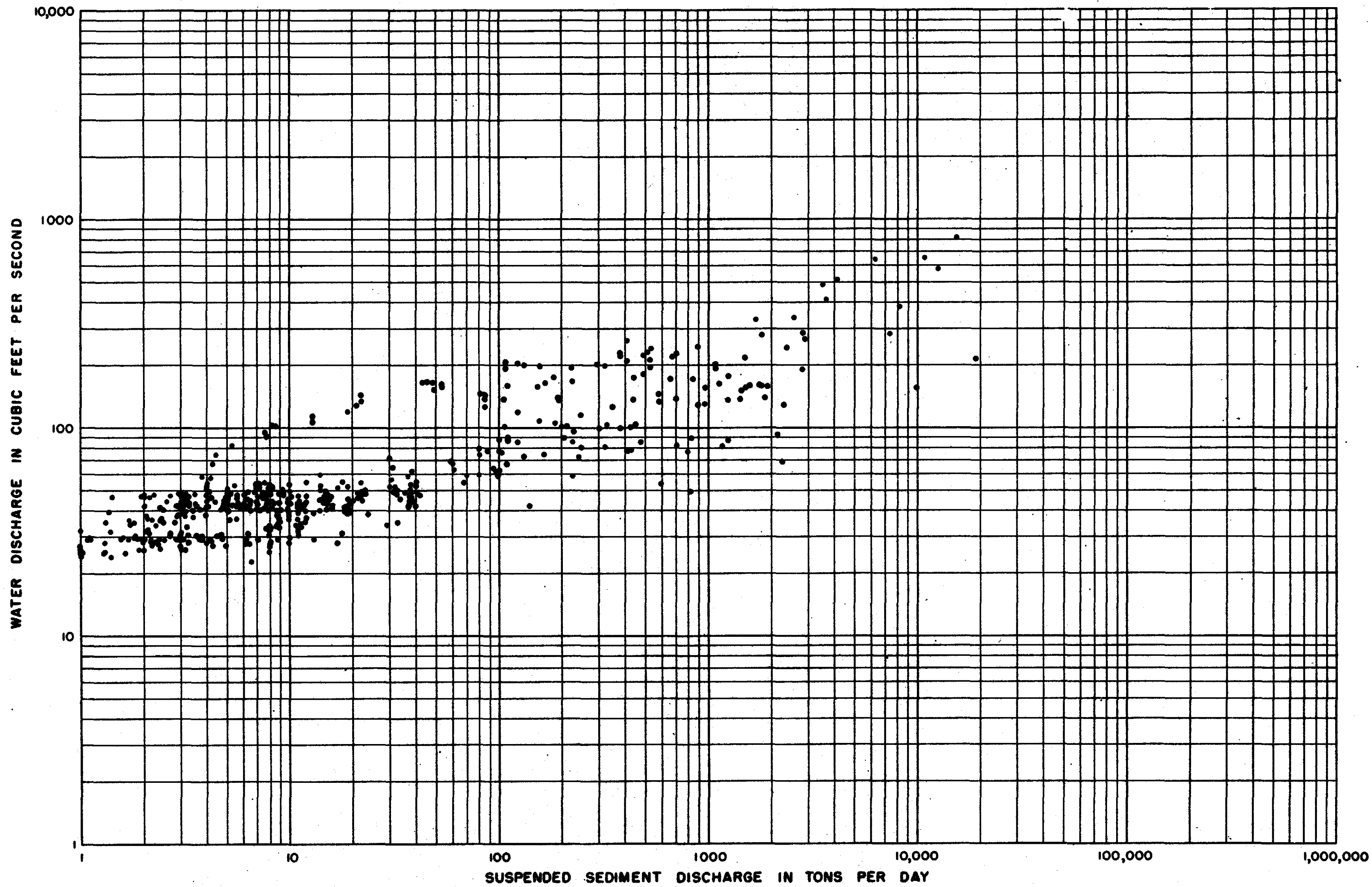


Figure 19.--Relation of suspended-sediment discharge to water discharge, Middle Fork Powder River above Kaycee, Wyo., Apr. 22, 1949, to Sept. 30, 1950.

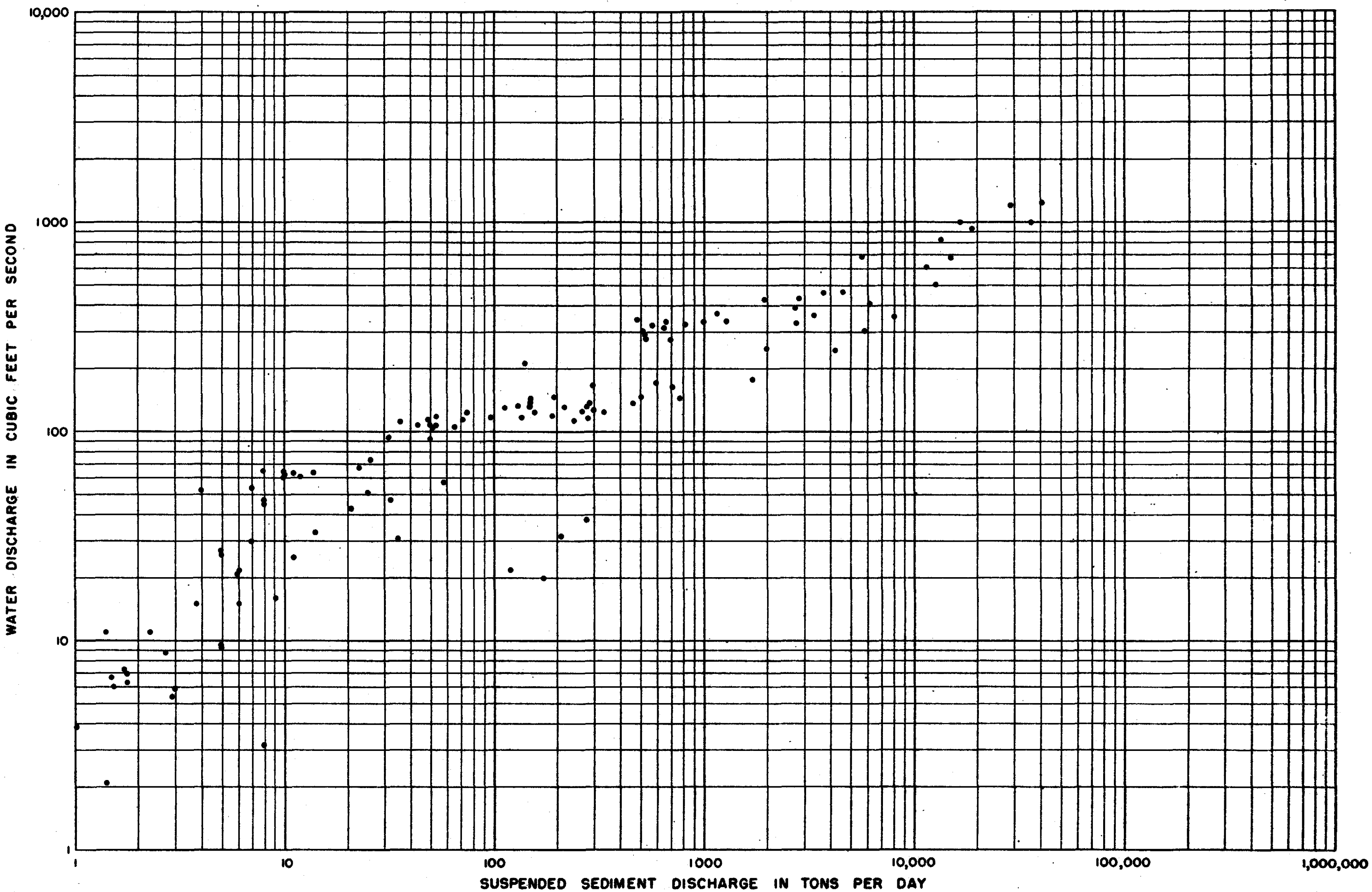


Figure 20.--Relation of suspended-sediment discharge to water discharge, Middle Fork Powder River near Kaycee, Wyo., Mar. 1, 1950, to Sept. 30, 1950.

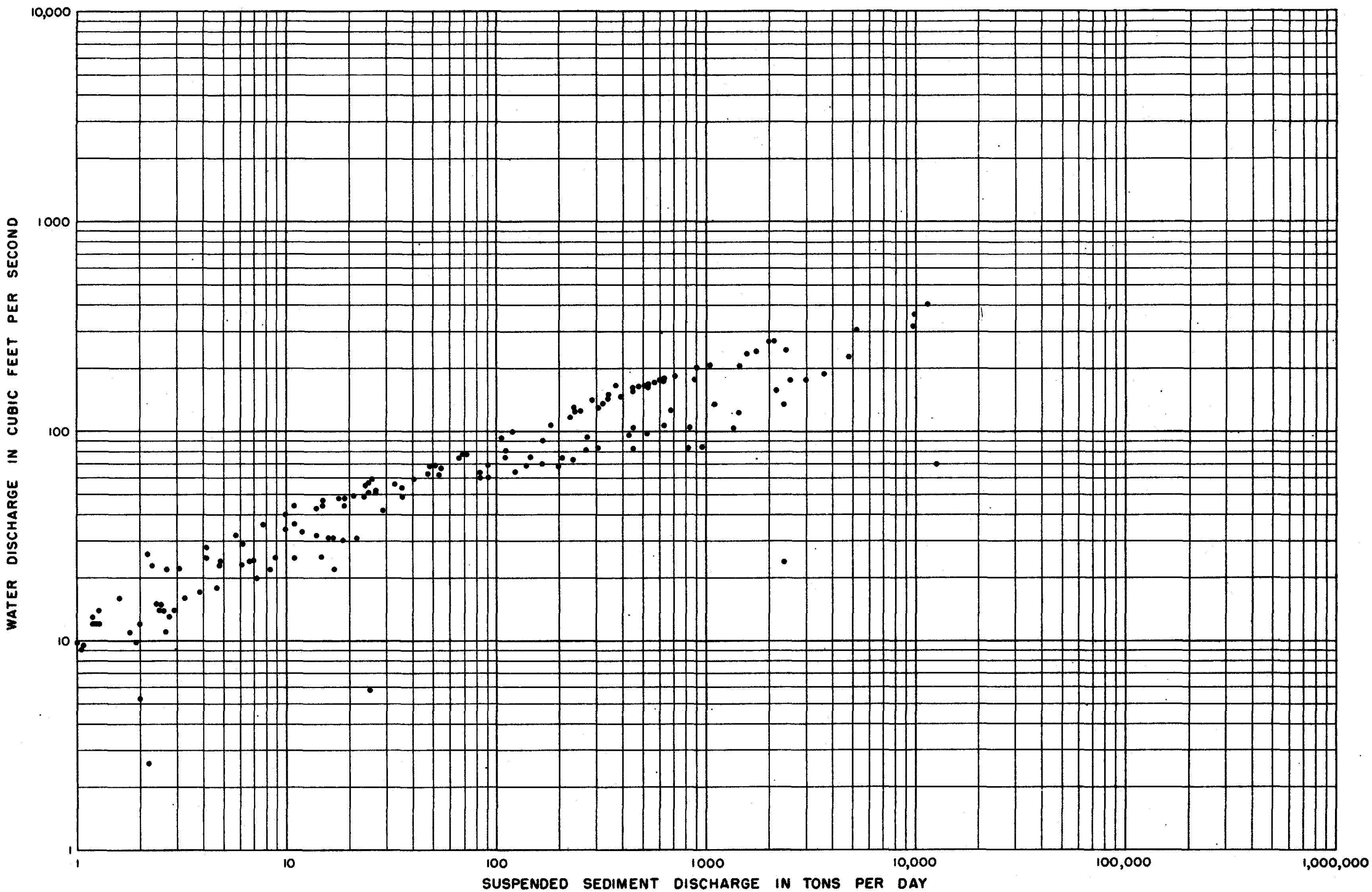


Figure 21.--Relation of suspended-sediment discharge to water discharge, Crazy Woman Creek near Arvada, Wyo., Mar. 15, 1950, to Sept. 30, 1950.

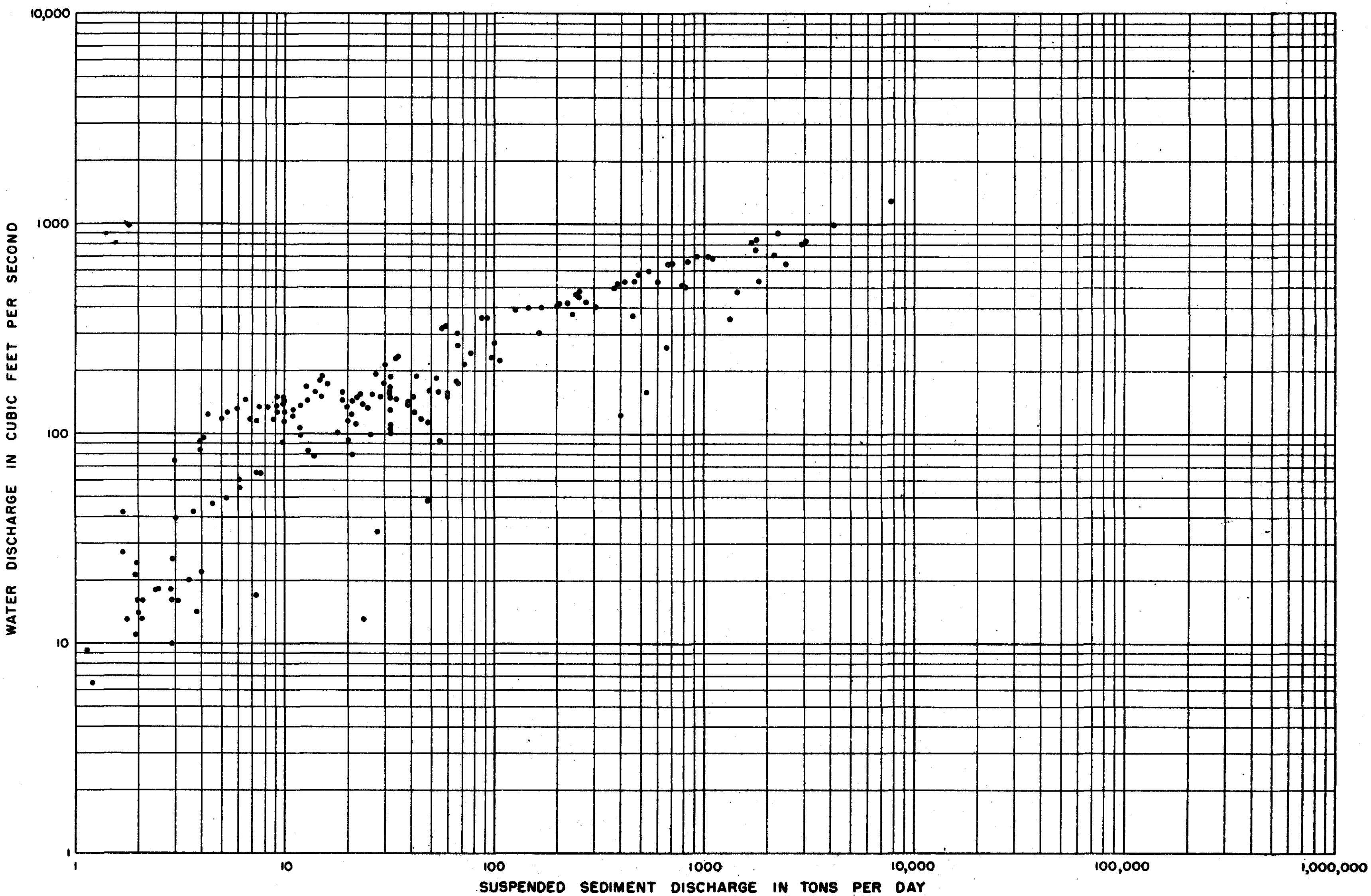


Figure 22.--Relation of suspended-sediment discharge to water discharge, Clear Creek near Arvada, Wyo., Mar. 21, 1950, to Sept. 30, 1950.

Table 4.--Summary of records of suspended-sediment discharge for the Powder River drainage basin

Number on map (fig. 12)	Gaging station	Drainage area (square miles)	Period of record	Water discharge (acre-feet)	Suspended-sediment discharge (tons)	Average concentration* (ppm)
1	South Fork Powder River near Kaycee, Wyo.......	1,150	May 17 to Sept. 30, 1950	4,110	76,640	13,700
2	Powder River at Sussex, Wyo....................	3,090	Mar. 1 to Sept. 30, 1950	99,780	1,500,000	11,000
3	Powder River at Arvada, Wyo....................	6,050	Apr. 4 to Sept. 30, 1946	120,600	3,774,000	23,000
			Water year 1946-47	274,800	5,323,000	14,200
			Water year 1947-48	248,900	9,428,000	27,800
			Water year 1948-49	184,000	4,883,000	19,500
			Water year 1949-50	131,700	2,738,000	15,300
6	Powder River near Locate, Mont..................	a 12,900	Mar. 1 to Sept. 30, 1950	255,900	4,310,000	12,400
7	Middle Fork Powder River above Kaycee, Wyo......	450	Apr. 22 to Sept. 30, 1949	27,780	70,600	1,870
			Water year 1949-50	49,680	108,800	1,610
9	Middle Fork Powder River near Kaycee, Wyo.......	980	Mar. 1 to Sept. 30, 1950	66,600	363,400	4,010
17	Crazy Woman Creek near Arvada, Wyo............	956	Mar. 15 to Sept. 30, 1950	27,000	107,300	2,920
21	Clear Creek near Arvada, Wyo....................	1,110	Mar. 21 to Sept. 30, 1950	81,630	52,670	470

* Weighted with water discharge.
a Approximate figure.

annual depth of soil that can be eroded from a drainage basin cannot exceed a fraction of an inch. If a cubic foot of the soil of a drainage area weighs 80 lb and the maximum concentration of sediment cannot reasonably be expected to exceed 250,000 ppm by weight, the maximum depth of erosion that accompanies 1 in. of runoff can be computed as follows:

1. An inch depth of water on a square foot of area is 62.4 lb divided by 12 or 5.2 lb. (The assumption is made here that 1 in. of runoff is clear water only, because much sediment may be deposited from the water before the water is measured.)

2. At 250,000 ppm, three-quarters of the sediment-water mixture is water and one-quarter is sediment. Hence, 5.2 lb divided by 3 or 1.73 lb of sediment will be in the mixture. (If the specific gravity of the sediment is 2.65, the water-sediment mixture would cover a square foot of area to a depth of 1.126 in.)

3. 1.73 lb divided by 80 is 0.0216 or the fraction of a foot of soil that could be eroded from a square foot of area by 5.2 lb of water. This is equivalent to 0.26 in.

The concentration of 250,000 ppm would be attained only when the soil was very easily erodible and the intensity of runoff was exceptionally high. A much more usual concentration would be 50,000 ppm, which would indicate a depth of erosion of 0.04 in. per inch of runoff.

Of course the average depth of net erosion over a large drainage basin can be computed from the measured sediment yield of a drainage basin, but it will normally be somewhat less than the average depth of erosion that may be expected for many small drainage areas within the large drainage basin. On large drainage areas the average depth will be reduced by inclusion of areas where only small amounts of erosion occurred and may be further reduced by deposition in some parts of the basin or may be increased by channel scour.

Nothing in this discussion should be interpreted to mean that erosion removes even an approximately uniform depth of soil from either large or small areas. It is intended only to establish a rough limit of possible depths of erosion that may be expected to accompany an inch of runoff. Also, the depths of erosion that are discussed here are for drainage areas without inflow of water from outside the areas.

Size Composition of Suspended Sediment

At all gaging stations where records of suspended-sediment discharge were obtained, representative samples were collected periodically for particle-size analyses. One or both of two general types of particle-size distributions were determined from a sample. One type showed particle sizes according to settling velocities in native water in which the degree of flocculation may have been about the same as in an assumed pool or reservoir. The other type of particle-size distribution was the classification of particles by their settling diameters when the particles were completely dispersed. For particle sizes smaller than 0.031 mm, the difference between the two types of particle-size distributions is large. The difference is due to flocculation of the soil particles, which is caused by the calcium and magnesium cations from dissolved solids in the native water. Average size distributions of samples for which duplicate portions were analyzed in native water and in distilled water are plotted on figure 23 for the Powder River near Arvada. Also plotted is the curve of average particle size for all samples analyzed in distilled water. Average particle sizes were not weighted with sediment discharge; they are simply arithmetic averages of the size distributions of the samples. Median particle sizes were taken from figure 23

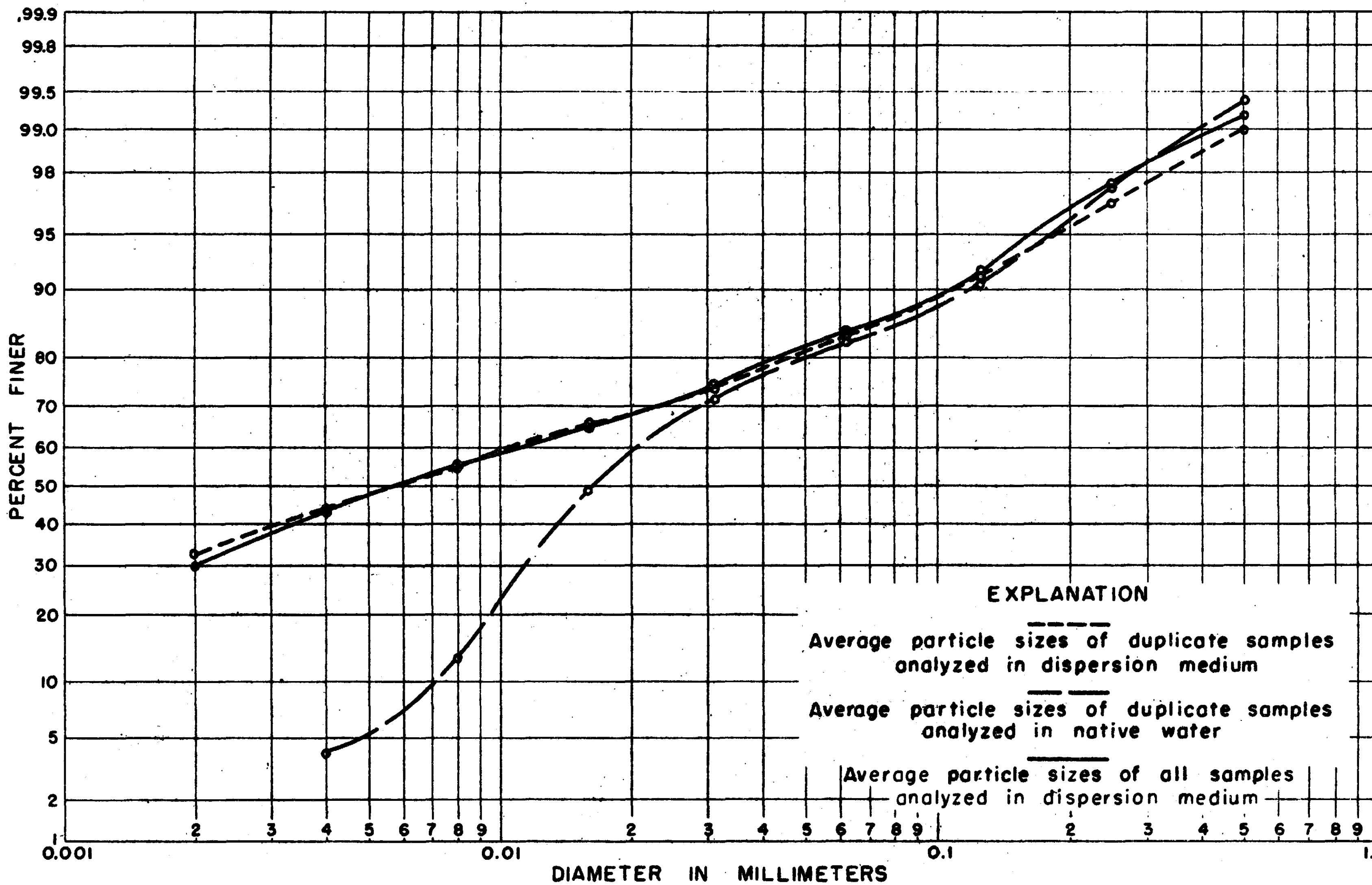


Figure 23.--Average particle-size distributions of suspended-sediment samples, Powder River at Arvada, Wyo.

and from similar figures for other stations where sediment records have been collected. They are listed in table 5.

Particle sizes as analyzed in native water are helpful in estimating the rates and locations of sediment deposition in slowly moving parts of a stream and in reservoirs. However, the degree of flocculation in a reservoir may not be the same as in the sedimentation cylinder in the laboratory.

Absolute particle sizes, measured by settling velocities of dispersed particles in distilled water, are probably the most suitable size distributions for computing the specific weight of sediment after it is deposited in a reservoir. Sediment particles, even though they may flocculate to a larger settling diameter in the process of deposition, may, after they are deposited in a reservoir, still retain the physical properties of the individual particles. Floccules can be dispersed by mechanical agitation. Therefore, the bonds that hold together the individual sediment particles are not strong enough to give a floccule the physical properties of an individual sediment particle. For this reason the determination of specific weights that are based on particles sizes should be computed from particle sizes obtained by analysis of dispersed particles.

Until 1950 the particle-size analyses both in native and in distilled water were made with the bottom-withdrawal tube. During 1950 many samples were analyzed for particle size by the sieve-pipette method. In this method particles coarser than 0.0625 mm are separated from the finer particles by a combination of wet and dry sieving. The coarser portion is then weighed and discarded or is subdivided into different size classifications by dry sieving. The finer portion is analyzed according to sedimentation diameters by the pipette method.

The suspended sediment transported by the Powder River is mostly fine material. (See fig. 24.) The average percentage of particles smaller than the lower limit of sand size (0.062 mm) was between 81 and 89 percent for all stations except the South Fork Powder River near Kaycee for which 97 percent of the suspended sediment was finer than sand. The particle-size curves of figure 24 were based on average sizes that were not weighted with either water or sediment discharge except that samples for size analysis were collected much more frequently at high discharges than at low discharges. Median particle sizes (table 5) based on the average size distributions for the different sampling stations were all smaller than 0.009 mm for samples that were analyzed in a dispersion medium. Median particle sizes of duplicate samples are for comparison between themselves only. For some stations they are based on only one of two samples, and these samples were collected when the concentration was high. The size distributions of individual analyses are listed in tables 22 to 29.

Specific Weight of Fluvial Sediment

Estimates of rates of reservoir depletion by sediment deposition require a knowledge of the probable location and specific weight of the deposited sediments. The location of the deposited sediments is dependent upon inflow-outflow relationships or elevation of water surface in the reservoir, sedimentation diameter of particles in transport, mineral constituents in solution, and effect of density currents. The specific weight of sediment deposits depends upon the type of material in transport, primary particle size, effect of change in concentration of the mineral constituents in solution, degree of sorting, and amount of consolidation.

The rate of deposition of sediment in the upper reaches of a reservoir is a function of the stream velocity (turbulence) and settling diameter of the material in transport. The coarse material will be deposited where the backwater begins, and much of the finest material will eventually reach the downstream end of the reservoir because of density currents or reservoir drawdown or both. The reservoir operation may thus result in deposition of coarse and fine material in alternate lenses at the same location.

The specific weight of sediment deposits in reservoirs increases with compaction. If all sediment particles have about the same specific gravity, the specific weight of sediment deposits depends upon the porosity of the deposit. Theoretically, if the sediment particles are uniform spheres and touch one another, the porosity depends upon the arrangement of the particles and not on the particle size. However, the porosity changes greatly when particles of different sizes are intermixed, as the smaller particles partly fill the pores between the large particles. Deposits of silts and clays have greater porosity and smaller specific weight than deposits of larger particles partly because the range in size may be greater in the coarser deposits.

Table 5.--Median particle sizes from unweighted average size distributions of suspended sediment for stations in the Powder River drainage basin

Sediment station	Duplicate samples		All samples analyzed in a dispersion medium (millimeter)
	Analyzed in native water (millimeter)	Analyzed in distilled water (millimeter)	
South Fork Powder River near Kaycee, Wyo......	0.010	a 0.0018	a 0.001
Powder River at Sussex, Wyo..................	.011	.0035	.0040
Powder River at Arvada, Wyo..................	.016	.0057	.0058
Powder River near Locate, Mont...............	.012	.0034	.0030
Middle Fork Powder River above Kaycee, Wyo....	.015	.0089	.0084
Middle Fork Powder River near Kaycee, Wyo.....	.021	.0245	.0080
Crazy Woman Creek near Arvada, Wyo...........	.015	.0140	a .003
Clear Creek near Arvada, Wyo.................	....	....	.0062

a Estimated by extrapolation.

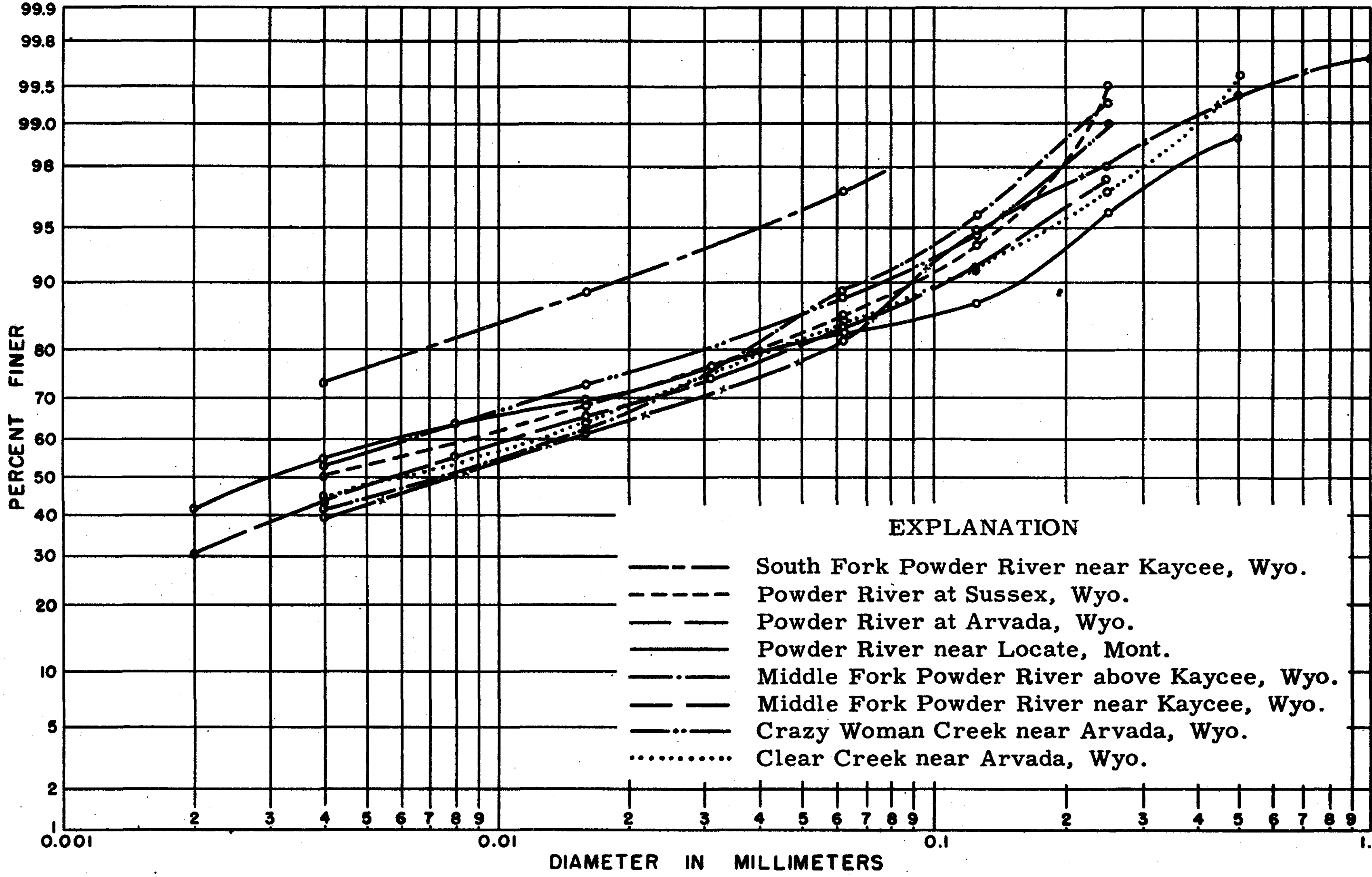


Figure 24.--Average particle-size distributions of all suspended-sediment samples analyzed in dispersion medium.

An increase in specific weight and a reduction in volume of deposits are usually accomplished by squeezing out part of the interstitial water and by closer packing of the sediment particles. The smaller the pore spaces are, the lower is the permeability and the slower is the release of the interstitial water. Hence, fine-grained deposits usually compact at a much slower rate than coarse-grained deposits. The rate and the amount of increase of specific weight depend not only on the particle size of the deposits but also on the method of operation of the reservoir. Consolidation is probably rather rapid in the first few years after deposition but decreases with time.

The determination of an average figure for the specific weight of a deposit that might be formed from the sediment in transport is necessary to ascertain the space the sediment will occupy in a reservoir. The accuracy of the determination is affected not only by reservoir operation but also by the inaccuracies introduced in measuring the total sediment discharge. At present only the suspended sediment is measured; the bed load must be estimated. Only an approximate figure for the average specific weight, which the material will assume on deposition, can be computed.

Median Particle-Size Method

The specific weight of a deposit that might be formed from a suspended sediment was computed by a method based on the median particle size of the suspended sediment. This method is believed to be superior to others that apply specific weights to different size grades because it is simple and is based on actual measurements of specific weights.

This method was applied as follows: The median particle size of each sample that was analyzed in a dispersed state was plotted against the instantaneous suspended-sediment discharge in tons per day. (See fig. 25.) The curve of figure 25 was so drawn that on the basis of the available particle-size analyses an average of about 50 percent by weight of the particles within each of several ranges of sediment discharge would be finer than the median size indicated by the curve. For predetermined class intervals of suspended-sediment discharge, the corresponding median particle sizes were taken from the curve of figure 25 and were listed in table 6.

Figure 26 shows the relation between the median particle size and the specific weight of relatively uncompacted sediment deposits in reservoirs in the Powder River drainage basin and other drainage basins. The data from which the figure was prepared are in table 30. These data are for samples that were all or nearly all collected near the surface of submerged sediment deposits. Thus the specific weights of the samples are representative of natural deposits that have been formed, probably within a few years of the sampling time, and that have not been compacted materially by overlying deposits.

The specific weight of a deposit that might be formed from the suspended sediment of the Powder River at Arvada was then computed as shown in table 6 and was found to be 56 lb per cu ft. This specific weight, which is for a sediment deposit that has not been compacted during a long period of time or under the weight of appreciable amounts of overlying deposits, was used to convert tons of suspended sediment to acre-feet of sediment. (See table 7.) The computed volume, 21,420 acre-ft, indicates the probable maximum space that would be occupied by the suspended sediment that was discharged by the Powder River at Arvada from April 4, 1946, to September 30, 1950, after deposition in a reservoir.

Size-Distribution Method

A second method of computing the specific weight of a deposit that might be formed from suspended sediments is the size-distribution method. This method consists of dividing the sediment into size fractions and computing the specific weight of the deposit from the percentages of each size fraction and from the density of each size fraction.

To determine the average distribution of sand, silt, and clay in the suspended sediment of the Powder River at Arvada, the percentages of these size fractions were taken from the particle-size analyses that were made in distilled water. The percentages of each size fraction were plotted against the suspended-sediment discharge in tons per day. Average curves were drawn through the plotted points. If these three curves are assumed to represent adequately the variations in the size distributions of suspended sediment with sediment discharge, the average percentage distribution of clay, silt, and sand can be determined as follows:

1. Select class intervals of suspended-sediment discharge in logarithmic progression.

2. Tabulate for each class interval the percentage of sand, silt, and clay as shown by

Table 6.--Specific weight based on median particle size for the Powder River at Arvada, Wyo., Oct. 1, 1946, to Sept. 30, 1950

Suspended-sediment discharge			Median particle size (millimeter)	Specific weight (pounds per cubic foot)	Total tons divided by specific weight
Class interval (tons per day)	Middle of class interval (tons per day)	Total tons			
0- 3,500	1,750	597,000	0.0059	53	11,264
3,500- 14,000	8,750	1,810,000	.0078	55	32,909
14,000- 58,000	36,000	5,420,000	.0090	56	96,786
58,000- 150,000	104,000	5,630,000	.0098	57	98,772
150,000-1,600,000	875,000	9,420,000	.0100	57	165,263
Total........	....	22,877,000	....	....	404,994

$$\text{Specific weight in pounds per cubic foot} = \frac{22{,}877{,}000}{404{,}994} = 56.49.$$

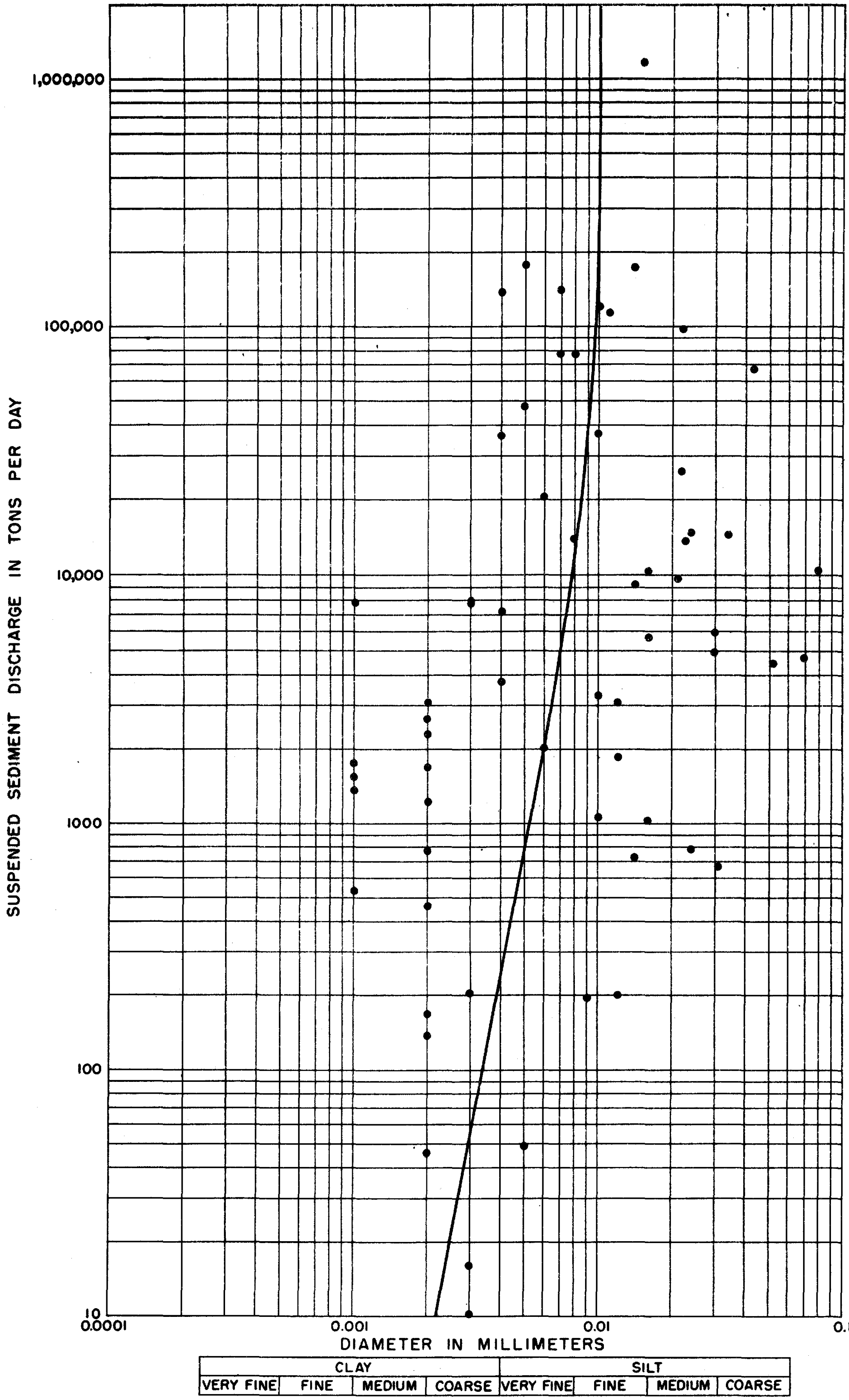


Figure 25.--Median particle size versus suspended-sediment discharge, Powder River at Arvada, Wyo.

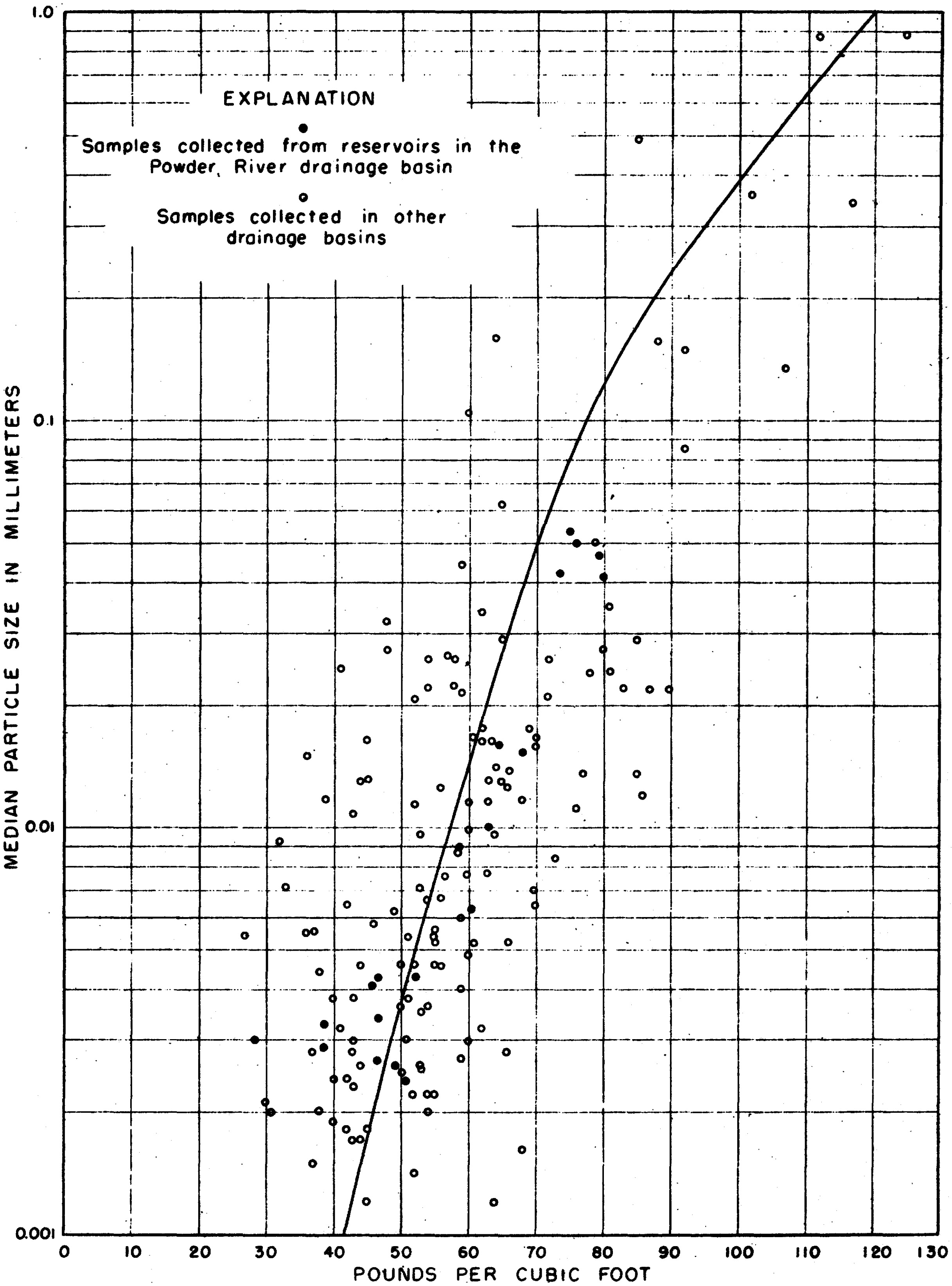


Figure 26.—Relation of specific weight of sediments deposited in reservoirs to median particle size.

Table 7.--Volume of suspended-sediment discharge at 56 lb per cu ft, Powder River at Arvada, Wyo.

Period	Suspended-sediment discharge (tons)	Volume of deposited sediment (acre-feet)
Apr. 4 to Sept. 30, 1946	3,774,000	3,090
Water year 1946-47	5,323,000	4,360
Water year 1947-48	9,428,000	7,730
Water year 1948-49	4,883,000	4,000
Water year 1949-50	2,738,000	2,240
Total	26,146,000	21,420

the average curves of percentage of each size fraction versus suspended-sediment discharge.

3. Compile a frequency table of suspended-sediment discharge from the daily sediment discharges during the four complete water years of sediment records of the Powder River at Arvada to determine the different tonnages of suspended-sediment discharge in each class interval of suspended-sediment discharge.

4. Compute the average percentage distribution of sand, silt, and clay from the tonnages and percentages in each class interval.

By this method of weighting with sediment discharge, the average percentages of sand, silt, and clay in the suspended-sediment discharge of the Powder River at Arvada during the period of 4 water years that ended September 30, 1950, are 20, 43, and 37 percent by weight, respectively. Clay was assumed to include all particles finer than 0.005 mm; silt, those between 0.005 and 0.05 mm; and sand, those between 0.05 and 1.0 mm. These are the size ranges for which Lane and Koelzer (1943, p. 49) state densities of 93, 65, and 30 lb per cu ft for the sand, silt, and clay fractions 1 yr after deposition in a reservoir in which the sediment deposit is always or nearly always submerged. Expressed in cubic feet, the volume occupied by 1 lb of the deposit that might be formed from the suspended sediment of the Powder River at Arvada would be

$$\frac{0.20}{93} + \frac{0.43}{65} + \frac{0.37}{30} = 0.0211$$

and the specific weight at the end of 1 yr would be $\frac{1}{0.0211}$ or 47 lb per cu ft.

The size-distribution method of computing the initial specific weight of the sediment deposit that might be formed from the suspended sediment of the Powder River was also applied to the size ranges and the initial densities as determined by Parker Trask and reported by Lane and Koelzer (1943, pp. 30-31). In these size ranges, clay includes all particles finer than 0.004 mm; silt, those between 0.004 and 0.062 mm; and sand, those between 0.062 and 0.5 mm. The sand, silt, and clay percentages computed by weighting with sediment discharge are 19, 46, and 35 percent by weight, respectively. In cubic feet the volume occupied by 1 lb of sediment deposit with these percentages of the three size fractions and with the initial densities as reported by Trask would be

$$\frac{0.19}{88} + \frac{0.46}{67} + \frac{0.35}{13} = 0.036$$

and the initial specific weight would be $\frac{1}{0.036}$ or 28 lb per cu ft. This low figure for initial specific weight is for sediment deposits that were formed during "a very short settlement period."

Sediment Transported as Bed Load

Because sediment transported as bed load in the Powder River has not been measured, empirical formulas developed from extensive laboratory experiments and limited field data were used to compute the approximate discharge of sediment in the form of bed load. Selection of independent theoretical approaches to bed-load determinations was somewhat simplified by the fact that nearly all are based on the concept of shifting layers of bed material that are kept in motion by the shear of the moving fluid. Bed-load formulas by Einstein (1950), Du Boys (1879, pp. 149-195), and Schoklitsch (Shulits, 1935, pp. 644-687) were used.

A representative cross section of the Powder River at Arvada, Wyo., was determined by averaging three cross sections (fig. 27) near the recording gage. Water levels for five representative water discharges that ranged from 20 to 12,000 cfs were taken from a stage-discharge rating table. Mean depths and widths for the selected discharges were obtained from the average cross section. (See fig. 28.)

The slope of the water surface was determined between the recording gage at Arvada and the highway bridge 2,100 ft downstream from the gage. Thirteen observations of the slope ranged from 4.70 to 5.86 without apparent correlation with water discharge. An average slope of 5.28 ft per mile, or 0.001 was used in the computations.

A median particle diameter of 0.228 mm or 0.00898 in. was taken from the average particle-size distribution curve of the bed material (fig. 29) and was used in Du Boys' and Schoklitsch's formulas.

Du Boys' Formula

Boyer and Laursen (1950, pp. 815-817) proposed the following form of the Du Boys' formula for computation of sediment discharge as bed load:

$$q_s = \frac{K}{d^{\frac{3}{4}}} (yS)^2$$

in which q_s = rate of bed-load transport in pounds per second per foot of width
K = a constant
d = median particle diameter of the bed material in millimeters
y = mean depth in feet
S = hydraulic slope

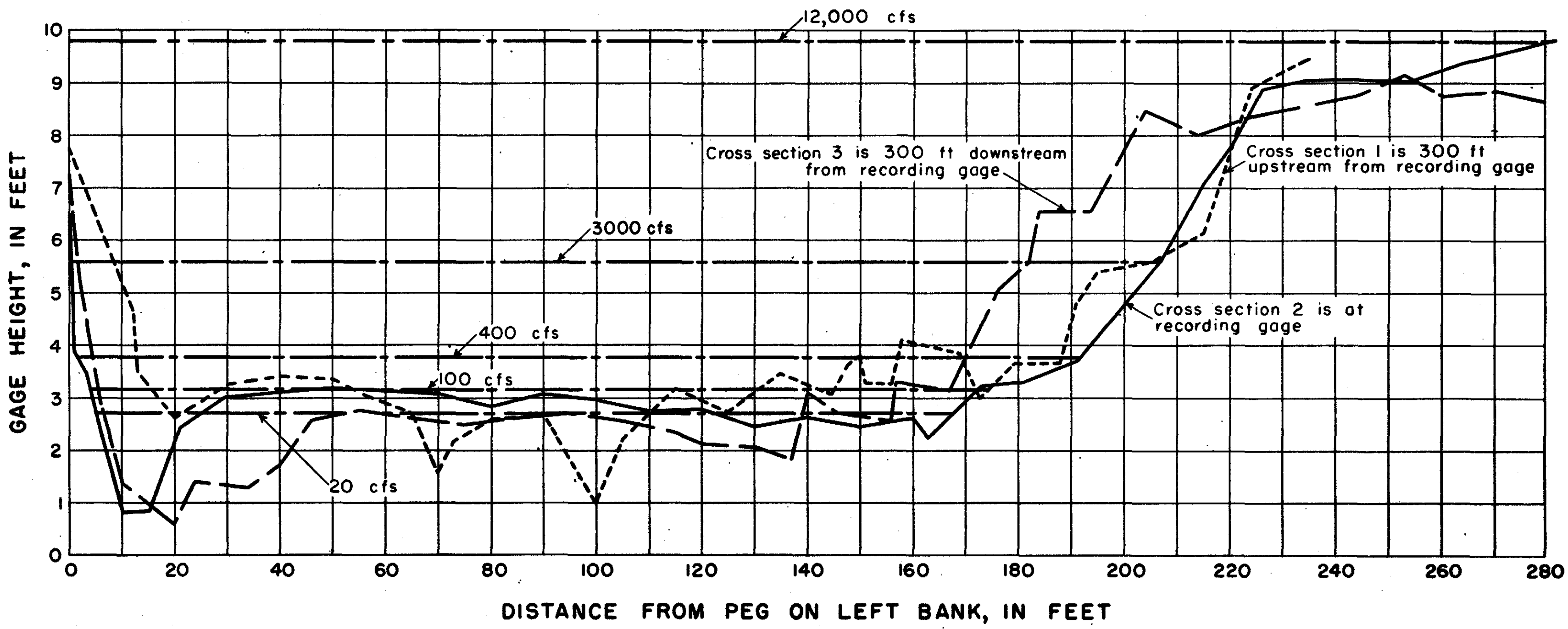
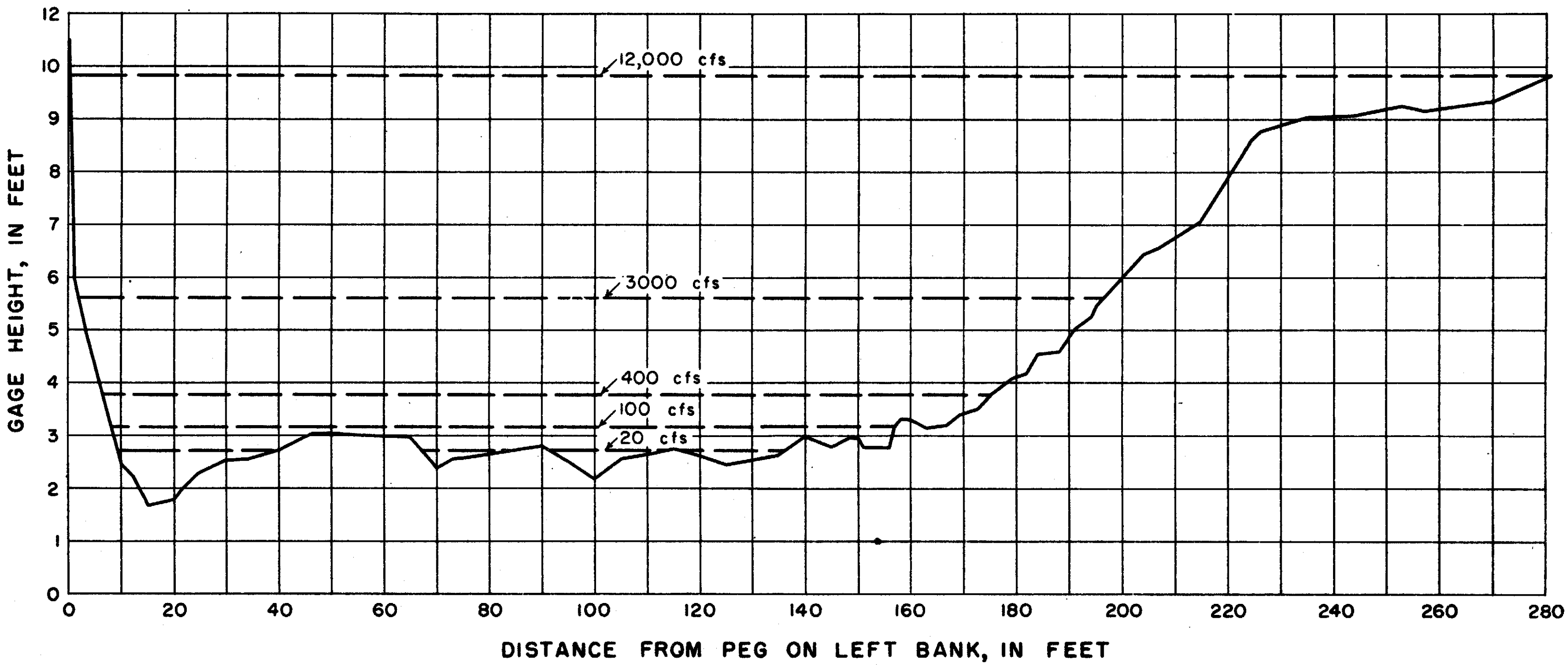


Figure 27.--Three cross sections of the Powder River at Arvada, Wyo.



SECTION CHARACTERISTICS

Gage height in feet	Discharge in cubic feet per second	Area in square feet	Width in feet	Mean depth in feet
2.73	20	28.8	90	0.320
3.18	100	72.4	149	.485
3.79	400	179.2	168	1.066
5.61	3,000	515.6	194	2.657
9.83	12,000	1,447.2	281	5.150

Figure 28.--Average of three cross sections of the Powder River at Arvada, Wyo.

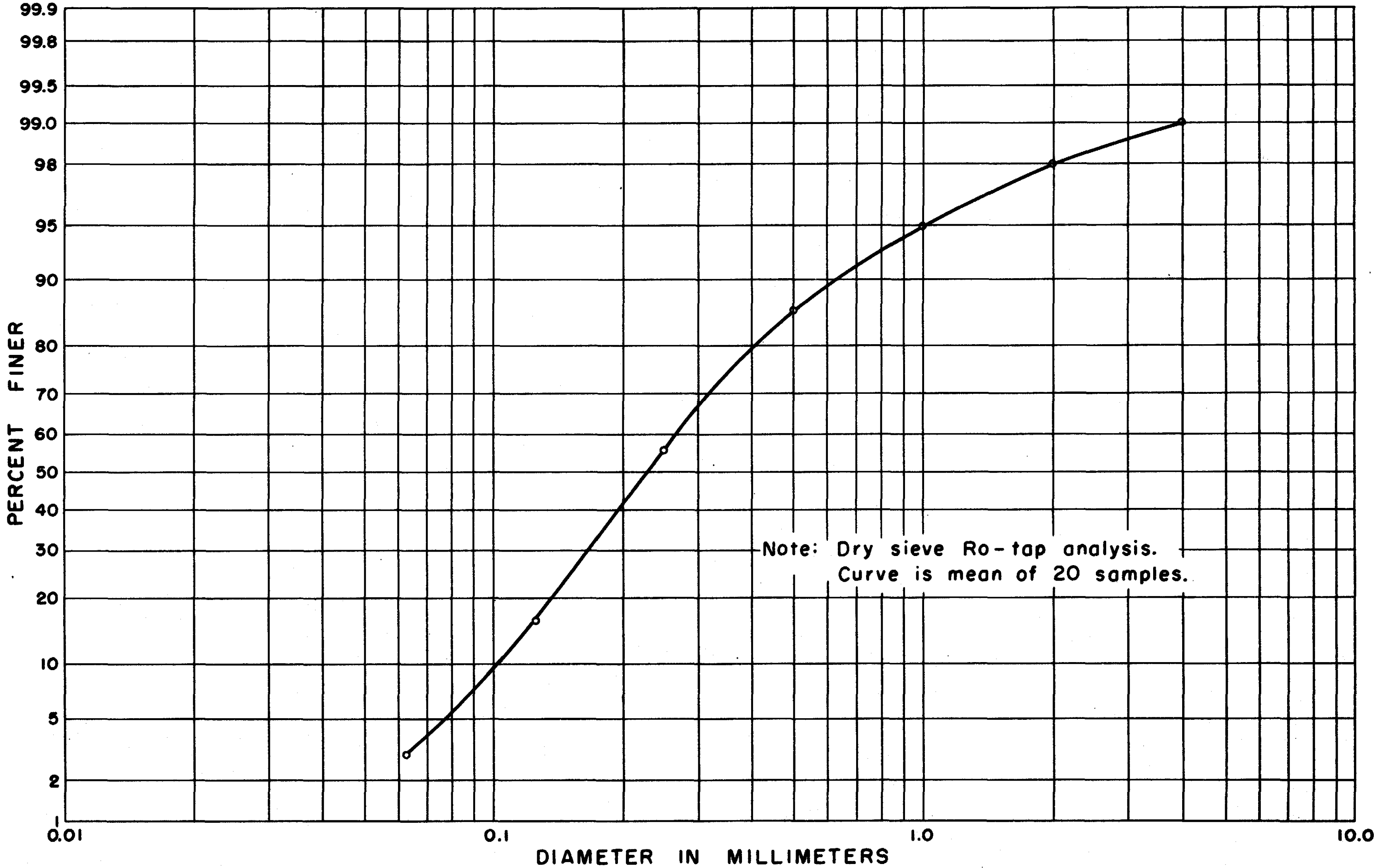


Figure 29.--Bed-material size analysis, Powder River, Wyo. and Mont.

The units were assigned for convenience, as the formula is not dimensionally correct. _K_ was evaluated (fig. 30) as 20,000 on the basis of data from the Niobrara and Middle Loup Rivers in Nebraska.

Rates of bed-load discharge as computed from this formula for five different water discharges are shown in table 8 and are plotted against water discharge in figure 31.

Schoklitsch's Formula

Shulits (1935, pp. 644-646, 687) presented the Schoklitsch bed-load formula as follows:

$$G = \frac{86.7}{D^{\frac{1}{2}}} S^{1.5} \left(Q - 0.00532 \frac{BD}{S^{\frac{4}{3}}}\right)$$

in which G = bed load in pounds per second
D = median diameter of the particles in inches
S = slope of energy gradient
B = width of stream in feet
Q = water discharge in second feet

This formula was developed by analyzing data from flume experiments in which the bed material was uniform quartz grains. A minimum fluid force is assumed to be necessary to start particle movement. This formula was chosen for its simplicity and because it contains no constants that must be evaluated by data from other streams.

The rates of sediment discharge as bed load at four different rates of water discharge were computed and are listed in table 8. Rates of sediment discharge are plotted against water discharge in figure 31.

Einstein's Formula

Einstein (1950) approached the problem of bed-load movement by a method different from that used by most investigators. He combined certain variables into dimensionless expressions for the probability that a given particle would be moved from its position in the bed surface. He developed a formula to compute the total sediment discharge of bed-load material, the material that is transported either in suspension or as bed load and that has particle sizes within the range of sizes that are found in significant quantities in the stream bed. The formula is complex, and its solution requires supplementary graphs for evaluating integrals and for determining other quantities that are included in the formula. A part of the formula can be used to compute bed-load discharge. However, the bed load as defined by Einstein (1950, p. 4) is not the same as the bed load as defined on page 22 of this report. His definition seems to limit the bed load to bed material that moves in a layer immediately above the stream bed and only two particle diameters thick.

Rates of bed-load discharge were computed with the Einstein formula for three different water discharges. The computed discharges of sediment as bed load are shown in table 8 and are plotted on figure 31.

Figures of bed-load discharge (table 8) as computed by the three different formulas are not directly comparable. The constant of the Du Boys formula was evaluated from bed-load discharges that were computed as the difference between total sediment discharge and suspended-sediment discharge as measured by the Geological Survey. Thus the Du Boys formula as evaluated should give bed-load discharges that can be added to suspended-sediment discharges to compute total sediment discharge. According to Shulits (1935, p. 645), Schoklitsch's formula computes "that portion of the total solids load of a river which is transported (not in suspension) along the river bed by the tractive force of the stream." Bed-load sediment discharge as computed by the Schoklitsch formula should be approximately the same as the difference between suspended-sediment discharge as measured by the Geological Survey and total sediment discharge of a stream. Only a part of Einstein's formula was used, and the bed-load discharge computed with it should, by definition, be only the discharge of material that moves in a layer two particle diameters thick and just above the stream bed. As Einstein's formula is based on a definition of bed load that differs widely from the definition that is used in this report, average annual discharge of bed load was not computed with his formula.

The Geological Survey measures suspended sediment with samplers that do not collect water-sediment mixture within about 0.3 ft of the stream bed. Hence measured suspended-sediment concentrations tend to be slightly low because the concentration of suspended sediment near the bottom of a stream is usually higher than the average concentration of the stream. However, except for shallow depths, the error is negligible, and bed-load discharge computed from a formula like Schoklitsch's can be added to the measured discharge of suspended sediment to obtain total sediment discharge.

Gilbert (1914, p. 11) concluded that the capacity of a stream to transport sediment as bed load varies on the average with the 3.2 power of the mean velocity if the slope is constant. The computed discharges of bed-load sediment (table 8) increase as approximately the 2.8 power of the velocity. As Gilbert found a range of about 2.0 to 5.0 in the power of the velocity, the bed-load discharges of table 8 are considered to be in good agreement with Gilbert's conclusion as to the change in discharge of bed-load sediment with velocity.

Table 8.--Computed rates of discharge of bed-load sediment for the Powder River at Arvada, Wyo.

Water discharge (cfs)	Average velocity (ft per sec)	Bed-load discharge, in tons per day		
		Du Boys	Schoklitsch	Einstein
20	0.69	24	....	....
100	1.38	91	36	....
400	2.23	500	398	331
3,000	5.82	3,580	3,620	4,210
12,000	8.29	19,500	14,800	13,900

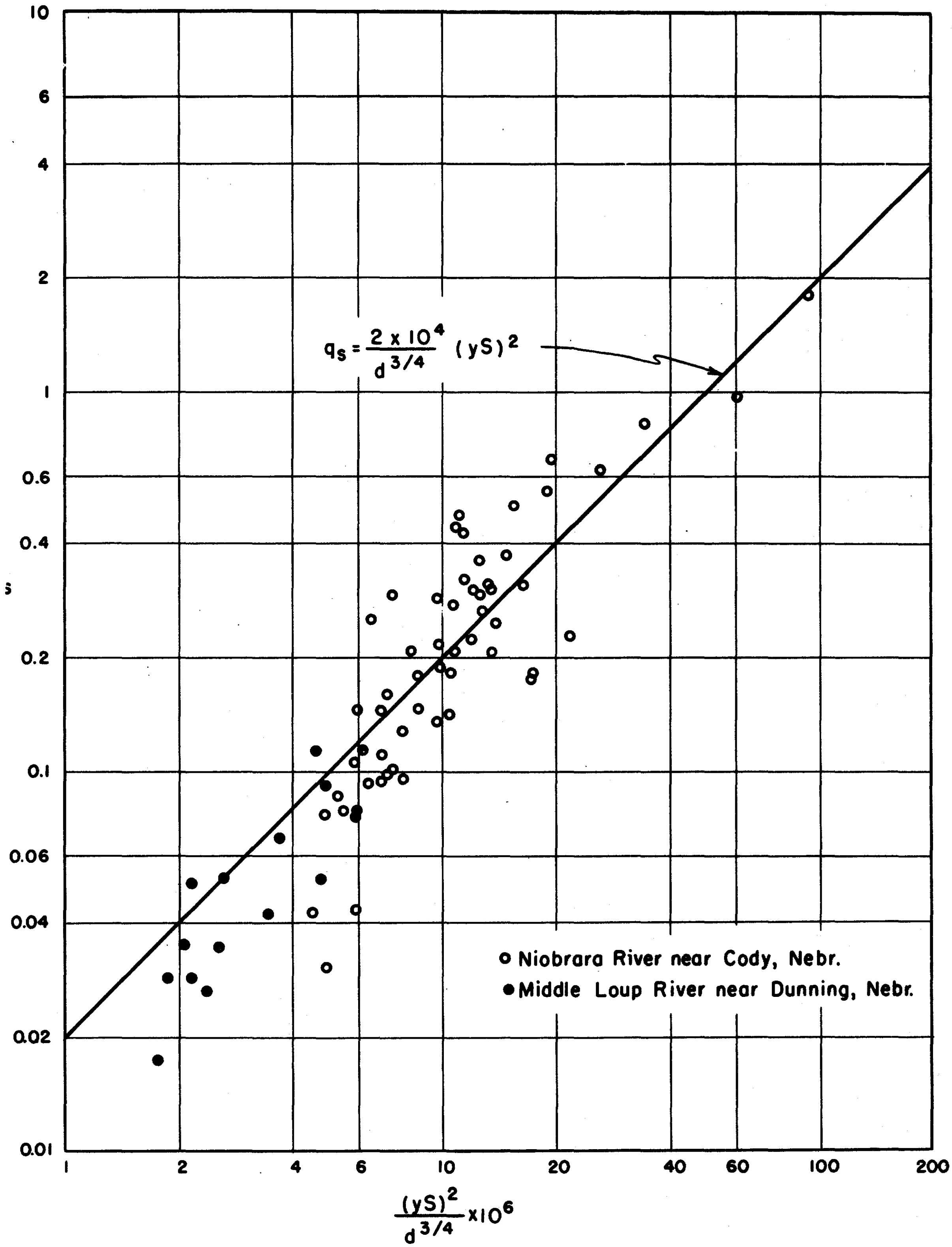


Figure 30.--Comparison of bed-load data from the Niobrara and Middle Loup Rivers in Nebraska with equation $q_s = \frac{2 \times 10^4}{d^{\frac{3}{4}}} (yS)^2$.

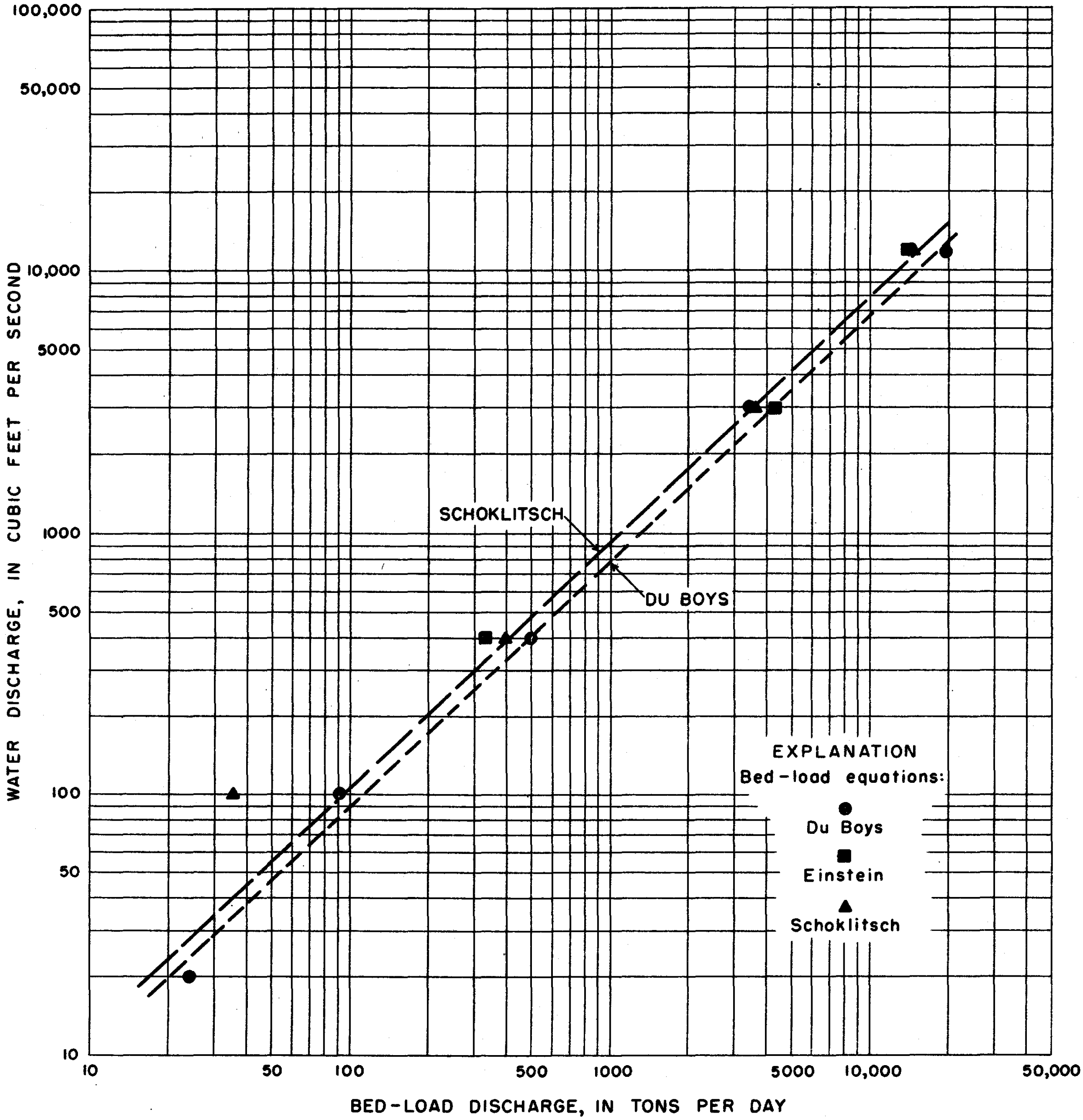


Figure 31.--Relation of bed-load discharge to water discharge, Powder River at Arvada, Wyo.

Sediment Discharged Annually as Bed Load

The relationship between water discharge and bed-load discharge as computed with the Du Boys' and Schoklitsch's formulas can be represented fairly well by straight lines on the logarithmic scales of figure 30. The slopes of the lines indicate that the bed-load discharge increases as about the 1.05 or 1.10 power of the water discharge. The suspended-sediment discharge increases approximately as the square of the water discharge. (See fig. 17.) Thus the ratio of bed-load discharge to suspended-sediment discharge decreases rapidly with increase in water discharge.

The straight-line relationships defined by bed-load computations that were made with the Du Boys' and Schoklitsch's formulas were used to compute annual discharge of sediment as bed load for the Powder River at Arvada. The flow-duration curve covering 33 yr of stream-flow records of the Powder River at Arvada (fig. 14) was used to define the percentage of time that the flow was within each of 19 class intervals of flow. Bed-load discharges corresponding to the middle water discharge of each class interval of flow were taken from the straight lines of figure 31. The products of these bed-load discharges and the percentages of time when the flow was within each interval were added, and the sum was divided by 100 to obtain average annual discharge of sediment as bed load. Bed-load discharge per year was also computed for the 4-year period that ended September 30, 1950, from a duration curve of water discharge for this 4-year period. All the computed average annual discharges of sediment as bed load are shown in table 9. The average specific weight of bed-material samples from the Powder River basin (table 32) was about 90 lb per cu ft. This specific weight was used to change the tonnage of bed-load discharge per year to yearly volume of bed-load sediment after deposition in a reservoir.

Table 9.--Computed annual discharge of bed-load sediment, Powder River at Arvada, Wyo.

Bed-load formula	Average annual discharge of bed-load sediment			
	33-year period		4-year period	
	Tons	Acre-feet	Tons	Acre-feet
Du Boys......	190,000	98	140,000	70
Schoklitsch..	160,000	82	110,000	58

The bed-load discharges computed from Du Boys' formula agree reasonably well with those computed from Schoklitsch's formula. According to these formulas, the discharge of sediment as bed load (table 9) amounts to only about 175,000 tons per yr on the basis of the water discharge during the period of stream-flow records for the Powder River at Arvada and about 125,000 tons per yr on the basis of the water discharge for a 4-year period that ended September 30, 1950. During the 4-year period, the computed discharge of bed-load sediment was only 2.2 percent of the suspended-sediment discharge by weight and 1.4 percent by volume after deposition in a reservoir.

Sources of Sediment Transported by the Powder River

Rates of erosion vary widely within the Powder River drainage basin. Major sources of sediment, areas where rates of erosion are high, can be correlated with different factors such as topography, vegetative cover, type of runoff, or types of rocks that underlie an area. Perhaps the large areas with high rates of erosion can best be delineated on the basis of the kinds of the underlying rocks.

Unfortunately, the sediment records during the spring and summer of 1950 are not representative data. As figure 13 shows, the water discharge for the water year ending September 30, 1950, was close to the lowest annual discharge for the period that is covered by stream-flow records. Presumably, the suspended-sediment discharge for 1950 was far below the average annual sediment discharge. Hence the available records of suspended-sediment discharge must be used with caution in delineating the major source areas of sediment that is transported by the Powder River.

Areas Underlain by Paleozoic and Pre-Cambrian Rocks

In the Powder River drainage basin the streams draining areas that are underlain by pre-Cambrian and Paleozoic rocks are clear streams in relatively stable channels. They are typical mountain streams transporting little sediment either in suspension or as bed load. High flows are seasonal and are caused mostly by snow melt. Some of the channels are in deep canyons, but the present rate of erosion in these canyons is slow. The areas underlain by Paleozoic and pre-Cambrian rocks are in the Bighorn Mountains except for a very small area in the Rattlesnake Range. (See fig. 5.) These areas are an insignificant source of the sediment that is transported by the Powder River.

Areas Underlain by Mesozoic Rocks

As the streams leave the mountains and enter the areas that are underlain by Mesozoic rocks, they begin to erode their channels more actively and soon become discolored with sediment. The Middle Fork Powder River is a good example of a mountain stream that begins to carry appreciable quantities of sediment after flowing for a few miles across an area that is underlain by Mesozoic rocks. Much of the sediment carried by the Middle Fork above Kaycee is derived from the channel, but during periods of storm runoff the minor tributaries that drain areas underlain by Mesozoic rocks discharge significant quantities of sediment that were eroded from the land surface and from ephemeral stream channels.

A large part of the sediment transported by the Powder River is contributed by streams whose drainage areas are almost completely underlain by Mesozoic rocks. The largest of these streams (fig. 5) are Salt Creek and the South Fork Powder River. (A very small area at the source of the South Fork is underlain by Paleozoic rocks, and a small percentage of the drainage area farther downstream is underlain by Tertiary rocks.) Both these streams have high concentrations of suspended sediment as is shown by the sediment record for the South Fork near Kaycee and by the large increase in sediment discharge from the stations on the Middle Fork near Kaycee and on the South Fork near Kaycee to the station on the Powder River near Sussex. Although part of this increase is due to scour of the channels between these stations, most of the increase during and following periods of storm runoff is due to the sediment that is discharged by Salt Creek and small streams. The sediment transported by Salt Creek and nearby small, intermittent streams is derived by sheet and rill erosion, channel scour, and gully cutting. (See p. 15 and fig. 8.)

Records of suspended-sediment discharge for the South Fork Powder River are much too short to show adequately the high rates of sediment discharge that may occur. The records summarized in tables 4 and 14 cover only periods of relatively low flow and correspondingly low concentrations of suspended sediment. Suspended-sediment samples were collected on May 3, 6, and 11 outside the period of daily records. The concentrations of the samples together with estimated water discharges indicate an average suspended-sediment discharge of 50,000 tons per day for these 3 days. In contrast, the total sediment discharge from May 17 to September 30, 1950, was 76,640 tons.

The effects of fairly rapid rates of erosion can be seen in most of the areas that are underlain by Mesozoic rocks, but the fastest rates of erosion probably occur in badland areas, at gullies that are actively eroding (fig. 8), and at stream meanders. The easily eroded soils, valley alluvium, and friable rocks of the areas that are underlain by Mesozoic rocks, plus the relatively steep land slopes and sparse vegetation, make these areas a major source of the sediments that are transported by the Powder River.

Areas Underlain by Tertiary Rocks

More than half of the Powder River drainage basin is underlain by Tertiary rocks. These rocks underlie most of the basin north of Sussex, Wyo., and outside the mountains except for an area east and northeast of Little Powder River that is underlain by Mesozoic rocks.

Clear Creek and its major tributaries are clear mountain streams when they enter the area that is underlain by Tertiary rocks. As they flow across this area, they begin to pick up small amounts of sediment from their channels, which are mostly boulder-lined and are fairly stable. During periods of storm runoff, the tributaries draining this area discharge sediment into the perennial streams, but the concentration of suspended sediment at the mouth of Clear Creek near Arvada normally is low. It averaged less than 500 ppm for the few months of suspended-sediment records during 1950. (See tables 4 and 21.)

The tributaries of Crazy Woman Creek transport very little sediment until they leave the mountains and flow across a narrow area that is underlain by Mesozoic rocks, where they begin to pick up a noticeable amount of sediment. Soon after leaving this narrow area, the tributaries join to form Crazy Woman Creek, which flows for its entire length across an area that is underlain by Tertiary rocks. Crazy Woman Creek has progressively higher concentrations of suspended sediment toward its mouth. Some of the sediment comes from the channel, some from return flow from irrigation, and some from small tributaries. Except during periods of runoff from intense rains, only a small tonnage of suspended sediment is discharged into the Powder River by Crazy Woman Creek. (See table 4.)

The only measure of suspended sediment yields from much of the area that is underlain by Tertiary rocks is the increase in the sediment discharge of the Powder River from Sussex downstream. From March 1 to September 30, 1950, the suspended-sediment discharge of the Powder River was nearly three times as large near Locate as at Sussex. Almost all the increase in sediment from Sussex downstream was derived from the general areas that are underlain by Tertiary rocks. Specifically, a large part of the increase probably came from Quaternary alluvium along the channel. At least during the water year that ended September 30, 1950, the sediment yield from the areas that are underlain by Tertiary rocks was greater than the sediment yield of all other parts of the Powder River drainage basin, largely because of the size of these areas. The rate of erosion may not have been as high from the areas that are underlain by Tertiary rocks as from those that are underlain by Mesozoic rocks.

CHEMICAL QUALITY OF THE WATER

Plan of Study

The chemical quality of water in the Powder River and its tributaries is defined from the analyses of 127 samples that were collected in the period November 1945 to September 1950. Main stem stations and the Middle Fork Powder River were sampled approximately monthly, whereas other tributary stations were sampled about once every 3 months. During the period September 10 to 14, 1949, samples were collected at 29 points for chemical analysis in connection with a basin salinity study of low flows. Records of sampling are shown in the following table:

Station operation records

Station	Drainage area (square miles)	Field-sampling program		
		Number of samples	Period of collection	Approximate schedule
Main stem				
Powder River at Sussex, Wyo.	3,090	10	Nov. 1949 to Sept. 1950	Monthly.
Powder River at Arvada, Wyo.	6,050	27	May 1946 to Sept. 1950	Do.
Powder River near Locate, Mont.	a 12,900	22	Nov. 1945 to Sept. 1950	Do.

a Approximate figure.

Station operation records--Continued

Station	Drainage area (square miles)	Field-sampling program		
		Number of samples	Period of collection	Approximate schedule
Tributaries				
Middle Fork Powder River near Kaycee, Wyo	980	25	May 1946 to Sept. 1950	Monthly.
Crazy Woman Creek near Arvada, Wyo	956	5	Dec. 1949 to Sept. 1950	Tri-monthly.
Clear Creek near Buffalo, Wyo	120	4	Dec. 1949 to Sept. 1950	Do.
Clear Creek near Arvada, Wyo	1,110	5	Dec. 1949 to Sept. 1950	Do.
Basin salinity study	a 13,400	29	Sept. 10 to 14, 1949	....

a Approximate figure.

A plan of study was selected that would furnish analytical data at key stations on the Powder River and its major perennial tributaries. The stations on the main stem at Sussex, Arvada, and Locate (fig. 32) provide information on the chemical character of the river water along a course of about 318 miles. Stations on tributary streams were installed at points close to the confluences of these tributaries with the Powder River. Analyses of samples of water from a tributary stream near its mouth show the quality of the water that is leaving the drainage basin. The location of sampling points was coordinated with the needs of planning agencies for information on the quality of water that may be impounded for irrigation.

The determinations of specific conductance, percentage of sodium, and boron were made for stations where samples were taken regularly, as these measurements have a direct bearing on the rating or classification of irrigation water. Silica, iron, calcium, magnesium, sodium and potassium, bicarbonate, sulfate, chloride, fluoride, and nitrate were also reported, together with pH and hardness, as these constituents and properties affect the suitability of the water for general use. Tables 33 and 34 show chemical analyses and water discharges.

Composition of River Water

The composition of a river water is dependent primarily upon the geological formations that are traversed, and it varies with time and place. River water is thus in unstable equilibrium and is undergoing continuous change by chemical reaction of various kinds. The rivers carry the weathering products in the form of ionic solutions or as colloidal dispersions. The amount of these materials varies according to the climate and to the chemical composition and physical properties of rocks and soils in the catchment area. Clarke (1924, p. 69) points out that a river water is the average of all its tributaries plus the influence of rain and ground water.

Geochemistry of the Basin Waters

The varied geology and topography of the Powder River drainage basin cause wide fluctuations in both composition and salinity of the waters in the basin. Clear Creek, which has its source in the Bighorn Mountains, flows for several miles through a region of pre-Cambrian granites. Near Buffalo, Wyo., this stream has the chemical characteristics of a typical mountain water; the mineral content and hardness are low, and bicarbonate exceeds sulfate. The Little Powder River, on the other hand, heads in upland country and drains an area that is largely underlain by Tertiary sandstones and shales. Water from the Little Powder River near Broadus, Mont., has high mineral content and hardness and contains much more sulfate than bicarbonate. The percentage composition of the mineral solids in several waters that have been in contact with principal rock types is shown in table 10.

It is seen from table 10 that the granite-type water in Clear Creek near Buffalo, Wyo., is a calcium carbonate water of low mineral content, and that silica composes much of the mineral solids. The limestone-type water is

Table 10.--Percentage composition of waters that drain from principal rock types, Powder River drainage basin

Mineral constituent	Granite-type water 1/	Limestone-type water 2/	Gypsum-type water 3/	Shale-type water 4/
Silica (SiO_2)	27.6	6.4	1.4	0.3
Calcium (Ca)	23.2	20.4	16.7	6.9
Magnesium (Mg)	2.2	10.8	5.5	3.8
Sodium and potassium (Na + K)	1.2	1.2	7.6	20.3
Carbonate (CO_3)	37.0	54.6	14.0	8.1
Sulfate (SO_4)	7.4	3.6	52.8	60.0
Chloride and nitrate (Cl + NO_3)	1.4	3.0	2.0	.6
Total	100.0	100.0	100.0	100.0
Dissolved solids (ppm)	43	158	727	2,020

1/ Clear Creek near Buffalo, Wyo.
2/ Middle Fork Powder River near Barnum, Wyo.
3/ Middle Fork Powder River above Kaycee, Wyo.
4/ Little Powder River near Broadus, Mont.

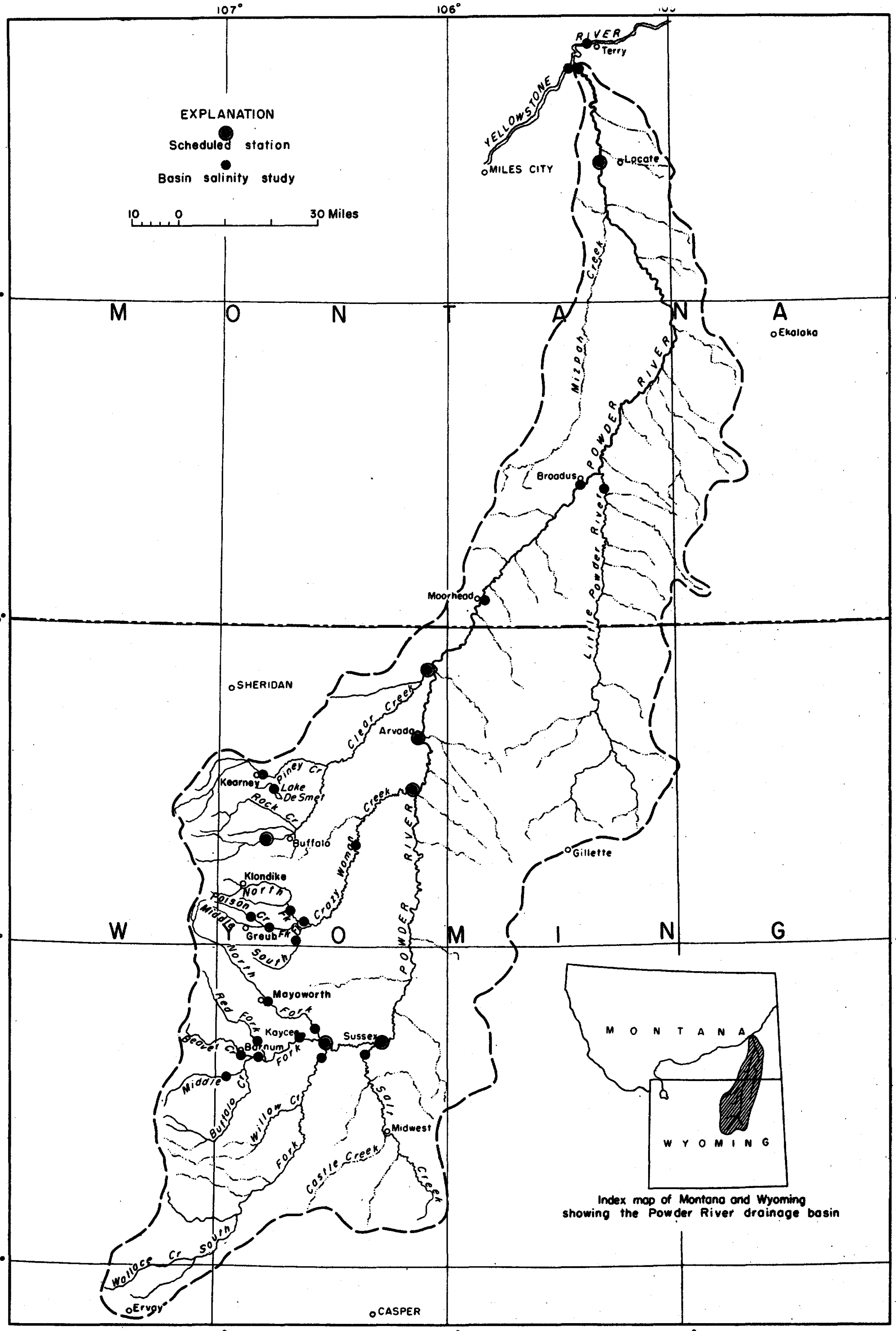


Figure 32.--Map of the Powder River drainage basin in Wyoming and Montana, showing chemical-quality stations.

a calcium carbonate water of moderate concentration but contains less silica and more magnesium than the granite-type water. The Middle Fork Powder River near Barnum, Wyo., drains an area that is underlain by the limestones in the Phosphoria and Madison formations and by the porous Bighorn dolomite. Downstream in the vicinity of Kaycee the river water has been altered in chemical character from a limestone-type to a gypsum-type ($CaSO_4 \cdot 2H_2O$) water. This change occurs because the river crosses an area that is underlain by gypsum beds, gypsiferous shales, and siltstones. A typical shale-type water is illustrated by the water in the Little Powder River near Broadus, Mont. This water contains considerable amounts of sodium sulfate that have been leached from Tertiary and Cretaceous shales and sandstones above Broadus. The composition of several waters in the basin is shown graphically in figure 33, in which cumulative percentages of the major mineral constituents are plotted.

Many of the basin waters are mixtures of those characteristic of two or more rock types. An example of a mixed type is the water in North Fork Crazy Woman Creek above Billy Creek, near Buffalo. This stream has its headwaters in pre-Cambrian granites and flows successively over Paleozoic limestones and dolomites and over an area that is underlain by Cretaceous shales. The composition of this creek water at the bridge on United States Highway No. 87 near Buffalo is as follows:

Silica (SiO_2)	9.7
Calcium (Ca)	16.8
Magnesium (Mg)	5.7
Sodium and potassium (Na + K)	7.7
Carbonate (CO_3)	32.9
Sulfate (SO_4)	25.8
Chloride and nitrate (Cl + NO_3)	1.4
Total	100.0
Dissolved solids (ppm)	155

In the above analysis it is seen that both carbonate and sulfate are present in significant amounts. Also, the percentage of silica is intermediate between that present in a granite water and that reported for a limestone water.

Table 11 lists the percentage compositions of 27 water samples that were collected at low flows in connection with a salinity study in the Powder River basin.

Chemical Quality and Stream Discharge

The chemical quality of water in a flowing stream varies from day to day or from hour to hour depending upon the stage of the stream. As a general rule, the salinity of a river water is highest during periods of low water discharge and lowest during periods of high runoff. This is so because the low or base flow of the stream is sustained by groundwater inflow that has leached the soluble minerals of rock and soil particles in reaching the stream. At high stages and during floods the salt concentration of the base flow is diluted by snow melt or surface runoff, and the resultant solution is much less concentrated. An exception to this normal occurrence is observed on occasions when a rise in stage is localized in a tributary stream, and the main stem remains practically unaffected. The reduction in salinity of the tributary water may not be sufficient to offset materially the concentration of salts in the primary stream.

Analyses of water in the Powder River and its tributaries at discharges that approximate the mean for the period of record are shown graphically, in equivalents per million, in figure 34. Weighted average analyses for main stem and tributary waters are not shown inasmuch as daily or subdaily samples were not collected. The calculation of weighted values that are based on monthly or quarterly sampling is not possible.

Powder River Main Stem

From Sussex, Wyo., to its confluence with the Yellowstone River near Terry, Mont., the Powder River meanders over a course of approximately 350 miles. A study of the quality of water in the main stem of the Powder River at low stage was made during the period September 11 to 14, 1949, and these results are reported in the following table:

Quality of the Powder River water at low flow

Station	Distance downstream from Sussex, Wyo. (miles)	Date September 1949	Daily mean discharge (cfs)	Tons per acre-foot	
				Dissolved solids	Sulfate
Sussex, Wyo.	0	11	....	2.49	1.31
Arvada, Wyo.	119	12	2.0	3.17	1.85
Moorhead, Mont.	165	13	54	1.54	.89
Broadus, Mont.	212	13	....	1.65	.97
Locate, Mont.	318	14	44	2.00	1.20
Mouth	350	14	....	2.19	1.32

In all reaches of the river the amount of sulfate in the water exceeded 50 percent of the total mineral content and ranged from 53 percent at Sussex to 60 percent at the mouth. The increase in the concentration of dissolved solids at the Arvada station was due partly to discharges from Crazy Woman Creek, about 12 miles upstream, and partly to accretions from other sources between Sussex and Arvada. The decrease in salinity at Moorhead is explained by the discharge of less concentrated water from the mouth of Clear Creek. At Locate the salinity of the water again increases, largely as the result of salt contribution from the Little Powder River. The composition of the main-stem water is shown graphically in figure 35.

The variation in salt concentration with discharge during the 12-month period that ended September 30, 1950, is shown for the Sussex, Arvada, and Locate stations in figures 36 to 38.

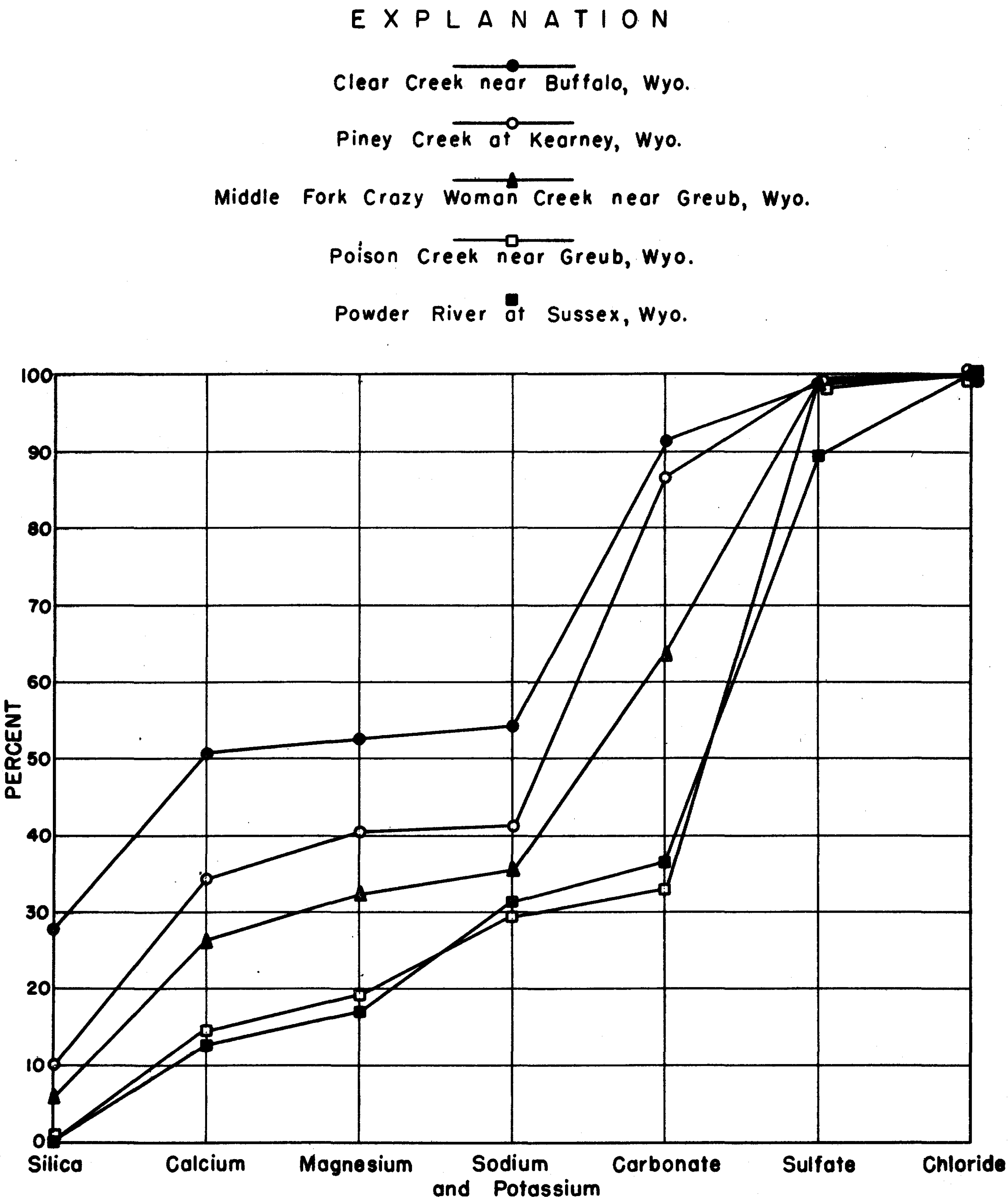
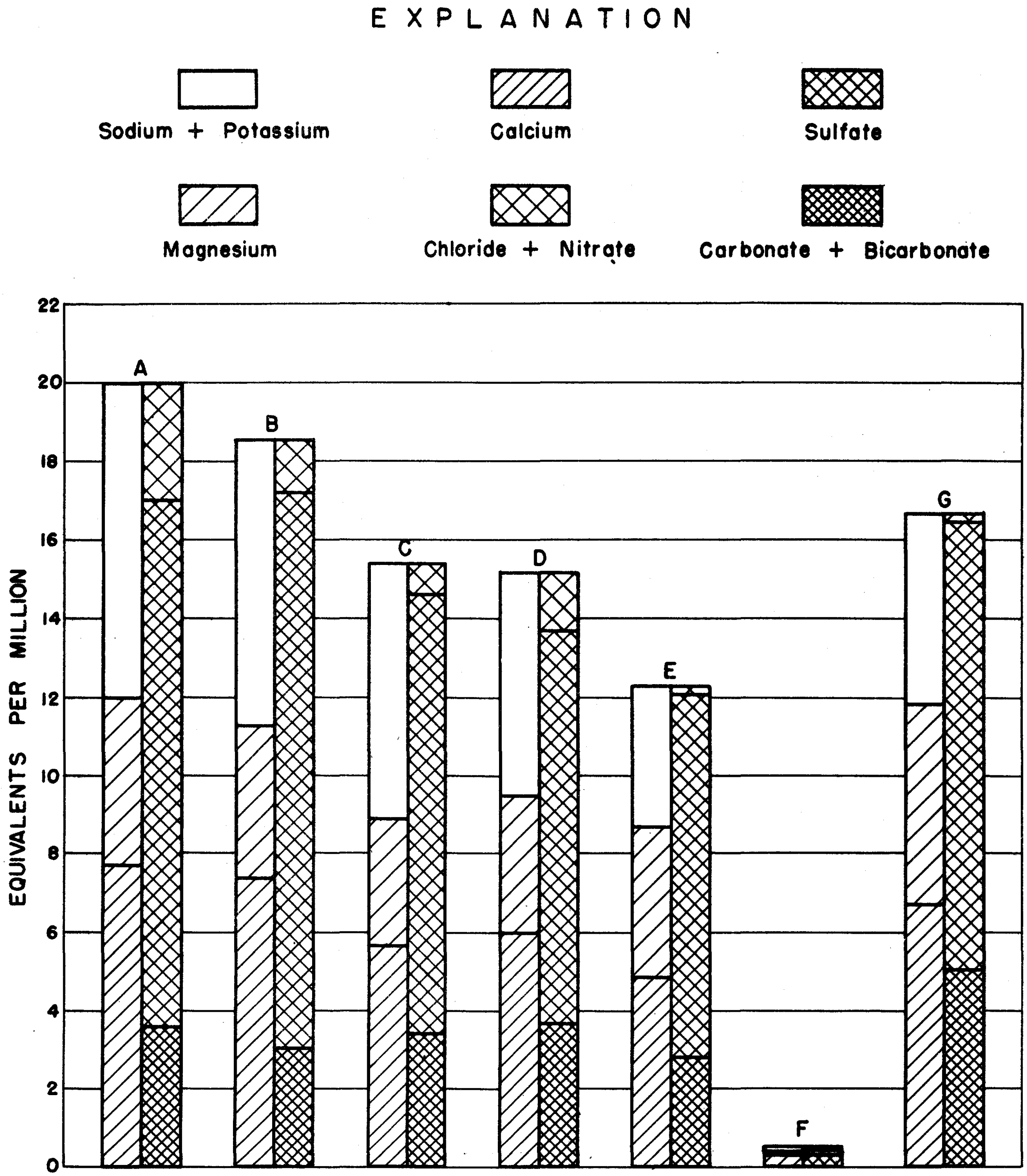


Figure 33.--Cumulative percentage composition of water from several streams.

Table 11.--Percentage composition of water in the Powder River drainage basin during low flow

Station	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride and nitrate ($Cl + NO_3$)	Dissolved solids (ppm)
South Fork Powder River near Kaycee, Wyo...	0.8	11.7	2.8	16.8	4.1	52.1	11.7	1,950
Powder River at Sussex, Wyo...............	.5	12.5	4.2	14.0	5.4	52.5	10.9	1,830
Powder River at Arvada, Wyo...............	.3	10.2	4.2	15.8	3.9	58.4	7.2	2,330
Powder River at Moorhead, Mont............	.5	11.2	7.4	10.2	11.6	58.1	1.0	1,130
Powder River near Broadus, Mont...........	.7	10.3	6.6	12.2	10.2	58.9	1.1	1,210
Powder River near Locate, Mont............	.7	9.4	5.4	15.0	8.3	59.6	1.6	1,470
Powder River at mouth near Terry, Mont.....	.6	9.6	4.4	16.1	7.5	60.0	1.8	1,610
Middle Fork Powder River near Barnum, Wyo..	6.4	20.4	10.8	1.2	54.6	3.6	3.0	158
Middle Fork Powder River above Kaycee, Wyo.	1.4	16.7	5.5	7.6	14.0	52.8	2.0	727
Middle Fork Powder River at Kaycee, Wyo....	1.1	12.7	5.2	12.6	10.2	49.9	8.3	1,010
Middle Fork Powder River near Kaycee, Wyo..	.6	12.4	4.9	13.5	10.2	51.2	7.2	1,090
Beaver Creek near Barnum, Wyo.............	2.0	14.8	7.0	6.9	14.0	54.4	.9	845
Red Fork near Barnum, Wyo.................	2.5	15.2	7.5	9.0	29.5	29.5	6.8	387
North Fork Powder River near Mayoworth, Wyo	2.4	13.4	6.4	10.1	21.2	46.3	.2	623
North Fork Powder River near Kaycee, Wyo...	.7	9.4	5.2	15.2	8.5	59.4	1.6	1,660
Salt Creek near Sussex, Wyo...............	.2	6.9	3.0	21.1	3.9	60.8	4.1	3,750
North Fork Crazy Woman Creek above Billy Creek, near Buffalo, Wyo...............	9.7	16.8	5.7	7.7	32.9	25.8	1.4	155
North Fork Crazy Woman Creek below Middle Fork near Buffalo, Wyo.................	1.7	12.6	7.4	8.9	14.7	53.8	.9	754
Crazy Woman Creek near Buffalo, Wyo........	.5	11.0	7.2	10.1	7.8	62.3	1.1	1,380
Middle Fork Crazy Woman Creek near Greub, Wyo................................	5.3	20.9	6.3	3.0	28.1	35.8	.6	302
Poison Creek near Greub, Wyo..............	.5	14.3	4.4	10.3	3.9	65.8	.8	3,250
South Fork Crazy Woman Creek near Greub, Wyo................................	1.6	11.1	6.8	11.9	16.7	51.3	.6	881
Clear Creek near Buffalo, Wyo.............	27.6	23.2	2.2	1.2	37.0	7.4	1.4	43
Clear Creek near Arvada, Wyo..............	.5	11.3	7.6	9.6	10.0	60.1	.9	1,170
Piney Creek at Kearney, Wyo...............	9.6	24.5	6.1	.8	45.4	12.3	1.3	114
Lake De Smet, Wyo.........................	1.4	7.6	6.3	16.2	14.3	52.8	1.4	698
Little Powder River near Broadus, Mont.....	.3	6.9	3.8	20.3	8.1	60.0	.6	2,020



A Powder River at Sussex, Wyo., 115 cfs, March 3, 1950.
B Powder River at Arvada, Wyo., 261 cfs, April 4, 1947.
C Powder River near Locate, Mont., 288 cfs, July 17, 1950.
D Middle Fork Powder River near Kaycee, Wyo., 145 cfs, April 6, 1950.
E Crazy Woman Creek near Arvada, Wyo., 57 cfs, July 5, 1950.
F Clear Creek near Buffalo, Wyo., 332 cfs, June 6, 1950.
G Clear Creek near Arvada, Wyo., 86 cfs, December 7, 1949.

Figure 34.--Graphical analyses of water in the Powder River and tributaries.

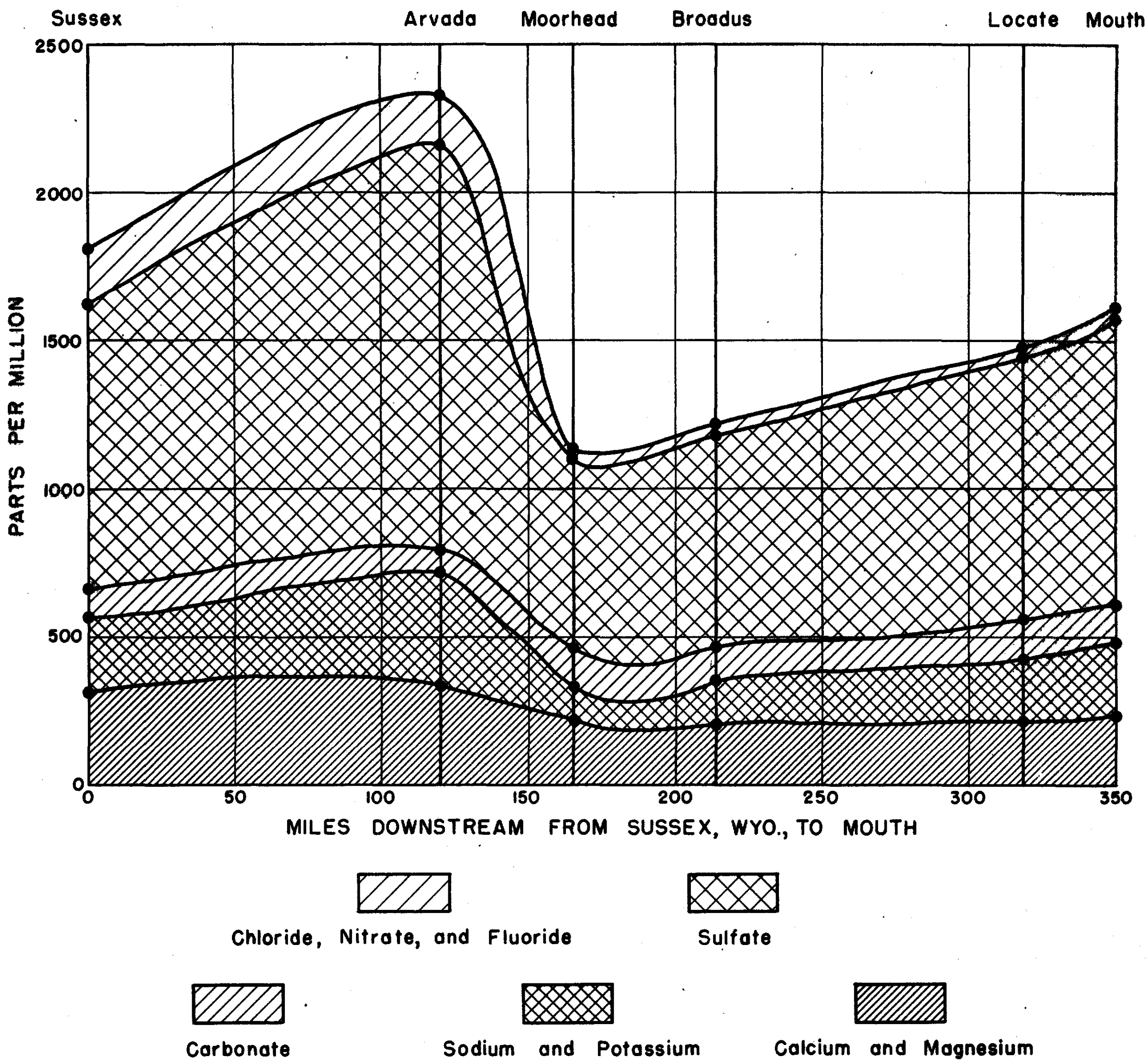


Figure 35.--Composition of the Powder River water at low stage, Sept. 11 to 14, 1949.

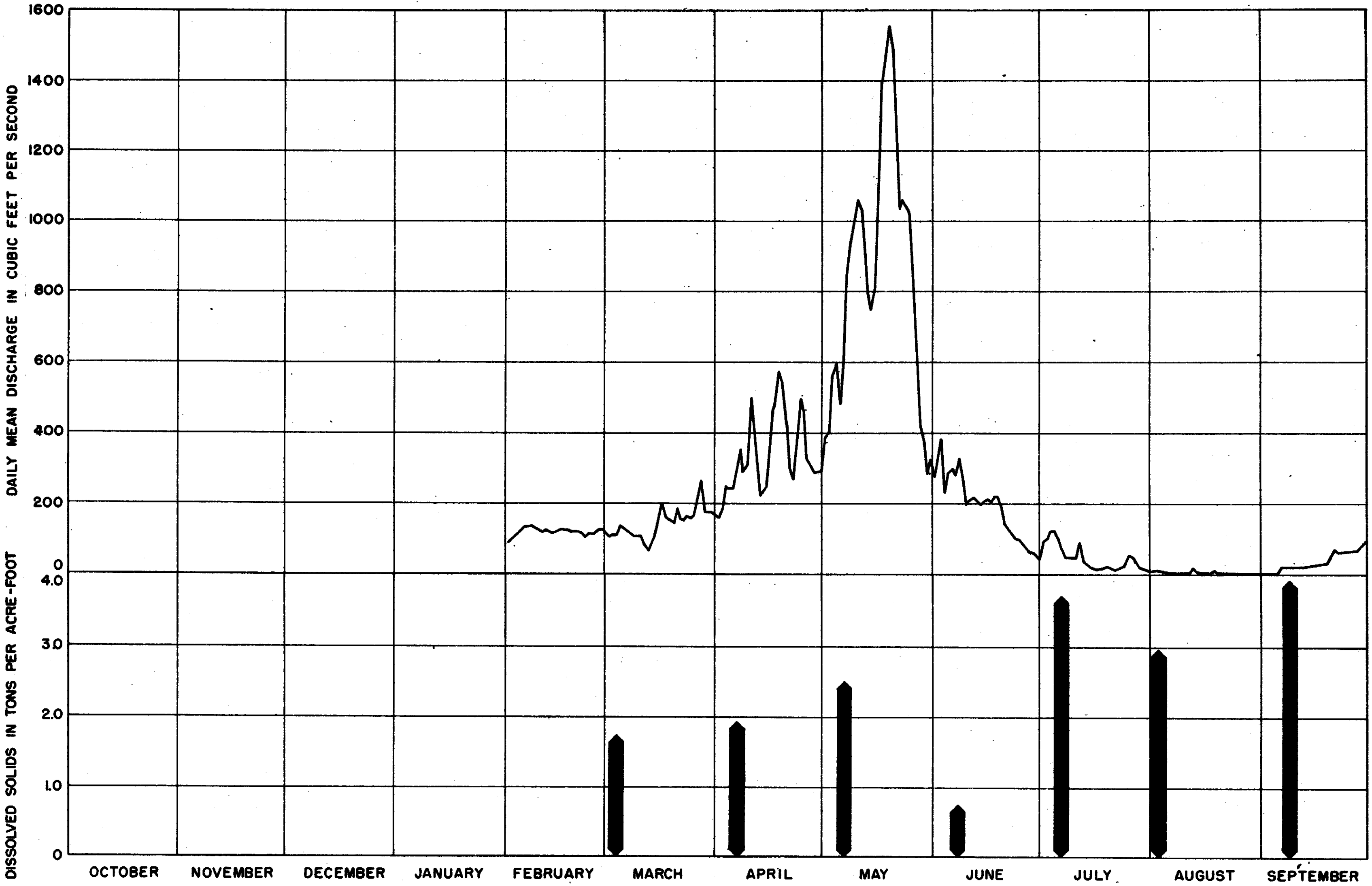


Figure 36.--The relation between discharge and concentration, Powder River at Sussex, Wyo., 1949-50.

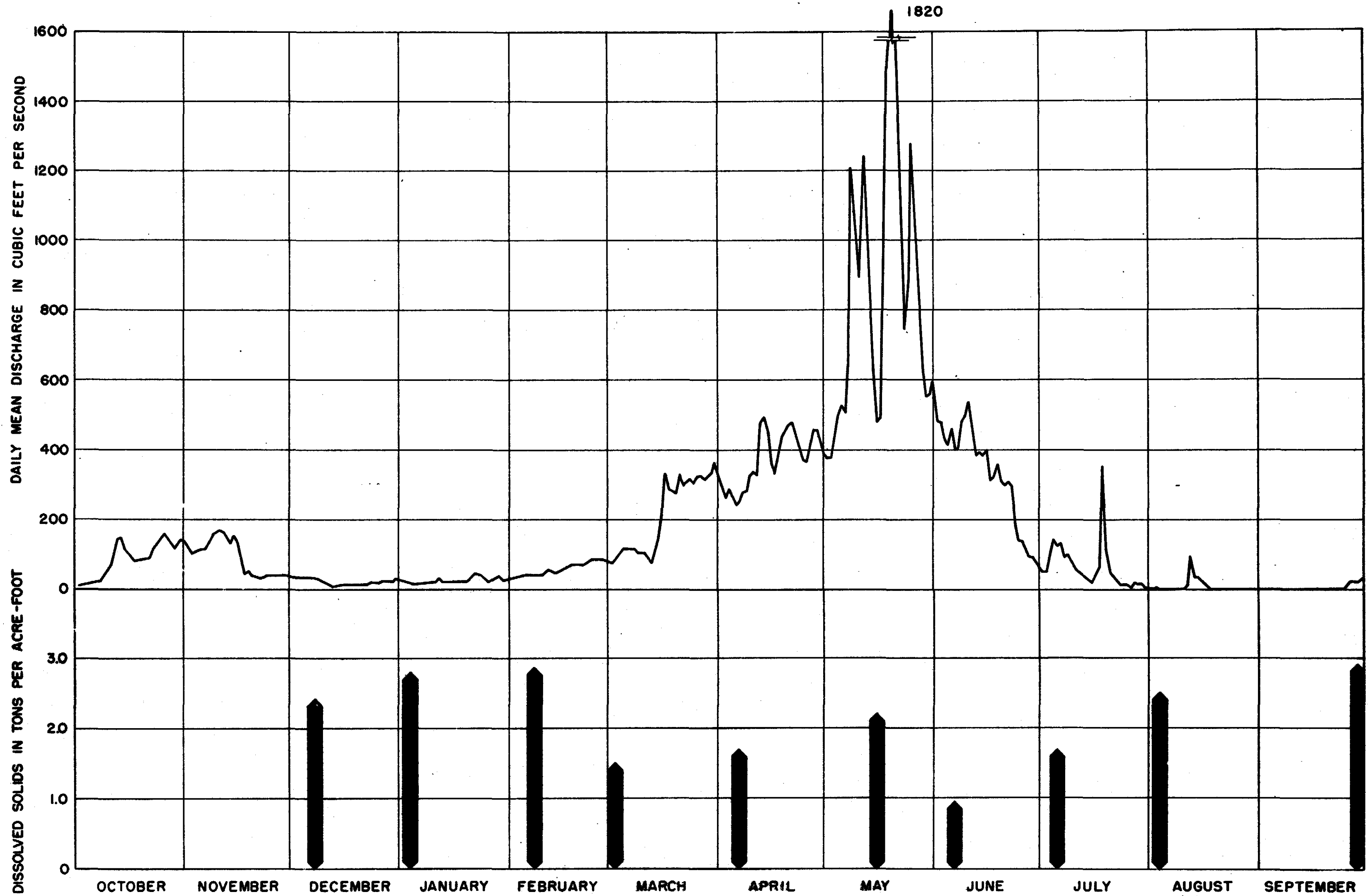


Figure 37.--The relation between discharge and concentration, Powder River at Arvada, Wyo., 1949-50.

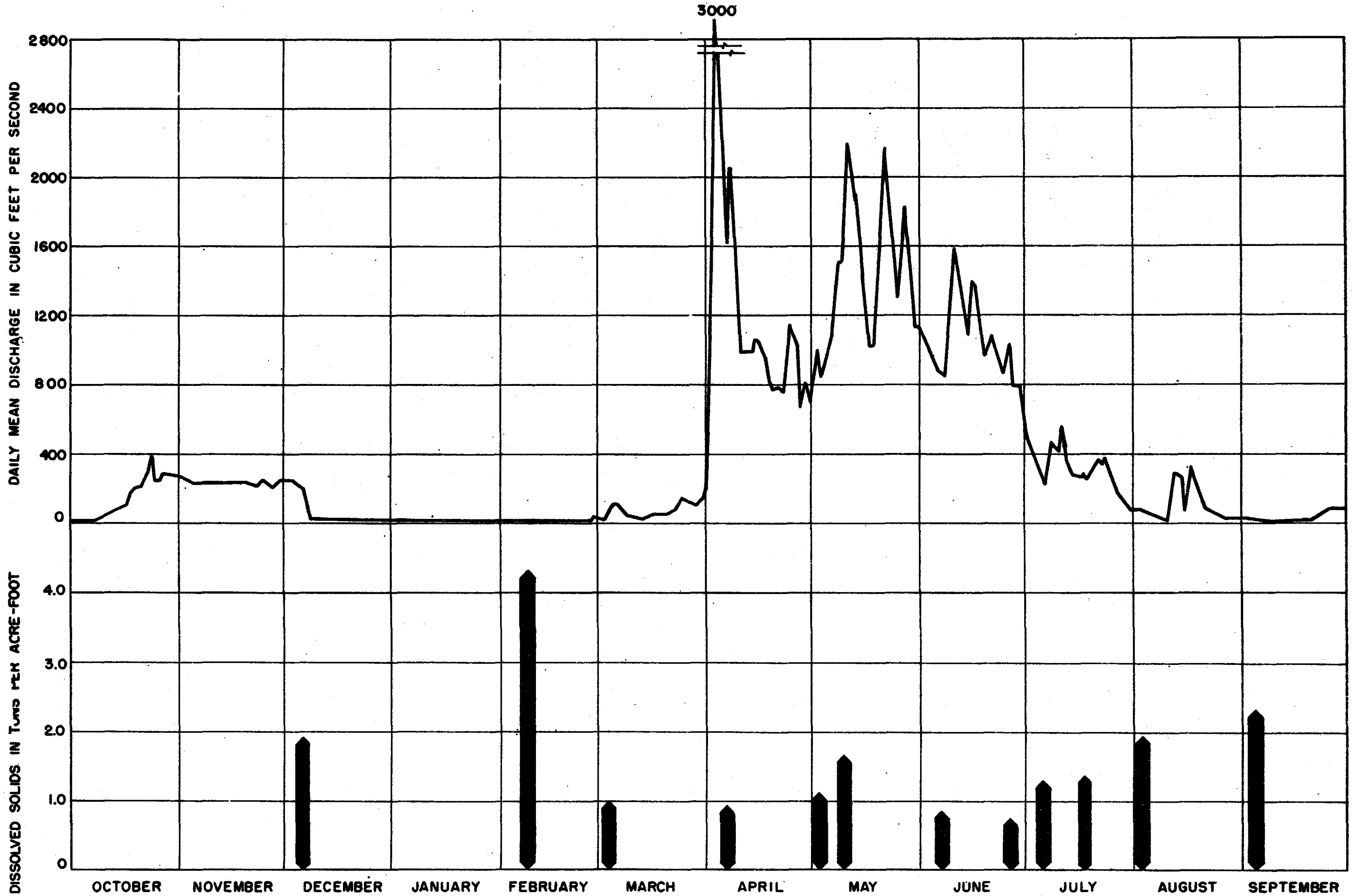


Figure 38.--The relation between discharge and concentration, Powder River near Locate, Mont., 1949-50.

Tributaries

Chemical analyses (tables 33 and 34) for the tributary stations--Middle Fork Powder River near Kaycee, Crazy Woman Creek near Arvada, Clear Creek near Buffalo, and Clear Creek near Arvada--show the normal concentration-discharge pattern. In general, the periods of high runoff correspond with periods of lower salinity, and days of low flows are associated with intervals of higher salinities. These relationships are plotted graphically in figures 39 to 42.

The concentrations of dissolved solids and sulfate in low flows were determined for tributaries to the Powder River and are reported in the following table:

Quality of tributary water at low flow

Station	Date September 1949	Daily mean discharge (cfs)	Tons per acre-foot	
			Dissolved solids	Sulfate
Middle Fork Powder River near Barnum, Wyo........	10	....	0.21	<0.01
Middle Fork Powder River above Kaycee, Wyo.......	10	40	1.03	.52
Middle Fork Powder River at Kaycee, Wyo..........	10	....	1.37	.69
Middle Fork Powder River near Kaycee, Wyo........	11	12	1.48	.76
Clear Creek near Buffalo, Wyo....................	11	20	.06	<.01
Clear Creek near Arvada, Wyo.....................	13	62	1.59	.96

Except for the Barnum and Buffalo stations, the amounts of sulfate constituted at least 50 percent of the mineral solids in the water.

Chemical Quality and Irrigation

The following statements have been largely drawn from publications in the field of irrigation, particularly the subject of the quality of water for irrigation (Wilcox, 1948; Scofield, 1936; Israelsen, 1950; Chemical and Engineering News, 1951).

The interpretation of the analysis of an irrigation water has been described as empirical in the sense that an explanation of the analysis is based on field observation, experience, and plant-tolerance research. It would appear that the rating or classification of an irrigation water under such circumstances would be wholly arbitrary, but the agreement among workers in this field is good.

Irrigation waters contain dissolved material that consists principally of cations (calcium, magnesium, sodium, and potassium) and anions (carbonate, bicarbonate, sulfate, chloride, fluoride, and nitrate). The nature and concentration of the cations in a water are important, as the reactions of the cations with the soil determine the suitability of both soil and water for agricultural use.

Calcium and magnesium tend to keep a soil permeable and in good tilth, whereas sodium produces the opposite effects. Sodium apparently increases the osmotic concentration of the cell sap in plants and thus retards desiccation. Also, in high concentrations the sodium ion is toxic to plants. The percentage of sodium is the ratio of sodium to the total cations (as equivalents) in the irrigation water and determines the adverse effect of sodium on the soil. Potassium occurs usually in low concentrations in irrigation water, and the reaction of potassium with the soil is similar to that of sodium, but the effects are not as harmful. However, potassium is essential to plant growth and is one of the major food elements.

The effects of the anions on soils are not too well understood. The hydrogen ion concentration of the water is determined chiefly by carbonate and bicarbonate, which buffer the water. Sulfate has no characteristic action on the soil other than to increase the salinity. Chloride inhibits the growth of most crop plants and becomes definitely toxic to many crops at moderate concentrations. Only traces of nitrate are present, as a rule, in surface waters, and these concentrations have little effect on the soil.

With the exception of boron, the minor constituents in water are not of great importance in their relation to the soil or to plants. Boron, which has no noticeable effect on soil, is an essential element for normal plant growth. At concentrations only slightly above optimum, however, it is exceedingly toxic to many plants. Boron is toxic to certain plants when present in concentrations that are required for optimum growth of other plants. The irrigation of some types of fruit trees with water of 1 ppm of boron causes harmful results, whereas the application of water of 1 to 2 ppm boron to alfalfa promotes maximum growth.

The characteristics of an irrigation water that must be known in order to make an estimate of the quality are: the total mineral concentration, either in terms of electrical conductivity units (micromhos per centimeter at 25 C) or dissolved solids, in parts per million; the percentage of sodium; and the concentration of boron. In the interpretation of the analysis it is assumed that the water will be used under average conditions as to soil, permeability, infiltration rate, drainage, texture, salt tolerance, climate, and crops. This method for the interpretation of water analyses is not directly applicable where unusual situations are found. It has been observed that the application of even an "excellent" rated water may present a salinity problem if drainage is poor and the ground-water table is less than 2 ft below the surface. In general, adequate drainage improves soil structure and increases and perpetuates the productivity of soils. In connection with salt tolerance of crops, a water of much higher salinity can be used in the growth of sugar beets than of green beans.

Table 12 lists the restrictions of several classes of irrigation water with respect to electrical conductivity and percentage of sodium; table 13 shows limits of boron for crops of different tolerances to boron.

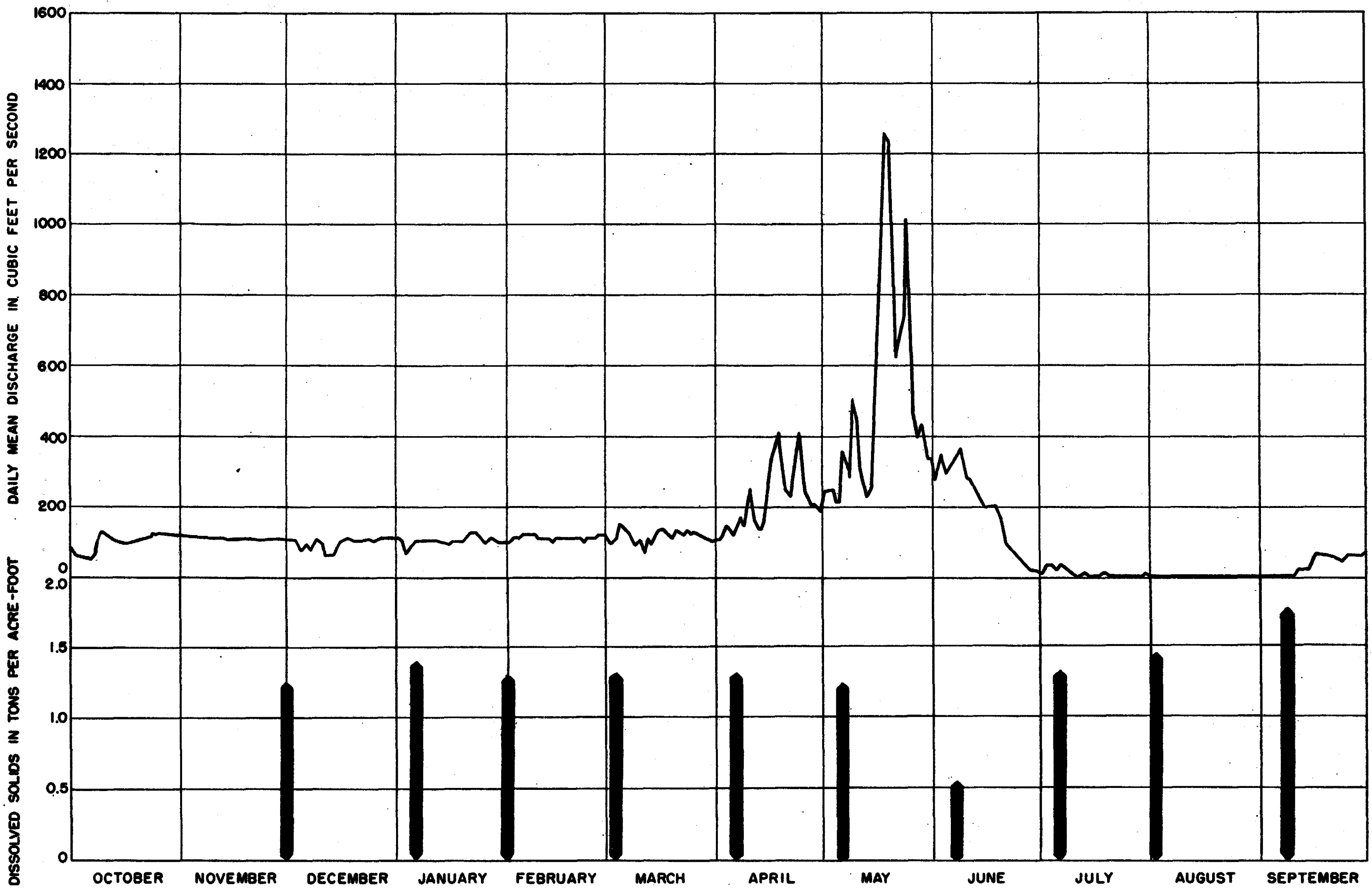


Figure 39.--The relation between discharge and concentration, Middle Fork Powder River near Kaycee, Wyo., 1949-50.

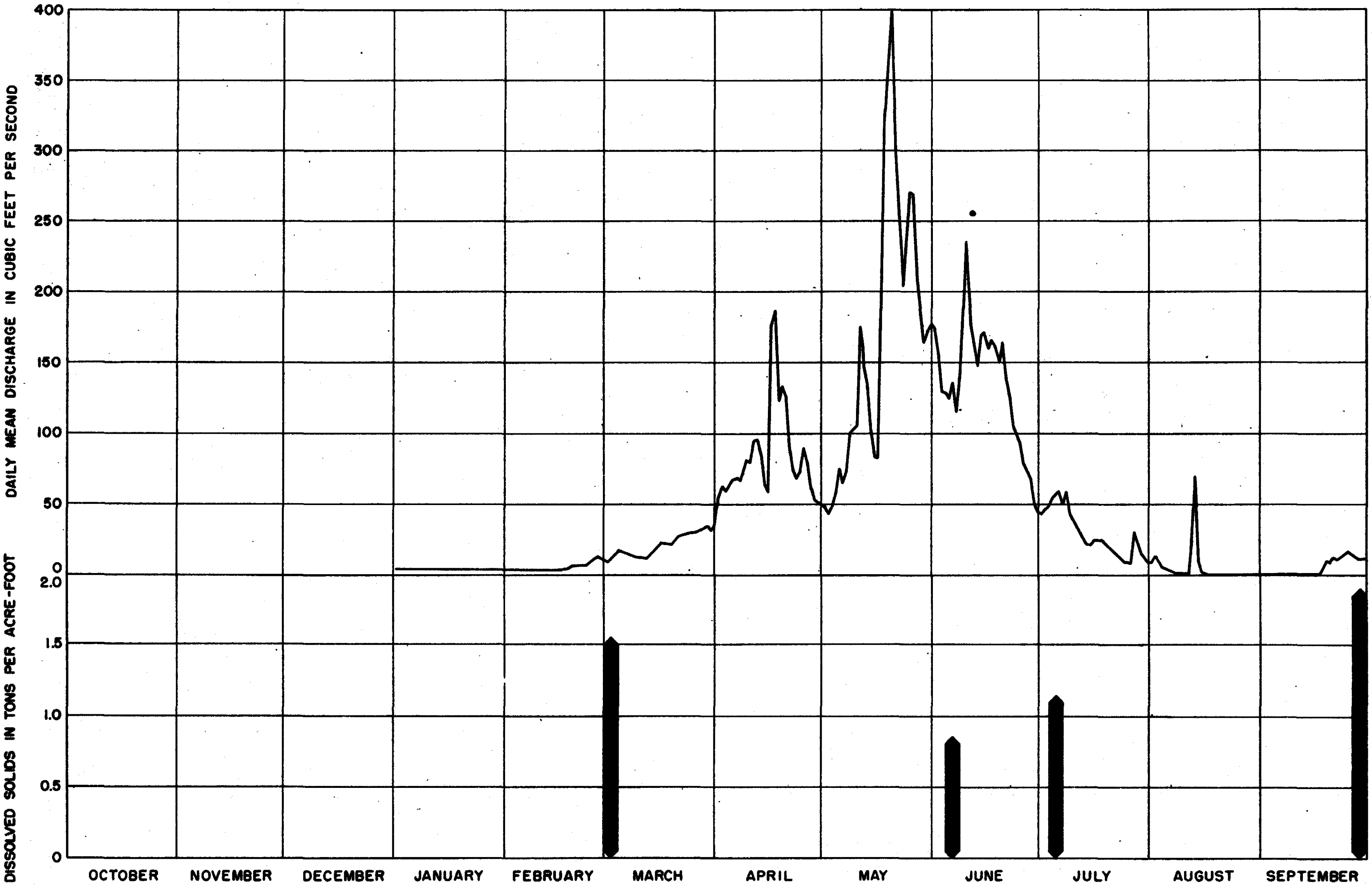


Figure 40.--The relation between discharge and concentration, Crazy Woman Creek near Arvada, Wyo., 1949-50.

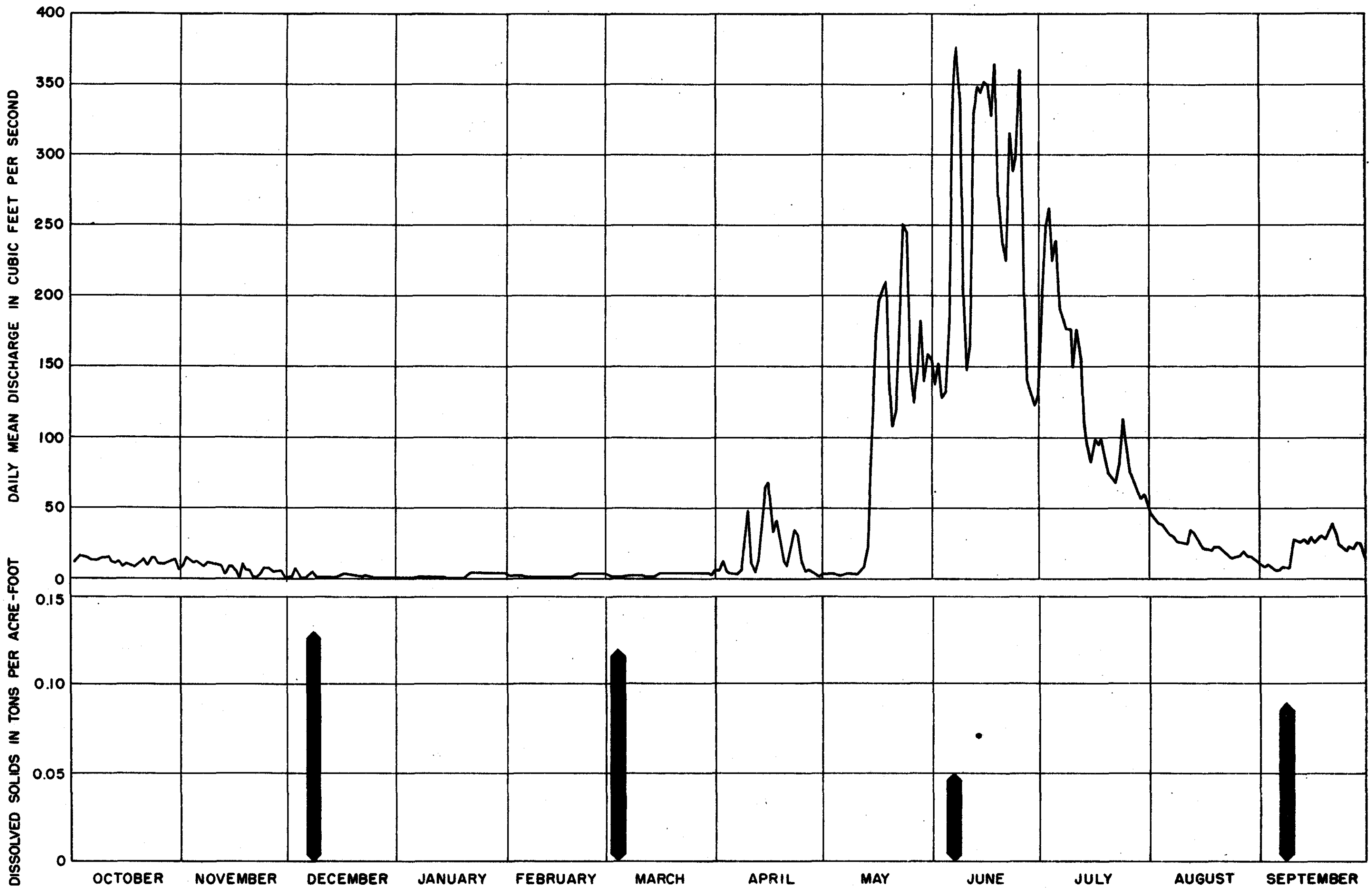


Figure 41.--The relation between discharge and concentration, Clear Creek near Buffalo, Wyo., 1949-50.

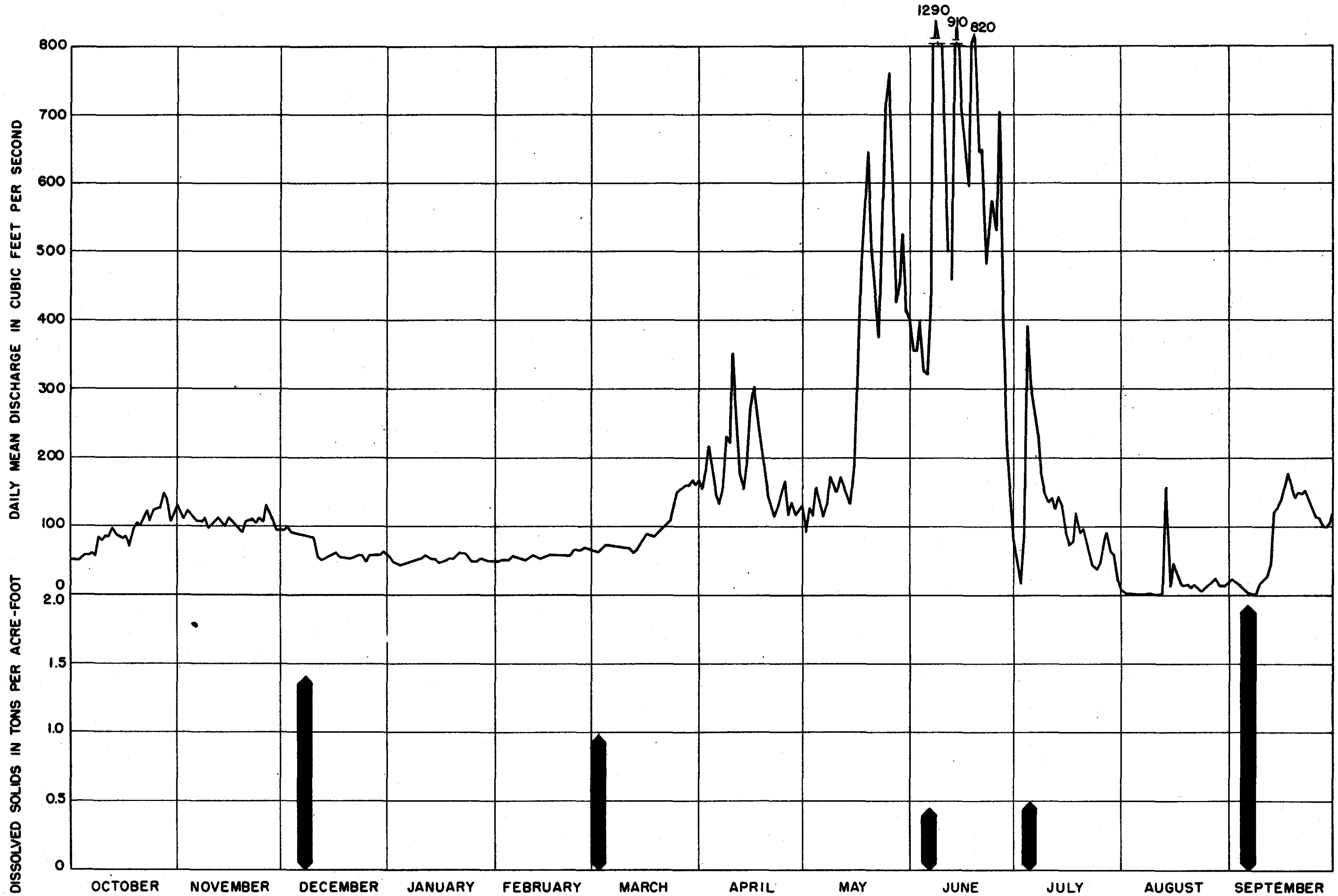


Figure 42.--The relation between discharge and concentration, Clear Creek near Arvada, Wyo., 1949-50.

Table 12.--Permissible limits for electrical conductivity and percentage of sodium for several classes of irrigation water

Classes of water		Electrical conductivity (micromhos per cm at 25 C)	Percent sodium
Rating	Grade		
1	Excellent.................	<250	<20
2	Good.......................	250 to 750	20 to 40
3	Permissible...............	750 to 2,000	40 to 60
4	Doubtful..................	2,000 to 3,000	60 to 80
5	Unsuitable................	>3,000	>80

Table 13.--Permissible limits for boron, in parts per million, of several classes of irrigation water

Classes of water		Sensitive crops	Semi-tolerant crops	Tolerant crops
Rating	Grade			
1	Excellent..........	<0.33	<0.67	<1.00
2	Good................	.33 to .67	.67 to 1.33	1.00 to 2.00
3	Permissible.........	.67 to 1.00	1.33 to 2.00	2.00 to 3.00
4	Doubtful............	1.00 to 1.25	2.00 to 2.50	3.00 to 3.75
5	Unsuitable..........	>1.25	>2.50	>3.75

It is thought that a better classification in respect to percentage of sodium is obtained diagrammatically. An abbreviated form of Wilcox's diagram is shown in figure 43 for waters in the Powder River drainage basin. Figure 43 is further considered under discussion of the quality of water at individual stations.

Powder River at Sussex, Wyo.

Of 10 samples of water from the Powder River at Sussex, half would be rated as 3 (permissible), and the remaining half would have ratings of 4 (doubtful) or higher. The classification is as follows:

Quality of water for irrigation, Powder River at Sussex

Number of samples	Irrigation quality		Range in daily mean discharge (cfs)
	Rating	Grade	
5	3	Permissible..	115 to 301
2	4	Doubtful.....	....
3	5	Unsuitable...	11 to 109

The water of higher numerical ratings represents sampling at periods of low water discharge when flow in the stream consists mostly of ground water. The river water at Sussex has received substantial contributions of saline water from Salt Creek. Improvement in the quality of the water at Sussex is concurrent, as a general rule, with increase in discharge, because the salt-laden base flows of the water in Salt Creek and the Powder River are then considerably diluted. The river at Sussex on May 6, 1950, however, discharged 608 cfs of water, and this water, on the basis of electrical conductivity and percentage of sodium, would be rated as 4, or doubtful as an irrigation supply. This apparent reversal in normal discharge-concentration relationship may have resulted from increased flow of very saline tributary water that was discharged from Salt Creek and the South Fork at a time when the river was at normal stage. The classification of these waters is also shown in figure 43.

The maximum concentration of boron that was reported was 0.30 ppm, and this low concentration would rate these waters as "excellent" with respect to crop tolerances to this element.

Powder River at Arvada, Wyo.

The classification of the river water at Arvada indicates that most of the 27 samples examined have ratings of 3 (permissible) or better. These waters of better ratings correspond approximately to periods of higher river discharges. This correlation is shown in the following table:

Quality of water for irrigation, Powder River at Arvada

Number of samples	Irrigation quality		Range in daily mean discharge (cfs)
	Rating	Grade	
1	2	Good.........	500
17	3	Permissible..	90 to 2,110
9	4	Doubtful.....	1.5 to 482

It is noteworthy that the maximum percentage of sodium for 27 samples that were collected over wide ranges in river discharge was 48, but that values less than this were reported for periods of low flow. Thus, many of the samples that have been classified as "doubtful" are so rated largely because of high salt concentrations (as indicated from the electrical conductivities) and not because of unusually high values for percentage of sodium. The quality of the river water at Arvada is affected by tributary flow from Crazy Woman Creek, about 18 miles upstream. The graphical presentation of the classes of irrigation water appears in figure 43.

Boron in the river water at Arvada presents no problem; the concentration of this element ranged from 0.05 to 0.35 ppm and averaged 0.23 for 12 samples.

Powder River near Locate, Mont.

Of 22 samples that were analyzed, 18 were graded as "permissible" or better as listed below:

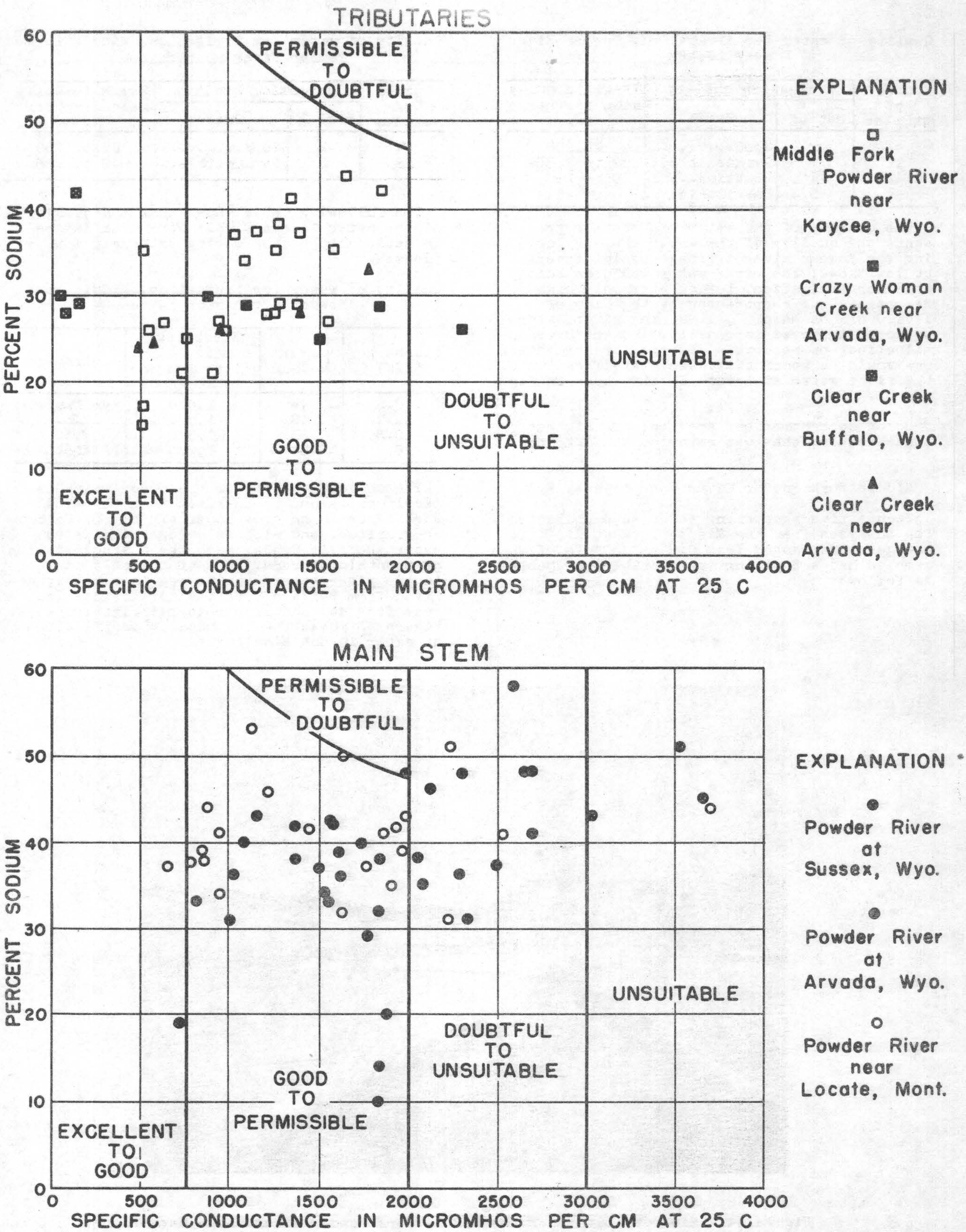


Figure 43.--Classification of water for irrigation use, Powder River drainage basin (modified after Wilcox).

Quality of water for irrigation, Powder River near Locate

Number of samples	Irrigation quality		Range in daily mean discharge (cfs)
	Rating	Grade	
1	2	Good.........	11,100
17	3	Permissible..	50 to 1,630
3	4	Doubtful.....	10 to 286
1	5	Unsuitable...	0.1

The quality of the water at Locate represents the quality of the water that is leaving the Powder River drainage basin. Except at low flows, the river water would be suitable for irrigation. During extremely high discharges, as represented by the flow of 11,100 cfs on March 7, 1949, the river water would be improved in quality, and the overall effect on reservoir storage for irrigation use would be beneficial. The classification of the river water at Locate is also seen in figure 43.

Boron concentrations are low; the highest concentration that was reported was 0.30 ppm.

Middle Fork Powder River near Kaycee, Wyo.

Twenty-five samples of water were collected for analyses from the Middle Fork at discharges that ranged from 0.2 to 730 cfs. All samples had a 3 rating (permissible) or better as follows:

Quality of water for irrigation, Middle Fork Powder River near Kaycee

Number of samples	Irrigation quality		Range in daily mean discharge (cfs)
	Rating	Grade	
7	2	Good.........	98 to 730
18	3	Permissible..	0.2 to 356

The following table shows that the quality of the water in the Middle Fork near Kaycee is satisfactory even during extremely low flows:

Quality of water for irrigation, Middle Fork Powder River near Kaycee

Discharge (cfs)	Percent sodium	Electrical conductivity (micromhos per cm at 25 C)	Grade
0.2	44	1,630	Permissible.
1.7	42	1,830	Do.
2.5	35	1,570	Do.
16	35	1,250	Do.

The uniform quality of the river water is partly explained by the fact that the Middle Fork rises in an area underlain by pre-Cambrian granites, and all its major tributaries, except Buffalo Creek, have the characteristics of mountain streams. Most of the salt content in the river water near Kaycee is probably derived from Buffalo Creek, minor tributaries, (see fig. 44) and from return irrigation flows. Figure 43 shows the graphical classification of water in the Middle Fork.

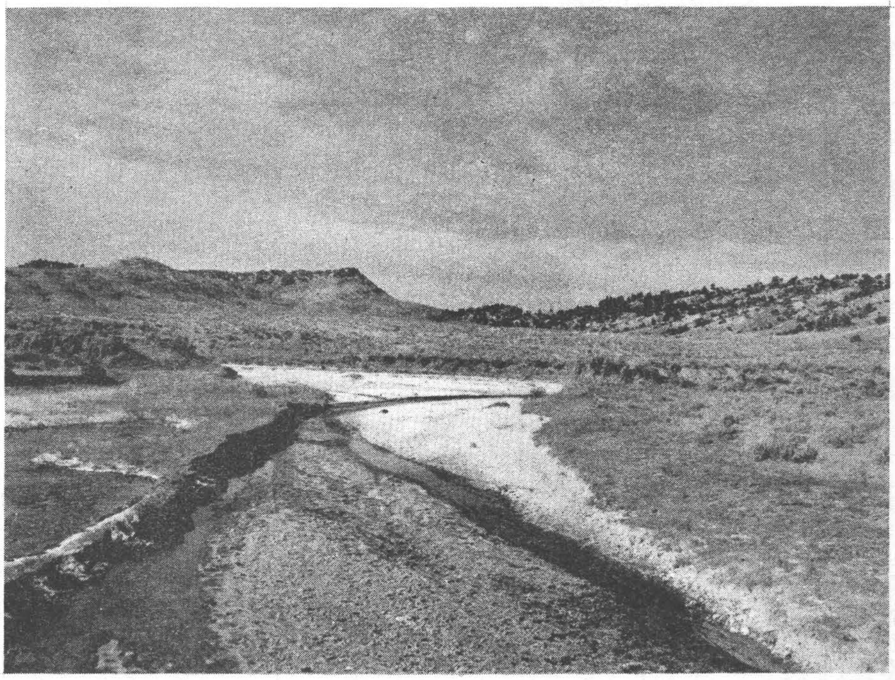


Figure 44.--Minor tributary of the Middle Fork Powder River above Kaycee. Encrustration of salts along stream channels occurs frequently along minor tributaries in this area.

Of nine samples that were analyzed for boron, eight had concentrations of less than 0.35 ppm; thus boron does not present a problem.

Crazy Woman Creek near Arvada, Wyo.

Five samples of this creek water were analyzed, and four were rated as "permissible" and one as "doubtful." The percentage of sodium of 25 to 30 was uniform, whereas the salt concentration (as micromhos per cm at 25 C) showed considerably greater variation. The highest concentration of boron that was reported (based on four samples) was 0.40 ppm and is not considered to be critical.

Clear Creek near Buffalo, Wyo.

The water in Clear Creek near Buffalo rated 2 (good) on the basis of four samples that were collected at discharges from 2.3 to 332 cfs. The water at this station was better in quality than that at other scheduled sampling points in the basin as is apparent from examination of figure 43. Boron is not present in harmful concentrations.

Clear Creek near Arvada, Wyo.

At the mouth of Clear Creek, approximately 80 miles downstream from Buffalo, the creek water is considerably more mineralized, but the quality of the water is nevertheless rated as 3 (permissible) or better. Of five samples, two are graded as "good" and three as "permissible"; the latter samples represent waters at low discharge. The quality of the water at the mouth is influenced by return irrigation flows that enter Clear Creek in the reach between the Buffalo and the Arvada stations. Boron is not present in significant amounts.

Chemical Quality and Domestic Use

Any water supply for domestic use should be clear, pleasant to the taste, of reasonable temperature, neither corrosive nor scale forming, free from minerals that would produce undesirable physiological effects, and free from organisms that are capable of producing intestinal infections. To accomplish this ideal, departments of health have from time to time established standards that govern the quality of water under their jurisdiction. The only Nation-wide government standards pertaining to the quality of potable water supplies are the Drinking Water Standards of the U. S. Public Health Service (1946). These standards were first enacted in 1914 under the provisions of the Interstate Quarantine Regulations and have since been revised in 1925, 1942, and 1946. Specifically, these standards apply only to the waters that are used for drinking and culinary purposes on railroad cars, aircraft, and vessels in interstate traffic. However, the standards are generally accepted by most States for evaluating municipal supplies, and those standards that pertain to chemical constituents are reproduced in part in the following table:

Standards regarding chemical constituents

	Limits (ppm)
Copper	3.0
Zinc	15
Iron plus manganese	.3
Magnesium	125
Chloride	250
Sulfate	250
Fluoride	1.5
Phenolic compounds as phenol.	.001
Total solids	500 (1,000 permitted)

Most of the surface waters in the Powder River drainage basin, with the exception of the mountain streams, would not meet the suggested limits as to sulfate and dissolved solids. The dissolved solids often exceed 1,000 ppm, and sulfate may constitute more than 50 percent of these solids. However, it is noted that waters containing more than 1,000 ppm of dissolved solids have been used for years in many western regions of the United States without adverse effects. The limits as to iron (including manganese), magnesium, chloride, and fluoride would not in general be exceeded. The tributary waters, as a rule, are of better domestic quality than the main stem waters.

Rural residents who are accustomed to drinking mineralized waters often find less saline waters unpalatable. The effects of a change in water are often related to the physiological action of the mineral constituents (American Water Works Association, 1950). When the mineral character of a drinking water supply differs appreciably from one previously used, this difference may affect the mineral balance of the human body.

SUMMARY OF RESULTS

Rocks in the drainage basin range in age from pre-Cambrian to Recent. The pre-Cambrian and Paleozoic rocks crop out in the mountains and are resistant to erosion. Areas outside the mountains are underlain by Mesozoic and Tertiary rocks. Mesozoic rocks underlie the plains south and west of Sussex and a smaller area north and east of the Little Powder River. Both the Mesozoic and the Tertiary rocks erode readily.

The Powder River, the South Fork Powder River, and Salt Creek are sediment-laden streams that flow on slopes of 10 ft or less per mile. In the mountains the streams, including the headwaters of the Middle Fork Powder River and Crazy Woman and Clear Creeks, are clear and fall more than 100 ft per mile over most of their lengths.

The processes of erosion and deposition are shown by a gully that is an ephemeral tributary of Salt Creek near its mouth. A change in local base level is suggested as a probable cause of gully formation.

Average annual runoff in the Powder River drainage basin ranges from a fraction of an inch over much of the plains area to more than 15 in. near the crest of the Bighorn Mountains. It averages less than 1 in. over the entire basin. Much of the runoff in the mountains is from snow melt. In the plains region, runoff is caused mostly by summer storms. The trend of discharge of the Powder River at Arvada and of Clear Creek near Buffalo has been downward during the period of stream-flow records. About 70,000 acres of land are irrigated by diversions from streams in the Powder River drainage basin.

The records of suspended-sediment discharge show an average of about 5,500,000 tons annually for the Powder River at Arvada during a period of nearly 5 yr that ended September 30, 1950. The average annual water discharge during the period was about 200,000 acre-ft. The average concentration weighted with water discharge was 2 percent.

Nearly all the records of suspended sediment at the seven other stations were for only a few months of 1950, but some records were obtained during 1949 on the Middle Fork Powder River above Kaycee. Because the average stream flow during 1950 was close to the minimum annual flow for many years of record, the sediment records during 1950 probably are considerably below the average rate of suspended-sediment discharge. Concentrations and tonnages of suspended sediment were very low near the mouths of Clear and Crazy Woman Creeks. Weighted average concentrations for the Middle Fork Powder River were less than 0.2 percent at the station above Kaycee and were about 0.4 percent at the station near Kaycee. From May 17 to September 30, 1950, the average weighted concentration for the South Fork Powder River near Kaycee was about 1.4 percent, which is undoubtedly far below the average concentration to be expected at this station. From March 1 to September 30, 1950, the suspended-sediment discharge of the Powder River was approximately 1,500,000 tons at Sussex, 2,600,000 tons at Arvada, and 4,300,000 tons near Locate.

The sediment carried in suspension by the Powder River is composed of fine particles. For each sampling station the unweighted average of all particle-size distributions of samples that were analyzed in a dispersion medium showed that at least 80 percent of the particles were finer than 0.062 mm and that the medium sizes were less than 0.009 mm. Particle sizes were smaller for the South Fork Powder River near Kaycee than for any of the other sediment stations and averaged 97 percent smaller than 0.062 mm.

Particle sizes of the suspended sediment of the Powder River at Arvada indicate a specific weight of 56 lb per cu ft for a deposit that might form in a reservoir without being compacted over long periods of time or under the weight of appreciable quantities of overlying deposits. At this specific weight, the suspended sediment discharged at the Arvada station from April 4, 1946, to September 30, 1950, would occupy a computed volume of 21,420 acre-ft.

Although quantities of sediment discharged as bed load by the Powder River at Arvada cannot be computed accurately, the computations indicate that bed-load discharge is only about 2 percent of the discharge of suspended sediment. Certainly the percentage of the total sediment discharge that is transported as bed load at Arvada is very small. Additional observations and computations are planned to obtain a more dependable estimate of the rate of discharge of bed-load sediment at Arvada.

Nearly all the sediment transported by the Powder River and its tributaries comes from the plains area, which is underlain by Mesozoic and Tertiary rocks. Much of it comes from gullies that are actively eroding and from erosion of alluvial deposits along the main streams. Studies are being continued by the Geological Survey to delineate more exactly the sources of sediment in the Powder River basin.

The variation in the chemical quality of waters in the Powder River drainage basin is largely the result of geological influences. Streams traversing areas of granitic rocks contain waters of low mineral content, whereas streams flowing through regions underlain by shale carry high concentrations of soluble salts. The chemical quality of the water in the Powder River and its tributaries is affected also by water discharge, the higher concentrations of salts as a rule corresponding with periods of low water discharge.

As an irrigation supply, the main-stem water at Arvada would be rated as "permissible" for all but very low flows. Most tributaries to the Powder River except Crazy Woman Creek furnish water that would be rated from "permissible" to "good." The main-stem waters are objectionable for general domestic use because of high concentrations of dissolved solids, but the tributary waters in most instances are of better quality.

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BASE DATA

(Tables 14-34)

Table 14.--Monthly and annual summary of water and suspended-sediment discharge, South Fork Powder River near Kaycee, Wyo.

Month	Water discharge (second-foot-days)	Runoff (acre-feet)	Suspended sediment					
			Load (tons)	Daily load (tons)			Concentration (ppm)	
				Mean	Maximum	Minimum	Weighted mean	Maximum daily
1950								
May 17-31...........	660	1,310	6,980	465	3,480	46	3,920	13,400
June................	397.9	789	1,060	35	232	t	987	7,520
July................	442.6	878	34,590	1,120	12,000	t	28,900	65,100
August..............	152.4	302	56	1.8	21	t	136	645
September...........	416.8	827	33,950	1,130	25,100	t	30,200	63,300
May 17 to Sept. 30...	2,069.7	4,110	76,640	559	25,100	t	13,700	65,100

t Sediment discharge less than 1 ton.

Table 15.--Monthly and annual summary of water and suspended-sediment discharge, Powder River at Sussex, Wyo.

Month	Water discharge (second-foot-days)	Runoff (acre-feet)	Suspended sediment					
			Load (tons)	Daily load (tons)			Concentration (ppm)	
				Mean	Maximum	Minimum	Weighted mean	Maximum daily
1950								
March............	4,642	9,210	a 60,420	1,950	4,450	....	4,820	8,670
April............	10,355	20,540	185,600	6,190	25,400	1,410	6,640	17,700
May..............	26,386	52,340	1,139,000	36,700	96,600	1,810	16,000	40,200
June.............	5,989	11,880	40,570	1,350	12,700	12	2,510	16,200
July.............	1,536	3,050	56,610	1,830	16,500	9	13,700	44,200
August...........	284.8	565	260	8.4	147	t	338	2,180
September........	1,104.7	2,190	17,780	593	9,320	t	5,960	44,400
Mar. 1 to Sept. 30	50,297.5	99,780	1,500,000	7,010	96,600	t	11,000	44,400

a Includes estimated loads for a few days.
t Sediment discharge less than 1 ton.

Table 16.--Monthly and annual summary of water and suspended-sediment discharge, Powder River at Arvada, Wyo.

Month	Water discharge (second-foot-days)	Runoff (acre-feet)	Suspended sediment					
			Load (tons)	Daily load (tons)			Concentration (ppm)	
				Mean	Maximum	Minimum	Weighted mean	Maximum daily
1946								
Apr. 4-30.........	11,552	22,910	466,100	17,300	54,800	3,660	14,900	36,300
May..............	14,776	29,310	411,000	13,300	19,000	7,690	10,300	14,600
June.............	18,287	36,270	1,531,000	51,000	533,000	2,840	31,000	78,000
July.............	11,268	22,350	1,008,000	32,500	374,000	88	33,100	58,600
August...........	141	280	131	4	74	0	344	546
September........	4,757	9,440	357,700	11,900	70,400	0	27,800	66,000
Apr. 4 to Sept. 30	60,781	120,600	3,774,000	21,000	533,000	0	23,000	78,000
October..........	4,492	8,910	69,680	2,250	5,560	484	5,740	14,200
November.........	4,805	9,530	62,710	2,090	5,910	84	4,830	8,330
December.........	3,833	7,600	b 33,000	1,100	....	....	3,200	....
1947								
January..........	2,763	5,480	b 3,500	110	....	....	470	....
February.........	5,163	10,240	b 20,000	710	5,260	....	1,400	....
March............	29,431	58,380	b 796,000	25,700	155,000	....	10,000	28,000
April............	10,038	19,910	327,000	10,900	43,400	3,040	12,100	23,800
May..............	43,550	86,380	2,320,000	74,800	227,000	13,000	19,700	32,200
June.............	23,233	46,080	1,044,000	34,800	189,000	9,280	16,600	41,100
July.............	10,468	20,760	639,100	20,600	300,000	464	22,600	50,500
August...........	225.9	448	472	15.2	173	0	773	1,940
September........	558.3	1,110	a 7,240	241	2,310	0	4,800	18,600
Water year 1946-47	138,560.2	274,800	b 5,323,000	14,600	300,000	0	14,200	50,500

See footnotes at end of table, p. 73.

Table 16.--Monthly and annual summary of water and suspended-sediment discharge, Powder River at Arvada, Wyo.--Con.

Month	Water discharge (second-foot-days)	Runoff (acre-feet)	Suspended sediment					
			Load (tons)	Daily load (tons)			Concentration (ppm)	
				Mean	Maximum	Minimum	Weighted mean	Maximum daily
1947--Continued								
October	2,665	5,290	26,920	868	3,200	85	3,740	7,000
November	4,314	8,560	26,110	870	2,160	11	2,240	5,000
December	3,345	6,630	b 7,700	250	2,560	....	850	4,870
1948								
January	2,541	5,040	a 3,550	115	189	....	518	777
February	6,438	12,770	a 22,930	791	5,710	111	1,320	3,300
March	26,728	53,010	1,027,000	33,100	120,000	290	14,200	42,700
April	7,498	14,870	116,300	3,880	7,820	1,420	5,740	9,580
May	16,437	32,600	922,900	29,800	146,000	4,570	20,800	40,000
June	39,287	77,920	5,858,000	195,000	1,200,000	5,670	55,200	81,600
July	12,372	24,540	979,700	31,600	305,000	125	29,300	50,000
August	2,286.7	4,540	162,500	5,240	61,000	1	26,300	51,500
September	1,557.8	3,090	274,700	9,160	185,000	0	65,300	87,000
Water year 1947-48	125,469.5	248,900	a 9,428,000	25,800	1,200,000	0	27,800	87,000
October	4,041	8,020	303,900	9,800	183,000	129	27,900	63,400
November	3,809	7,560	31,240	1,040	2,620	142	3,040	7,200
December	2,633	5,220	4,070	131	336	68	572	920
1949								
January	1,824	3,620	a 1,720	56	147	18	349	718
February	2,165	4,290	3,730	133	1,830	33	638	2,050
March	27,296	54,140	640,500	20,700	65,000	723	8,690	25,600
April	9,837	19,510	203,800	6,790	11,100	3,690	7,670	9,410
May	17,040	33,800	903,300	29,100	95,500	8,960	19,600	31,300
June	19,994	39,660	2,303,000	76,800	382,000	1,000	42,700	67,000
July	3,922.9	7,780	479,000	15,500	249,000	0	45,200	70,500
August	4.0	7.9	110	3.5	104	0	10,200	10,700
September	184.6	366	8,690	290	3,270	0	17,400	97,200
Water year 1948-49	92,750.5	184,000	a 4,883,000	13,400	382,000	0	19,500	97,200
October	2,806	5,570	78,400	2,530	9,000	10	10,300	22,500
November	2,680	5,320	42,260	1,410	2,880	350	5,840	7,220
December	713	1,410	b 1,600	52	464	....	831	4,910
1950								
January	908	1,800	a 804	26	49	8	328	497
February	1,770	3,510	4,380	156	540	38	917	2,220
March	6,860	13,610	91,730	2,960	11,800	150	4,950	13,200
April	11,335	22,480	395,900	13,200	28,200	7,770	12,900	21,700
May	27,164	53,880	1,833,000	59,100	143,000	6,440	25,000	46,700
June	9,806	19,450	179,000	5,970	13,800	202	6,760	12,800
July	1,967.5	3,900	80,570	2,600	50,400	7	15,200	34,000
August	249.2	494	a 25,360	818	16,000	0	36,300	45,000
September	141	280	4,910	164	1,730	0	12,900	30,600
Water year 1949-50	66,399.7	131,700	a 2,738,000	7,500	143,000	0	15,300	46,700

a Includes estimated loads for a few days.
b Includes estimated loads for many days.

Table 17.--Monthly and annual summary of water and suspended-sediment discharge, Powder River near Locate, Mont.

Month	Water discharge (second-foot-days)	Runoff (acre-feet)	Suspended sediment					
			Load (tons)	Daily load (tons)			Concentration (ppm)	
				Mean	Maximum	Minimum	Weighted mean	Maximum daily
1950								
March	2,485	4,930	a 15,360	495	4,110	....	2,290	7,610
April	37,077	73,540	1,088,000	36,300	126,000	11,100	10,900	21,200
May	44,862	88,980	2,423,000	78,200	218,000	19,900	20,000	35,600
June	31,478	62,440	637,800	21,300	54,100	6,670	7,500	14,100
July	9,316	18,480	60,860	1,950	22,500	86	2,410	12,900
August	2,946	5,840	83,970	2,710	15,400	4	10,600	20,200
September	837.2	1,660	842	28	155	t	372	585
Mar. 1 to Sept. 30	129,001.2	255,900	a 4,310,000	20,100	218,000	t	12,400	35,600

a Includes estimated loads for a few days.
t Sediment discharge less than 1 ton.

Table 18.--Monthly and annual summary of water and suspended-sediment discharge, Middle Fork Powder River above Kaycee, Wyo.

Month	Water discharge (second-foot-days)	Runoff (acre-feet)	Suspended sediment					
			Load (tons)	Daily load (tons)			Concentration (ppm)	
				Mean	Maximum	Minimum	Weighted mean	Maximum daily
1949								
Apr. 22-30........	1,379	2,740	9,560	1,060	2,830	89	2,570	3,690
May...............	5,921	11,740	19,680	630	2,890	82	1,230	5,030
June..............	3,292	6,530	40,140	1,340	18,700	10	4,520	24,000
July..............	1,198	2,380	267	8.6	69	1	82	474
August............	982	1,950	a 733	24	446	1	276	1,390
September.........	1,230	2,440	a 224	7.5	24	2	67	214
Apr. 22 to Sept. 30	14,002	27,780	a 70,600	436	18,700	1	1,870	24,000
October...........	1,508	2,990	a 167	5.4	10	3	41	....
November..........	1,384	2,750	a 136	4.5	11	1	36	....
December..........	1,075	2,130	b 270	8.7	....	....	93	....
1950								
January...........	1,066	2,110	b 310	10	....	....	108	....
February..........	1,195	2,370	a 730	26	....	....	226	....
March.............	1,519	3,010	a 1,050	34	....	....	256	....
April.............	2,713	5,380	a 14,840	495	2,800	10	2,030	....
May...............	7,966	15,880	a 86,960	2,810	15,100	80	4,040	8,710
June..............	3,241	6,430	738	26	109	4	90	215
July..............	1,227	2,430	155	5.0	22	1	47	168
August............	961	1,910	a 3,190	103	2,250	t	1,230	....
September.........	1,156	2,290	a 189	6.3	22	1	61	....
Water year 1949-50.	25,011	49,680	a 108,800	298	15,100	t	1,610	8,710

a Includes estimated loads for a few days.
b Includes estimated loads for many days.
t Sediment discharge less than 1 ton.

Table 19.--Monthly and annual summary of water and suspended-sediment discharge, Middle Fork Powder River near Kaycee, Wyo.

Month	Water discharge (second-foot-days)	Runoff (acre-feet)	Suspended sediment					
			Load (tons)	Daily load (tons)			Concentration (ppm)	
				Mean	Maximum	Minimum	Weighted mean	Maximum daily
1950								
March............	3,632	7,200	a 5,200	168	....	....	530	....
April............	6,589	13,070	a 52,500	1,750	....	44	2,950	....
May..............	16,139	32,010	a 296,000	9,550	39,100	....	6,790	....
June.............	5,744	11,390	b 8,500	283	1,150	....	548	1,150
July.............	363.9	722	a 717	23	....	t	730	....
August...........	74.9	149	a 190	61	172	t	940	1,910
September........	1,040.8	2,060	a 297	9.9	58	t	106	375
Mar. 1 to Sept. 30	33,583.6	66,600	a 363,400	1,700	39,100	t	4,010	....

a Includes estimated loads for a few days.
b Includes estimated loads for many days.
t Sediment discharge less than 1 ton.

Table 20.--Monthly and annual summary of water and suspended-sediment discharge, Crazy Woman Creek near Arvada, Wyo.

Month	Water discharge (second-foot-days)	Runoff (acre-feet)	Suspended sediment					
			Load (tons)	Daily load (tons)			Concentration (ppm)	
				Mean	Maximum	Minimum	Weighted mean	Maximum daily
1950								
Mar. 15-31.......	516	1,020	204	12	36	2	146	270
April............	2,535	5,030	14,050	468	3,640	24	2,050	7,170
May..............	5,232	10,380	66,260	2,140	11,100	15	4,690	11,100
June.............	4,069	8,070	11,470	382	1,570	19	1,040	2,460
July.............	935.4	1,860	357	12	55	t	141	308
August...........	162.0	321	14,910	481	12,500	0	34,100	36,500
September........	162.7	323	a 29	1.0	4	0	66	....
Mar. 15 to Sept.30	13,612.1	27,000	a 107,300	536	12,500	0	2,920	36,500

a Includes estimated loads for a few days.
t Sediment discharge less than 1 ton.

Table 21.—Monthly and annual summary of water and suspended-sediment discharge, Clear Creek near Arvada, Wyo.

Month	Water discharge (second-foot-days)	Runoff (acre-feet)	Suspended sediment					
			Load (tons)	Daily load (tons)			Concentration (ppm)	
				Mean	Maximum	Minimum	Weighted mean	Maximum daily
1950								
Mar. 21-31...........	1,563	3,100	a 350	32	....	....	83	....
April................	5,461	10,830	3,120	104	1,320	4	212	1,380
May..................	10,220	20,270	14,510	468	2,490	4	526	1,430
June.................	17,312	34,340	32,440	1,080	7,660	4	694	2,200
July.................	3,517.2	6,980	a 964	31	402	t	100	1,230
August...............	504.5	1,000	679	22	536	t	498	980
September............	2,576.2	5,110	603	20	68	t	87	141
Mar. 21 to Sept. 30..	41,153.9	81,630	a 52,670	271	7,660	t	474	2,200

a Includes estimated loads for a few days.

t Sediment load less than 1 ton.

Table 22.—Particle-size analyses of suspended sediment, South Fork Powder River near Kaycee, Wyo.

[Methods of analyses: S, sieve; P, pipette; N, in native waters; W, in distilled water; C, chemically dispersed; M, mechanically dispersed; B, bottom withdrawal tube]

Date	Time	Water discharge (cfs)	Suspended sediment										Methods of analysis
			Concentration of sample (ppm)	Concentration of suspension analyzed (ppm)	Percent finer than indicated size (mm)								
					0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	
1950													
May 3...	12:54 p.m.	a 336	69,900	58,100	.....	0	71	74	86	91	98	100	SPN
Do....	12:54 p.m.	a 336	69,900	5,010	35	48	57	70	81	93	98	100	SPWCM
May 11..	1:33 p.m.	a 450	50,500	39,700	.....	0	5	61	76	88	97	100	SPN
Do....	1:33 p.m.	a 450	50,500	5,500	29	36	46	55	66	84	94	99	BWC
May 17..	10:00 a.m.	a 96	14,000	4,590	.....	64	.....	83	.....	89	95	97	SPWCM
May 25..	5:45 p.m.	a 57	2,570	2,100	.....	76	.....	90	.....	96	.....	.....	SPWCM
June 2..	9:45 a.m.	a 29	1,210	916	.....	65	.....	87	.....	91	.....	.....	SPWCM
June 8..	10:45 a.m.	20	3,360	2,720	.....	67	.....	91	.....	98	.....	.....	SPWCM
June 21.	5:15 p.m.	12	10,900	9,080	.....	87	.....	98	.....	100	.....	.....	SPWCM
July 4..	5:45 p.m.	118	83,500	8,920	.....	63	.....	93	.....	98	.....	.....	SPWCM
July 5..	8:45 a.m.	66	68,300	7,460	.....	72	.....	.....	.....	99	.....	.....	SPWCM
July 6..	6:40 p.m.	16	21,200	24,200	12	13	14	97	99	100	.....	.....	SPN
Do....	6:40 p.m.	16	21,200	3,440	.....	86	95	98	99	100	.....	.....	BWC
July 12.	8:00 a.m.	38	62,300	6,510	.....	71	.....	98	.....	99	.....	.....	SPWCM
July 13.	10:50 a.m.	8.3	1,200	890	.....	78	.....	88	.....	99	.....	.....	SPWCM
July 25.	7:45 a.m.	16	6,100	4,980	.....	88	.....	97	.....	99	.....	.....	SPWCM
July 26.	5:30 p.m.	75	55,500	5,820	.....	60	.....	88	.....	99	.....	.....	SPWCM
July 27.	3:44 p.m.	12	10,900	11,000	.....	0	4	93	99	99	.....	.....	SPN
Do....	3:44 p.m.	12	10,900	5,260	68	88	94	97	99	100	.....	.....	SPWCM
Sept. 11	1:45 p.m.	15	3,240	2,470	.....	84	.....	93	.....	99	.....	.....	SPWCM
Do....	6:10 p.m.	16	1,950	1,400	.....	93	.....	.....	.....	99	.....	.....	SPWCM
Sept. 15	8:00 a.m.	15	1,300	1,070	.....	69	.....	83	.....	98	.....	.....	SPWCM
Do....	5:00 p.m.	17	15,000	6,060	.....	69	.....	92	.....	99	.....	.....	SPWCM
Sept. 20	8:30 a.m.	22	5,500	4,300	.....	68	.....	85	.....	96	.....	.....	SPWCM
Sept. 21	8:30 a.m.	152	62,600	6,000	.....	63	.....	90	.....	98	.....	.....	SPWCM
Sept. 24	8:30 a.m.	14	5,500	4,420	.....	97	.....	.....	.....	100	.....	.....	SPWCM
Sept. 25	4:09 p.m.	9.6	1,720	2,010	.....	0	2	93	96	100	.....	.....	SPN
Do....	4:09 p.m.	9.6	1,720	2,130	78	90	93	93	95	99	.....	.....	SPWCM
Sept. 30	5:00 p.m.	19	2,450	1,750	.....	75	.....	93	.....	97	.....	.....	SPWCM

a Mean daily discharge.

Table 23.--Particle-size analyses of suspended sediment, Powder River at Sussex, Wyo.

[Methods of analyses: B, bottom withdrawal tube; W, in distilled water; S, sieve; P, pipette; C, chemically dispersed; M, mechanically dispersed; N, in native water]

Date	Time	Water discharge (cfs)	Suspended sediment											Methods of analysis
			Concentration of sample (ppm)	Concentration of suspension analyzed (ppm)	Percent finer than indicated size (mm)									
					0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.500	
1950														
Mar. 4.......	7:30 a.m.	a 140	6,340	1,530	26	34	57	70	80	88	94	100	......	BW
Mar. 16......	2:45 p.m.	175	7,240	1,150	14	16	26	36	60	78	90	98	......	BW
Apr. 6.......	9:30 a.m.	356	8,060	3,520	......	53	......	72	......	87	95	99	100	SPWCM
Apr. 7.......	6:00 p.m.	368	19,200	10,800	......	60	......	79	......	92	97	100	......	SPWCM
Apr. 8.......	5:30 p.m.	254	9,720	5,290	......	53	......	68	......	86	95	99	100	SPWCM
Apr. 10......	9:30 a.m.	590	22,200	15,300	......	35	......	56	......	81	90	99	100	SPWCM
Apr. 16......	8:50 a.m.	470	13,800	8,850	......	37	......	56	......	81	92	99	100	SPWCM
May 1........	9:30 a.m.	416	10,700	6,970	......	34	......	51	......	78	95	100	......	SPWCM
May 3........	6:30 p.m.	645	48,500	9,400	......	45	......	71	......	89	94	99	100	SPWCM
May 6........	1:06 p.m.	662	29,900	43,600	......	4	19	63	82	91	99	100	......	BN
Do..........	1:06 p.m.	662	29,900	13,500	22	33	45	60	74	85	94	99	......	BW
May 11.......	4:57 p.m.	1,090	32,500	10,900	......	42	......	63	......	91	98	100	......	SPWCM
May 17.......	6:41 p.m.	b 1,450	19,400	20,000	......	1	3	31	55	78	96	100	......	BN
Do..........	6:41 p.m.	b 1,450	19,400	15,100	11	16	22	30	47	76	93	100	......	BW
May 24.......	2:06 p.m.	a 1,040	9,510	4,260	......	14	......	23	......	60	92	100	......	SPWCM
June 2.......	7:20 p.m.	416	2,420	1,370	......	12	......	19	......	54	88	100	......	SPWCM
June 9.......	7:00 p.m.	254	1,680	682	......	11	......	19	......	44	79	99	100	SPWCM
June 14......	12:00 m.	200	1,090	832	......	12	......	22	......	56	86	99	100	SPWCM
June 19......	10:45 a.m.	a 225	16,000	3,050	......	59	......	84	......	93	......	......	......	SPWCM
July 2.......	7:00 p.m.	130	18,300	7,590	......	69	......	94	......	100	......	......	......	SPWCM
July 6.......	2:49 p.m.	84	30,600	6,230	......	80	......	98	......	99	......	......	......	SPWCM
July 12......	9:00 a.m.	180	81,000	8,880	......	......	......	74	......	99	......	......	......	SPN
Do..........	9:00 a.m.	180	81,000	1,970	47	56	71	88	97	99	100	......	......	BWCM
July 13......	1:52 p.m.	a 42	38,900	37,100	......	1	98	99	......	100	......	......	......	SPN
Do..........	1:52 p.m.	a 42	38,900	5,650	58	78	94	98	......	100	......	......	......	SPWCM
July 14......	9:30 a.m.	60	7,400	5,660	......	78	......	94	......	97	......	......	......	SPWCM
July 27......	1:13 p.m.	50	9,580	9,130	......	1	2	73	98	99	......	......	......	SPN
Do..........	1:13 p.m.	50	9,580	3,890	......	74	87	96	98	99	100	......	......	BWCM
July 28......	9:30 a.m.	29	27,000	5,250	......	84	96	98	......	......	......	......	......	BWCM
Aug. 13......	8:05 a.m.	30	3,280	2,530	......	73	......	......	......	99	......	......	......	SPWCM
Sept. 13.....	1:45 p.m.	a 23	890	2,260	......	56	......	77	......	91	......	......	......	SPWCM
Sept. 16.....	3:30 p.m.	a 27	4,250	3,100	......	70	......	88	......	97	......	......	......	SPWCM
Sept. 21.....	12:30 p.m.	39	3,890	2,830	......	61	......	75	......	94	......	......	......	SPWCM
Sept. 22.....	9:45 a.m.	73	57,700	4,770	......	72	......	89	......	95	......	......	......	SPWCM
Sept. 24.....	8:30 a.m.	67	6,260	4,020	......	82	......	94	......	98	......	......	......	SPWCM
Sept. 26.....	1:35 p.m.	69	1,670	2,450	......	......	14	72	78	88	......	......	......	SPN
Do..........	1:35 p.m.	69	1,670	2,320	49	56	67	74	82	87	......	......	......	SPWCM

a Mean daily discharge.

b Discharge measurement.

Table 24.—Particle-size analyses of suspended sediment, Powder River at Arvada, Wyo.

[Methods of analyses: B, bottom withdrawal tube; N, in native waters; W, in distilled water; C, chemically dispersed; S, sieve; P, pipette; M, mechanically dispersed]

Date	Time	Water discharge (cfs)	Suspended sediment: Concentration of sample (ppm)	Concentration of suspension analyzed (ppm)	Percent finer than indicated size (mm): 0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.500	Methods of analysis
1946														
June 1......	2:30 p.m.	544	12,800	9,890	......	4	31	44	51	70	84	93	......	BN
June 21......	1:30 p.m.	979	39,200	7,370	......	6	48	78	81	88	91	96	......	BN
1947														
Mar. 18......	11:30 a.m.	3,360	8,210	6,170	......	3	6	34	......	56	63	84	......	BN
Oct. 3.......	3:08 p.m.	45	1,030	3,750	......	2	7	15	25	46	69	97	......	BN
1948														
Mar. 18......	8:15 p.m.	2,140	13,400	6,080	......	5	10	......	......	88	97	100	......	BN
Do.........	8:20 p.m.	2,140	13,400	5,790	......	37	51	62	70	81	94	99	......	BW
Do.........	8:50 p.m.	2,140	13,400	7,600	......	36	50	58	68	75	84	96	......	BW
Mar. 19......	5:00 p.m.	2,140	20,000	9,260	......	3	8	44	59	66	80	96	......	BN
Do.........	4:45 p.m.	2,140	20,000	5,870	......	33	44	56	68	79	91	100	......	BW
Apr. 8.......	1:30 p.m.	237	4,700	....	......	27	42	56	67	95	95	98	......	BW
Do.........	1:30 p.m.	237	4,700	6,730	......	2	5	18	59	72	94	98	......	BN
Apr. 14......	2:40 p.m.	202	3,760	2,770	......	4	12	47	65	77	94	98	......	BN
May 4........	2:50 p.m.	416	7,460	10,900	......	1	3	9	71	81	94	100	......	BN
May 18.......	2:25 p.m.	458	11,800	9,610	......	2	6	30	68	80	95	100	......	BN
Do.........	2:25 p.m.	458	11,800	10,300	......	18	28	40	60	82	95	100	......	BW
Do.........	2:25 p.m.	458	11,800	10,200	......	18	27	39	57	74	90	96	......	BWC
May 26.......	4:30 p.m.	1,680	37,100	4,550	......	2	7	33	72	84	89	96	......	BN
Do.........	4:30 p.m.	1,680	37,100	4,940	......	28	40	53	70	84	90	96	......	BW
June 4.......	12:30 p.m.	672	20,500	5,000	......	4	9	45	......	89	95	98	......	BN
Do.........	12:30 p.m.	672	20,500	....	......	34	46	58	75	90	95	99	......	BW
July 14......	4:20 p.m.	5,000	84,500	8,660	......	2	4	24	......	76	86	92	......	BN
Do.........	4:20 p.m.	5,000	84,500	8,760	......	26	39	51	66	78	88	92	......	BW
Do.........	4:20 p.m.	5,000	84,500	8,640	......	26	39	51	66	80	88	97	......	BWC
July 27......	7:00 p.m.	175	7,930	6,140	......	3	6	......	......	89	96	100	......	BN
Do.........	7:00 p.m.	175	7,930	6,490	......	51	65	74	80	89	97	100	......	BW
Aug. 17......	6:00 p.m.	35	2,130	2,400	......	8	14	......	......	93	97	99	......	BN
Do.........	6:00 p.m.	35	2,130	2,440	......	64	80	86	89	92	98	98	......	BW
Sept. 22.....	6:40 p.m.	616	80,600	18,400	......	1	3	70	......	94	96	99	......	BN
Do.........	6:40 p.m.	616	80,600	16,900	......	47	66	83	89	93	96	100	......	BW
Oct. 5.......	12:30 p.m.	35	1,760	2,700	......	......	10	......	94	95	95	98	......	BN
Do.........	12:30 p.m.	35	1,760	2,830	......	72	88	92	94	96	96	100	......	BW
1949														
Mar. 3.......	10:00 a.m.	1,430	2,660	1,000	......	14	24	38	40	48	63	86	......	BN
Mar. 11......	2:00 p.m.	500	4,170	1,870	......	6	44	56	63	73	88	100	......	BN
Do.........	2:00 p.m.	500	4,170	1,630	......	33	42	50	58	74	90	98	......	BW
Mar. 23......	2:50 p.m.	656	11,400	1,190	......	38	56	70	86	97	100	......	......	BW

See footnotes at end of table, p. 79.

Table 24.--Particle-size analyses of suspended sediment, Powder River at Arvada, Wyo.--Continued

[Methods of analyses: B, bottom withdrawal tube; N, in native waters; W, in distilled water; C, chemically dispersed; S, sieve; P, pipette; M, mechanically dispersed]

Date	Time	Water discharge (cfs)	Suspended sediment											Methods of analysis
			Concentration of sample (ppm)	Concentration of suspension analyzed (ppm)	Percent finer than indicated size (mm)									
					0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.500	
1949														
Apr. 12......	2:20 p.m.	342	10,100	2,240	......	36	42	53	81	86	93	96	......	BW
May 21.......	11:30 a.m.	716	24,200	1,120	......	46	60	70	78	88	95	98	......	BW
June 3.......	12:42 p.m.	512	26,100	1,230	......	44	72	76	84	92	98	98	......	BW
June 10......	10:30 a.m.	1,350	47,000	1,420	......	36	60	66	76	90	95	100	......	BW
July 6.......	1:00 p.m.	264	19,600	1,990	......	38	51	68	79	88	93	96	......	BW
July 19......	1:30 p.m.	44	25,800	2,460	......	75	90	96	97	98	98	100	......	BW
Sept. 2......	10:55 a.m.	9.8	94,200	3,840	......	4	6	96	100	......	......	......	......	BN
Do.........	10:55 a.m.	9.8	94,200	4,000	42	68	94	100	......	......	......	......	......	BW
Do.........	5:15 p.m.	9.8	83,000	2,070	48	70	92	98	98	100	......	......	......	BW
Sept. 12.....	5:20 p.m.	4.0	387	277	20	36	64	92	97	99	100	......	......	BW
Oct. 1.......	6:10 p.m.	15	210	154	......	......	59	65	71	83	90	94	......	BW
Oct. 4.......	2:13 p.m.	b 16.9	355	2,380	27	56	79	87	89	93	95	98	......	BW
Oct. 18......	12:50 p.m.	a 82	7,560	1,320	1	4	19	......	92	93	93	97	......	BN
Do.........	12:50 p.m.	a 82	7,560	1,400	45	62	79	87	90	93	94	97	......	BW
Oct. 31......	11:20 a.m.	148	8,320	1,770	2	6	14	......	67	75	87	98	......	BN
Do.........	11:20 a.m.	148	8,320	1,730	20	34	46	56	64	75	88	97	......	BW
Nov. 2.......	10:53 a.m.	85	8,160	1,730	......	4	14	......	61	70	83	92	......	BN
Do.........	10:53 a.m.	85	8,160	1,760	23	32	44	54	60	68	79	88	......	BW
Nov. 4.......	7:30 a.m.	119	6,230	2,400	29	39	54	63	69	75	85	90	......	BW
Nov. 17......	10:22 a.m.	62	6,340	2,110	......	1	13	60	63	71	83	94	......	BN
Do.........	10:22 a.m.	62	6,340	2,920	22	25	38	66	70	80	94	99	......	BW
Nov. 18......	7:30 a.m.	65	5,780	2,390	18	29	41	50	57	65	79	90	......	BW
1950														
Feb. 4.......	2:20 p.m.	a 43	400	325	49	70	76	79	80	89	97	100	......	BW
Feb. 21......	4:40 p.m.	a 75	950	611	26	36	47	60	68	78	91	100	......	BW
Feb. 27......	5:10 p.m.	a 88	3,300	2,610	19	22	33	44	55	65	74	96	......	BW
Mar. 1.......	4:45 p.m.	a 80	3,050	2,580	14	18	27	38	50	58	70	98	......	BW
Mar. 13......	9:10 a.m.	a 110	675	527	28	32	43	55	67	80	89	96	......	BW
Mar. 23......	4:15 p.m.	a 320	8,300	1,740	19	27	38	54	75	85	93	98	......	BW
Apr. 5.......	1:55 p.m.	247	14,700	18,000	......	23	......	43	......	83	91	100	......	SPWCM
Do.........	6:05 p.m.	270	14,000	9,170	......	30	......	50	......	86	97	100	......	SPWCM
Apr. 20......	2:08 p.m.	491	19,700	18,700	......	......	0	16	63	75	89	98	......	BN
Do.........	2:08 p.m.	491	19,700	12,900	13	24	31	41	62	80	81	98	......	BW
Apr. 25......	5:09 p.m.	370	13,500	10,300	......	......	4	36	54	81	95	99	100	SPN
Do.........	5:09 p.m.	370	13,500	4,780	20	24	31	41	58	81	95	99	100	SPWCM
May 9........	5:30 p.m.	1,130	44,500	7,420	......	43	......	64	......	91	98	100	......	SPWCM
May 10.......	1:47 p.m.	1,040	41,100	7,440	......	39	......	58	......	86	96	99	100	SPWCM
May 18.......	5:36 p.m.	1,370	26,500	27,700	......	3	5	32	62	79	89	100	......	BN

Do.......	5:36 p.m.	1,370	26,500	10,300	16	25	33	43	59	75	89	99	......	BW
May 25......	12:59 p.m.	1,320	19,000	17,800	......	......	14	21	47	67	80	94	......	BN
Do.......	12:59 p.m.	1,320	19,000	4,110	12	17	21	30	41	61	78	91	......	BWCM
June 6......	2:51 p.m.	410	5,410	6,280	......	21	......	32	......	76	92	98	100	SPWCM
June 10.....	7:50 a.m.	566	9,500	4,970	......	18	......	......	......	76	96	100	......	SPWCM
June 13.....	7:18 p.m.	370	4,940	4,760	......	23	......	34	......	75	96	99	100	SPWCM
June 21.....	8:00 a.m.	276	6,000	3,140	......	15	......	21	......	68	95	99	100	SPWCM
June 29.....	5:50 a.m.	82	2,100	857	......	14	......	20	......	45	86	98	100	SPWCM
July 5......	4:14 p.m.	110	5,200	5,180	......	3	6	73	84	89	96	99	......	BN
Do.......	4:14 p.m.	110	5,200	2,090	58	65	74	77	80	89	96	99	......	BWCM
July 12.....	3:52 p.m.	45	4,370	10,100	......	87	......	96	......	97	......	......	......	SPWCM
July 19.....	1:30 p.m.	87	33,700	34,100	......	7	10	89	97	98	99	100	......	BN
Do.......	1:30 p.m.	87	33,700	2,520	63	79	94	96	97	98	100	......	......	BWCM
July 26.....	10:25 a.m.	19	951	2,660	36	47	60	68	76	89	96	99	......	BWCM
Aug. 12.....	8:10 a.m.	56	50,000	4,640	......	69	......	94	......	98	......	......	......	SPWCM
Aug. 13.....	6:30 p.m.	76	35,000	12,400	......	57	......	90	......	96	......	......	......	SPWCM
Aug. 14.....	8:25 a.m.	67	42,000	8,290	......	68	......	94	......	98	......	......	......	SPWCM
Aug. 15.....	3:13 p.m.	25	6,770	7,230	......	......	1	52	91	99	......	......	......	SPN
Do.......	3:13 p.m.	25	6,770	2,800	68	86	96	98	99	100	......	......	......	BWCM
Sept. 26....	5:00 p.m.	a 23	2,200	1,810	......	80	......	95	......	97	......	......	......	SPWCM
Sept. 27....	5:25 p.m.	a 20	25,000	5,160	......	89	......	97	......	99	......	......	......	SPWCM
Sept. 28....	3:30 p.m.	a 22	29,500	30,200	......	4	82	93	96	97	98	99	......	BNM
Do.......	3:30 p.m.	a 22	29,500	6,380	......	92	98	99	100	......	......	......	......	BWCM
Sept. 29....	8:55 a.m.	25	17,900	7,720	......	89	......	98	......	99	......	......	......	SPWCM
Sept. 30....	8:30 a.m.	a 38	7,600	4,620	......	62	......	74	......	76	......	......	......	SPWCM

a Mean daily discharge.
b Discharge measurement.

Table 25.--Particle-size analyses of suspended sediment, Powder River near Locate, Mont.

[Methods of analyses: B, bottom withdrawal tube; N, in native waters; W, in distilled water; S, sieve; P, pipette; C, chemically dispersed; M, mechanically dispersed]

Date	Time	Water discharge (cfs)	Suspended sediment													Methods of analysis
			Concentration of sample (ppm)	Concentration of suspension analyzed (ppm)	Percent finer than indicated size (mm)											
					0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.500	1.000	2.000	
1950																
Mar. 3	10:25 a.m.	a 50	777	1,170	.....	17	27	30	42	61	83	98	.....	.....	.....	BN
Do	10:25 a.m.	a 50	777	1,130	17	21	25	32	43	58	78	95	.....	.....	.....	BW
Mar. 24	4:35 p.m.	a 150	9,440	4,870	.....	33	.....	43	.....	71	85	98	100	.....	.....	SPWCM
Mar. 31	4:45 p.m.	200	8,540	5,460	.....	38	.....	53	.....	80	92	99	100	.....	.....	SPWCM
Apr. 3	6:10 a.m.	a 3,000	15,500	9,410	.....	42	.....	58	.....	80	93	99	100	.....	.....	SPWCM
Apr. 5	12:36 p.m.	2,230	9,960	3,280	5	8	20	.....	71	77	83	95	.....	.....	.....	BN
Do	12:36 p.m.	2,230	9,960	6,860	25	34	47	58	69	74	88	97	.....	.....	.....	BW
Apr. 7	10:25 a.m.	1,740	12,200	8,760	.....	41	.....	60	.....	88	95	99	100	.....	.....	SPWCM
Apr. 16	6:15 a.m.	1,040	9,320	6,220	.....	57	.....	73	.....	84	94	98	100	.....	.....	SPWCM
Apr. 18	6:47 p.m.	745	8,000	8,890	15	16	18	.....	.....	91	95	99	.....	.....	.....	BN
Do	6:47 p.m.	745	8,000	4,690	47	61	76	84	87	90	92	97	.....	.....	.....	BW
Apr. 26	9:15 a.m.	1,060	16,300	4,540	.....	51	.....	71	.....	80	89	96	100	.....	.....	SPWCM
May 2	8:22 a.m.	1,040	11,900	6,720	42	52	63	74	84	89	96	99	100	.....	.....	SPWCM
Do	8:22 a.m.	1,040	11,900	11,300	.....	1	4	76	87	89	94	98	.....	.....	.....	BN
May 9	9:00 a.m.	1,590	18,300	3,270	.....	30	.....	42	.....	54	66	87	96	99	100	SPWCM
May 11	9:30 a.m.	2,020	33,200	7,710	.....	31	.....	46	.....	63	79	98	100	.....	.....	SPWCM
May 16	10:30 a.m.	1,120	23,200	7,080	.....	46	.....	65	.....	73	80	94	99	100	.....	SPWCM
May 18	8:20 a.m.	1,030	17,200	18,400	.....	8	10	84	94	95	96	99	.....	.....	.....	BN
Do	8:20 a.m.	1,030	17,200	3,350	51	67	77	86	90	92	95	97	.....	.....	.....	BWCM
June 1	6:52 p.m.	1,040	5,850	5,420	.....	6	15	49	56	71	81	96	.....	.....	.....	BN
Do	6:52 p.m.	1,040	5,850	3,470	33	40	46	52	61	75	88	96	.....	.....	.....	BWCM
June 8	5:45 p.m.	1,070	8,280	4,040	.....	33	.....	45	.....	69	86	97	100	.....	.....	SPWCM
June 15	9:00 a.m.	1,570	16,600	5,570	.....	37	.....	51	.....	85	94	97	98	98	98	SPWCM
June 26	5:45 p.m.	1,070	11,400	4,310	.....	24	.....	34	.....	54	68	78	89	97	100	SPWCM
July 2	5:15 p.m.	450	1,230	737	47	54	60	64	68	76	89	96	.....	.....	.....	BWCM
July 11	5:35 p.m.	513	15,400	11,800	.....	73	.....	93	.....	99	.....	.....	.....	.....	.....	SPWCM
July 12	5:40 a.m.	398	6,210	2,960	.....	66	.....	71	.....	84	.....	.....	.....	.....	.....	SPWCM
July 17	7:38 p.m.	288	2,560	2,010	71	.....	80	84	89	94	.....	.....	.....	.....	.....	SPWCM
Do	7:38 p.m.	288	2,560	2,430	.....	4	11	.....	.....	94	97	100	.....	.....	.....	BN
July 18	5:50 a.m.	270	3,520	2,450	.....	76	.....	88	.....	98	.....	.....	.....	.....	.....	SPWCM
July 21	5:35 a.m.	360	3,200	2,260	.....	71	.....	75	.....	87	.....	.....	.....	.....	.....	SPWCM
July 26	6:05 p.m.	192	3,230	2,220	.....	92	.....	95	.....	98	.....	.....	.....	.....	.....	SPWCM
Aug. 11	5:55 p.m.	294	22,800	4,640	.....	74	.....	91	.....	96	.....	.....	.....	.....	.....	SPWCM
Aug. 13	6:05 a.m.	294	23,400	8,410	.....	76	.....	97	.....	97	.....	.....	.....	.....	.....	SPWCM
Aug. 14	6:56 p.m.	106	12,000	12,600	3	3	.....	.....	93	99	.....	.....	.....	.....	.....	SPN
Do	6:56 p.m.	106	12,000	2,370	.....	92	97	98	99	100	.....	.....	.....	.....	.....	BWCM
Aug. 16	3:30 p.m.	282	16,200	6,580	.....	73	.....	93	.....	98	.....	.....	.....	.....	.....	SPWCM
Aug. 22	6:30 p.m.	63	4,910	3,960	.....	93	.....	96	.....	99	.....	.....	.....	.....	.....	SPWCM

a Mean daily discharge.

Table 26.—Particle-size analyses of suspended sediment, Middle Fork Powder River above Kaycee, Wyo.

[Methods of analyses: B, bottom withdrawal tube; W, in distilled water; S, sieve; P, pipette; N, in native waters; C, chemically dispersed; M, mechanically dispersed]

Date	Time	Water discharge (cfs)	Suspended sediment: Concentration of sample (ppm)	Concentration of suspension analyzed (ppm)	Percent finer than indicated size (mm): 0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.500	Methods of analysis
1949														
Nov. 30......	11:37 a.m.	48	269	796	22	32	50	78	96	98	99	100	......	BW
1950														
Apr. 6.......	9:25 p.m.	60	8,530	10,100	10	10	11	85	100	......	......	......	......	SPN
Do..........	9:25 p.m.	60	8,530	5,500	45	59	78	93	97	98	99	100	......	BWCM
Apr. 15......	7:30 a.m.	145	4,550	3,540	......	38	......	66	......	99	......	......	......	SPWCM
Apr. 18......	11:06 a.m.	165	3,540	7,100	......	22	......	40	......	91	99	100	......	SPWCM
May 6........	7:05 p.m.	92	11,800	9,610	......	65	......	90	......	100	......	......	......	SPWCM
May 9........	5:30 p.m.	103	19,700	15,800	......	55	......	82	......	99	100	......	......	SPWCM
May 15.......	11:45 a.m.	260	2,850	4,600	......	......	......	20	34	60	84	97	......	BWCM
May 16.......	3:24 p.m.	315	4,150	2,930	6	9	17	20	36	66	93	99	100	SPN
Do..........	3:24 p.m.	315	4,150	1,910	15	16	19	26	43	72	93	99	100	SPWCM
May 24.......	11:12 a.m.	467	2,310	4,040	......	18	......	34	......	70	88	98	100	SPWCM
Aug. 12......	1:20 p.m.	42	2,720	2,330	......	66	......	93	......	100	......	......	......	SPWCM

Table 27.—Particle-size analyses of suspended sediment, Middle Fork Powder River near Kaycee, Wyo.

[Methods of analyses: S, sieve; P, pipette; W, in distilled water; C, chemically dispersed; M, mechanically dispersed; N, in native waters]

Date	Time	Water discharge (cfs)	Suspended sediment: Concentration of sample (ppm)	Concentration of suspension analyzed (ppm)	Percent finer than indicated size (mm): 0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.500	1.000	Methods of analysis
1950															
Mar. 26......	5:00 p.m.	a 125	1,500	980	......	82	......	97	......	100	......	......	......	......	SPWCM
Apr. 6.......	8:00 a.m.	145	1,790	3,300	......	80	......	97	......	100	......	......	......	......	SPWCM
Apr. 15......	6:00 p.m.	316	5,320	2,310	......	48	......	83	......	100	......	......	......	......	SPWCM
May 17.......	2:25 p.m.	1,330	15,100	10,900	1	2	10	40	65	89	92	98	100	......	SPN
Do..........	2:25 p.m.	1,330	15,100	5,600	18	23	30	40	56	76	93	98	100	......	SPWCM
May 18.......	1:00 p.m.	1,540	12,400	8,130	......	21	......	48	......	73	93	98	100	......	SPWCM
May 24.......	3:25 p.m.	1,060	6,100	3,140	......	16	......	30	......	62	88	97	100	......	SPWCM
May 31.......	6:00 p.m.	342	1,190	306	......	13	......	33	......	50	......	......	......	......	SPWCM
June 9.......	7:00 a.m.	332	790	3,880	......	29	......	42	......	74	88	93	96	98	SPWCM
July 6.......	10:57 a.m.	58	517	1,180	......	40	......	83	......	97	......	......	......	......	SPWCM

a Mean daily discharge.

Table 28.—Particle-size analyses of suspended sediment, Crazy Woman Creek near Arvada, Wyo.

[Methods of analyses: B, bottom withdrawal tube; W, in distilled water; S, sieve; P, pipette; C, chemically dispersed; M, mechanically dispersed N, in native water]

Date	Time	Water discharge (cfs)	Suspended sediment: Concentration of sample (ppm)	Concentration of suspension analyzed (ppm)	Percent finer than indicated size (mm): 0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.500	Methods of analysis
1950														
Apr. 9......	3:36 p.m.	82	1,160	1,120	......	68	82	92	97	98	99	100	......	BW
Apr. 16......	8:20 a.m.	140	3,200	2,470	......	60	......	77	......	95	98	100	......	SPWCM
Apr. 17......	9:20 a.m.	192	7,620	5,820	......	41	......	70	......	96	99	100	......	SPWCM
Apr. 18......	8:07 a.m.	121	4,300	3,230	......	52	......	75	......	91	95	100	......	SPWCM
Apr. 20......	1[illegible]:18 a.m.	124	1,900	3,770	36	45	57	68	78	86	92	99	100	SPWCM
May 10......	3:16 p.m.	100	1,750	3,720	......	73	......	87	......	94	......	......	......	SPWCM
May 12......	4:10 p.m.	178	6,360	5,140	......	60	......	80	......	94	98	100	......	SPWCM
May 13......	4:00 p.m.	132	9,740	8,180	......	74	......	91	......	96	97	99	100	SPWCM
May 18......	4:17 p.m.	396	12,600	11,200	2	3	13	54	72	89	......	......	......	SPN
Do........	4:17 p.m.	396	12,600	4,480	......	32	40	53	68	81	92	97	......	BWCM
May 25......	10:42 a.m.	285	3,040	4,920	......	31	......	45	......	74	92	99	100	SPWCM
June 1......	5:20 p.m.	176	1,210	540	......	39	......	49	......	67	85	97	100	SPWCM
June 6......	4:28 p.m.	140	886	1,640	......	41	......	57	......	74	89	98	100	SPWCM
June 11......	8:25 a.m.	180	2,060	1,230	......	36	......	47	......	71	88	98	100	SPWCM
Aug. 12......	7:10 a.m.	18	15,400	6,630	......	74	......	97	......	100	......	......	......	SPWCM
Aug. 13......	7:30 a.m.	73	54,000	5,520	......	56	......	87	......	93	......	......	......	SPWCM
Do........	6:10 p.m.	15	12,400	5,480	......	74	......	93	......	99	......	......	......	SPWCM

Table 29.—Particle-size analyses of suspended sediment, Clear Creek near Arvada, Wyo.

[Methods of analyses: S, sieve; P, pipette; W, in distilled water; C, chemically dispersed; M, mechanically dispersed; B, bottom withdrawal tube]

Date	Time	Water discharge (cfs)	Suspended sediment: Concentration of sample (ppm)	Concentration of suspension analyzed (ppm)	Percent finer than indicated size (mm): 0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.500	1.000	Methods of analysis
1950															
May 18......	7:16 p.m.	444	895	2,490	......	50	......	76	......	95	97	99	100	......	SPWCM
May 25......	2:48 p.m.	740	855	2,240	......	34	......	54	......	81	90	97	99	100	SPWCM
June 8......	9:00 a.m.	1,210	2,670	1,660	......	34	......	47	......	71	80	92	99	100	SPWCM
June 13......	11:15 a.m.	904	959	2,150	......	23	......	42	......	76	91	97	100	......	SPWCM
Aug. 13......	1:30 p.m.	99	1,440	1,120	69	82	94	100	......	......	......	......	......	......	BWCM

Table 30.--Specific weight and median diameter of reservoir sediment

Source	Sample number	Specific weight (lb per cu ft)	Median diameter (mm)
Lake Clarmore, Rogers County, Okla. 1/..........	FC 39 CM-1	43	0.0017
	FC 39 CM-2	45	.0018
	FC 39 CM-3	40	.0019
	FC 39 CM-4	44	.0026
	FC 39 CM-5	51	.0054
	FC 39 CM-6	55	.0046
	FC 39 CM-7	54	.0066
	FC 39 CM-8	63	.0116
	FC 39 CM-9	51	.0038
	FC 39 CM-10	65	.0290
High Point Reservoir, High Point, N. C. 1/......	FC 38 HPR-6	59	.0215
	FC 38 HPR-9	62	.0338
	FC 38 HPR-10	68	.0016
	FC 38 HPR-13	41	.0032
	FC 38 HPR-14	60	.0105
	FC 38 HPR-16	44	.0130
	FC 38 HPR-18	64	.0012
	FC 38 HPR-21	45	.0163
	FC 38 HPR-22	37	.0055
	FC 38 HPR-23	40	.0008
Wills Point Reservoir, Wills Point, Tex. 1/.....	1	51	.0030
	2	53	.0026
	3	53	.0035
	4	59	.0027
	5	54	.0022
	6	86	.0120
	7	85	.0135
	8	45	.0012
	9	52	.0014
Grisham Lake, Washington County, Mo. 1/.........	FC 39 GR-1	53	.0096
	FC 39 GR-2	56	.0125
	FC 39 GR-3	117	.3330
Kirk Lake, Allen County, Kans. 1/...............	FC 39 KR-1	42	.0024
	FC 39 KR-2	55	.0054
Lancaster Reservoir, Lancaster, S. C. 1/........	FC 38 LA-1	54	.0020
	FC 38 LA-2	70	.0064
	FC 38 LA-3	70	.0166
	FC 38 LA-4	79	.0248
	FC 38 LA-5	68	.0117
	FC 38 LA-6	39	.0118
	FC 38 LA-7	62	.0163
	FC 38 LA-8	....	.6070
Mountain Lake, Wayne County, Mo. 1/.............	FC 39 MO-1	57	.0076
	FC 39 MO-2	41	.0244
	FC 39 MO-3	66	.0137
Moran Reservoir, Allen County, Kans. 1/.........	FC 39 MN-1	50	.0025
	FC 39 MN-2	38	.0020
	FC 39 MN-3	52	.0046
	FC 39 MN-4	62	.0177
	FC 39 MN-5	49	.0061
	FC 39 MN-6	43	.0023
Neosha County State Lake, Kans. 1/..............	FC 39 NE-1	37	.0015
	FC 39 NE-2	30	.0021
	FC 39 NE-3	36	.0055
	FC 39 NE-4	38	.0044
	FC 39 NE-5	45	.0130
Shepherd Mountain Lake, Iron County, Mo. 1/.....	FC 39 SH-1	43	.0109
	FC 39 SH-3	85	.4900

See footnotes at end of table, p. 85.

Table 30.--Specific weight and median diameter of reservoir sediment--Continued

Source	Sample number	Specific weight (lb per cu ft)	Median diameter (mm)
Lake Lee, Monroe, N. C. 1/	FC 38 LE-1	62	0.0032
	FC 38 LE-2	60	.0030
	FC 38 LE-3	59	.0040
	FC 38 LE-4	59	.0060
	FC 38 LE-5	60	.0048
	FC 38 LE-6	61	.0052
	FC 38 LE-7	66	.0052
	FC 38 LE-8	73	.0084
Lake Marinuka, Galesville, Wis. 1/	FC 39 MA-1	40	.0024
	FC 39 MA-2	52	.0022
	FC 39 MA-3	56	.0046
	FC 39 MA-4	55	.0052
	FC 39 MA-5	60	.0076
	FC 39 MA-6	70	.0070
	FC 39 MA-7	63	.0077
	FC 39 MA-8	60	.0099
	FC 39 MA-9	66	.0126
	FC 39 MA-10	80	.0274
	FC 39 MA-11	77	.0136
	FC 39 MA-12	69	.0175
	FC 39 MA-13	85	.0290
	FC 39 MA-14	87	.0220
Arrowrock Reservoir, Idaho 2/	1	53.9	.0260
	2	87.9	.1580
	3	60.4	.1050
	4	44.2	.0046
	5	102.2	.3580
	6	64.2	.1700
	7	52.7	.0071
	8	61.5	.0176
	10	47.7	.0310
	11	57.9	.0234
	12	52.3	.0208
	13	58.8	.0445
	14	57.3	.0265
	15	48.3	.0275
	16	112.5	.8800
	18	52.1	.0114
Guernsey Reservoir, Guernsey, Wyo. 2/	1	30.7	.0020
	2	32.4	.0092
	3	...	...
	4	43.1	.0028
	5	...	...
	6	41.7	.0064
	7	50.1	.0046
	8	56.5	.0067
	9	54.6	.0022
	10	76.5	.0111
	11	125.4	.8950
Tongue River Reservoir, Sheridan, Wyo. 2/	1	72	.0260
	2	78	.0240
	3	81	.0240
	7	43	.0030
	8	44	.0017
	9	65	.0130
	10	74	.0140
	11	83	.0220
	12	37	.0028
	12A	42	.0018
	13	55	.0056
	14	63	.0130

See footnotes at end of table, p. 85.

Table 30.--Specific weight and median diameter of reservoir sediment--Continued

Source	Sample number	Specific weight (lb per cu ft)	Median diameter (mm)
Tongue River Reservoir, Sheridan, Wyo. 2/--Con..	15	64	0.0096
	16	79	.0500
	17	70	.0160
	18	92	.0860
	19	90	.0220
Altus Reservoir, Altus, Okla. 2/................	1	26.7	.0054
	8	53.6	.0220
	4	36.5	.0150
	11	91.6	.1500
	A1	106.6	.1350
	A3	45.8	.0058
	A6	65.4	.0620
	12	80.8	.0350
	10	54.3	.0036
	A4	57.9	.0260
	A2	32.8	.0071
	A10	39.6	.0038
	3	43.1	.0038
	A8	49.3	.0036
Salt Creek Reservoir south of Midwest, Wyo......	66	74.7	.0535
	67	75.8	.0500
	68	79.1	.0470
	69	73.2	.0425
	70	79.8	.0415
Snodgrass Ranch Reservoir, Wyo., SE¼ sec. 22, T. 40 N., R. 81 W............................	16	46.7	.0034
	17	52.0	.0043
	18	45.9	.0041
	19	46.5	.0043
	20	38.4	.0033
Snodgrass Ranch Reservoir, Wyo., (upper end) NE¼ sec. 20, T. 40 N., R. 81 W...............	21	50.6	.0024
	22	49.0	.0026
	23	46.7	.0027
	24	38.3	.0029
	25	28.1	.0030
Snodgrass Ranch Reservoir, Wyo., SW¼ sec. 8, T. 39 N., R. 81 W............................	26	60.5	.0063
	27	58.5	.0090
	28	62.8	.0100
	29	64.1	.0160
	30	67.7	.0152
Darlington Reservoir, Wyo., sec. 13, T. 43 N., R. 67 W.:			
upper end..................................	3297	71.6	.0210
lower end..................................	3298	58.3	.0087
Darlington Reservoir, sec. 36, T. 45 N., R. 67 W.:			
upper end..................................	3299	65.7	.0028
lower end..................................	3300	53.0	.0026
East Slagle Reservoir, near Lance Creek, Wyo.:			
upper end..................................	3287	63.1	.0163
lower end..................................	3288	60.4	.0168

1/ Collected by Soil Conservation Service.
2/ Collected by U. S. Bureau of Reclamation.

Table 31.--Particle-size analyses of sediments deposited in reservoirs, Powder River drainage basin

[Methods of analysis: S, sieve; P, pipette; C, chemically dispersed]

Date	Specific weight (lb per cu ft)	Deposited sediment: Percent finer than indicated size (mm) 0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.500	Methods of analysis	Remarks
Sept. 1949..	74.7	24	28	33	39	57	93	100	......	SPC	Salt Creek Reservoir north of Midwest, Wyo.
Do......	75.8	28	31	36	42	59	94	100	......	SPC	Do.
Do......	79.1	26	31	37	42	58	91	99	100	SPC	Do.
Do......	73.2	27	31	36	43	63	95	100	......	SPC	Do.
Do......	79.8	27	32	38	45	61	92	99	100	SPC	Do.
Do......	46.7	53	68	80	90	97	99	100	......	SPC	Snodgrass Ranch Reservoir, Wyo., SE¼ sec. 22, T. 40 N., R. 81 W.
Do......	52.0	48	61	74	85	96	100	......	......	SPC	Do.
Do......	45.9	50	65	78	88	96	100	......	......	SPC	Do.
Do......	46.5	49	64	77	86	93	100	......	......	SPC	Do.
Do......	38.4	55	72	86	94	97	100	......	......	SPC	Do.
Do......	50.6	70	76	88	94	98	100	......	......	SPC	Snodgrass Ranch Reservoir, Wyo., NE¼ sec. 20, T. 40 N., R. 81 W.
Do......	49.0	60	77	89	96	97	99	100	......	SPC	Do.
Do......	46.7	59	74	84	90	96	98	100	......	SPC	Do.
Do......	38.3	58	74	86	94	97	100	......	......	SPC	Do.
Do......	28.1	58	74	86	94	98	100	......	......	SPC	Do.
Do......	60.5	43	54	63	73	89	100	......	......	SPC	Snodgrass Ranch Reservoir, Wyo., SW¼ sec. 8, T. 39 N., R. 81 W.
Do......	58.5	38	48	59	71	89	100	......	......	SPC	Do.
Do......	62.8	32	45	59	73	92	100	......	......	SPC	Do.
Do......	64.1	25	38	50	64	88	100	......	......	SPC	Do.
Do......	67.7	26	38	51	64	88	100	......	......	SPC	Do.

Table 32.--Particle-size analyses of stream-bed material, Powder River drainage basin

[Methods of analysis: S, sieve; P, pipette; C, chemically dispersed]

Date	Specific weight (lb per cu ft)	Deposited sediment: Percent finer than indicated size (mm) 0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.500	1.000	2.000	4.000	Methods of analysis	Remarks
1949														
Aug. 6...	92.6	......	......	......	......	11	33	45	71	93	99	100	S	South Fork Powder River near Kaycee, Wyo.
Do.....	90.9	......	......	......	......	4	9	23	53	72	83	93	S	Do.
Do.....	91.5	......	......	......	......	8	15	22	48	76	86	91	S	Do.
Do.....	88.5	......	......	......	......	3	8	35	71	84	90	95	S	Do.
Do.....	94.3	......	......	......	......	0	2	6	15	63	75	86	S	Do.
Do.....	83.6	5	5	7	11	29	48	54	76	94	100	......	SPC	Do.
Do.....	81.9	7	8	10	15	33	91	100	......	......	......	......	SPC	Middle Fork Powder River near Kaycee, Wyo.
Do.....	76.3	7	7	10	19	39	90	99	100	......	......	......	SPC	Do.
Do.....	83.7	7	7	10	14	34	91	100	......	......	......	......	SPC	Do.

Do.....	68.7	8	9	13	20	38	90	100	......	......	......	......	SPC	Do.
Do.....	82.8	7	8	12	20	31	47	100	......	......	......	......	SPC	Do.
Aug. 8...	93.9	......	......	......	......	2	9	90	100	......	......	......	S	Salt Creek near Sussex, Wyo.
Do.....	87.1	......	......	......	......	2	8	88	100	......	......	......	S	Do.
Do.....	86.7	......	......	......	......	3	14	87	99	99	100	......	S	Do.
Do.....	74.9	......	......	......	......	2	15	94	100	......	......	......	S	Do.
Do.....	88.6	......	......	......	......	2	16	94	100	......	......	......	S	Do.
Aug. 24..	82.6	......	......	......	......	1	6	52	89	96	98	100	S	Crazy Woman Creek near Arvada, Wyo.
Do.....	94.4	......	......	......	......	2	2	6	56	91	97	99	S	Do.
Do.....	90.7	......	......	......	......	2	2	6	57	90	96	98	S	Do.
Do.....	89.4	......	......	......	......	1	2	5	52	92	98	100	S	Do.
Do.....	81.3	......	......	......	......	1	2	7	62	95	99	100	S	Do.
Aug. 8...	86.8	......	......	......	......	2	7	40	90	99	100	......	S	Powder River at Sussex, Wyo.
Do.....	86.7	......	......	......	......	3	14	50	94	99	100	......	S	Do.
Do.....	91.7	......	......	......	......	6	22	68	97	100	......	......	S	Do.
Do.....	84.5	......	......	......	......	3	16	43	92	99	100	......	S	Do.
Do.....	86.5	......	......	......	......	2	15	45	93	99	100	......	S	Do.
Aug. 24..	73.1	......	......	......	......	7	21	53	95	100	......	......	S	Powder River at Arvada, Wyo.
Do.....	70.8	......	......	......	......	9	21	55	94	99	100	......	S	Do.
Do.....	85.9	......	......	......	......	3	17	73	98	100	......	......	S	Do.
Do.....	90.6	......	......	......	......	3	17	77	97	99	100	......	S	Do.
Do.....	82.3	......	......	......	......	1	5	55	95	99	100	......	S	Do.
Aug. 26..	92.3	......	......	......	......	1	4	36	74	92	94	96	S	Powder River near confluence with Clear Creek.
Do.....	84.2	......	......	......	......	1	5	34	73	94	97	98	S	Do.
Do.....	92.8	......	......	......	......	1	17	65	92	99	100	......	S	Do.
Do.....	96.0	......	......	......	......	0	5	30	72	94	98	99	S	Do.
Do.....	73.4	16	20	24	27	42	72	93	100	......	......	......	SPC	Do.
Do.....	77.1	15	18	21	24	40	69	92	99	100	......	......	SPC	Do.
Aug. 28..	80.8	16	23	39	60	82	99	100	......	......	......	......	SPC	Powder River near Moorhead, Mont.
Do.....	90.1	8	11	16	23	37	61	98	100	......	......	......	SPC	Do.
Do.....	73.8	24	29	34	43	60	94	100	......	......	......	......	SPC	Do.
Do.....	78.1	20	25	32	40	54	82	97	100	......	......	......	SPC	Do.
Do.....	65.8	28	37	53	72	86	98	100	......	......	......	......	SPC	Do.
Do.....	90.3	......	......	......	......	2	16	64	94	99	100	......	S	Powder River near Mizpah, Mont.
Do.....	93.6	......	......	......	......	2	15	63	86	98	99	100	S	Do.
Do.....	92.5	......	......	......	......	2	12	54	88	97	99	99	S	Do.
Do.....	96.3	......	......	......	......	1	9	46	73	88	92	93	S	Do.
Do.....	91.1	......	......	......	......	1	12	62	90	98	99	100	S	Do.
Aug. 30..	95.2	......	......	......	......	3	15	62	78	87	93	95	S	Powder River near Powderville, Mont.
Do.....	91.0	......	......	......	......	4	27	65	80	94	97	99	S	Do.
Do.....	103.9	......	......	......	......	4	23	49	61	81	92	97	S	Do.
Do.....	97.2	......	......	......	......	4	22	51	66	84	93	98	S	Do.
Do.....	105.6	......	......	......	......	2	17	40	57	81	92	95	S	Do.

Table 33.—Analyses of water in the Powder River drainage basin in Wyoming and Montana

[Analytical results in parts per million except as indicated]

Date of collection	Daily mean discharge (cfs)	pH	Specific conductance (micromhos/cm at 25 C)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$		Percent sodium
																	Total	Noncarbonate	
Powder River at Sussex, Wyo.																			
Nov. 30, 1949	....	7.8	1,500	14	0.04	127	60	152		240	548	87	0.6	3.9	....	1,110	564	367	37
Jan. 6, 1950	....	7.7	2,030	16	.06	191	66	213		288	758	127	.6	5.5	....	1,520	748	512	38
Jan. 31	....	7.5	1,830	22	....	282	63	48		304	643	102	.6	2.8	0.30	1,310	963	714	10
Mar. 3	115	7.8	1,740	23	.02	154	53	184		218	645	103	.8	5.2	....	1,280	602	423	40
Apr. 6	301	7.7	1,990	23	.10	144	49	241		216	750	84	.6	10	.25	1,410	561	384	48
May 6	608	7.6	2,600	13	.10	160	47	373		196	1,100	67	.6	1.2	.20	1,860	593	432	58
June 7	282	7.4	790	14	.02	80	24	68		161	255	33	.4	2.1	.10	572	298	166	33
July 6	109	7.2	3,510	15	.06	259	87	490		219	1,640	118	.8	3.6	....	2,720	1,000	820	51
Aug. 2	11	7.8	3,030	12	.04	248	88	342		226	1,190	210	.9	.8	.26	2,200	980	795	43
Sept. 8	24	7.7	3,660	11	.04	321	109	467		238	1,540	327	1.1	.8	.30	2,890	1,250	1,060	45
Powder River at Arvada, Wyo.																			
May 3, 1946	500	7.7	704	......	0.05	94	24	37		206	203	21	0.3	4.0	....	509	333	164	19
June 1	530	8.2	1,000	......	.05	111	34	85		190	385	30	.4	3.0	....	789	417	261	31
July 20	184	8.2	1,770	......	.05	239	55	155		181	922	35	.8	1.0	....	1,590	822	674	29
Sept. 9	230	7.8	1,830	......	.05	341	68	84		186	1,080	21	.7	.6	....	1,690	1,130	977	14
Oct. 2	90	8.2	1,520	......	.10	165	58	153		a 208	676	75	.8	1.0	....	1,230	650	479	34
Apr. 4, 1947	261	8.2	1,610	12	.10	149	47	168		184	682	46	.4	4.0	.19	1,200	565	414	39
May 1	814	8.2	1,580	17	.05	153	51	193		b 196	756	42	.4	4.4	.29	1,310	591	430	42
June 4	1,040	8.1	1,080	14	.08	106	30	120		154	462	26	.5	4.0	.28	818	388	262	40
June 29	494	8.2	1,150	14	.10	99	30	127		143	477	21	.8	4.0	.20	872	370	253	43
Aug. 20	1.5	8.4	2,500	14	.04	253	101	288		c 213	1,240	146	.4	.6	.33	2,150	1,050	870	37
July 14, 1948	2,110	6.6	1,860	19	.50	271	64	111		236	916	23	.5	.3	....	1,520	939	745	20
Nov. 3	121	8.0	1,620	9.0	.02	157	55	162		220	666	66	.7	2.6	.12	1,230	618	438	36
Nov. 30	120	7.9	2,070	12	.05	209	85	214		311	924	82	.6	2.9	.28	1,680	871	616	35
Mar. 3, 1949	1,500	7.3	1,360	9.8	.04	122	35	125		124	552	29	.4	3.0	.09	938	448	346	38
Apr. 12	342	7.5	2,300	14	.02	175	68	298		207	1,060	61	.8	3.7	....	1,780	716	546	48
June 1	324	7.5	1,370	13	.02	123	34	147		179	532	43	.7	3.2	....	985	447	300	42
July 6	214	7.3	1,820	15	.02	201	57	162		210	800	57	.5	1.3	....	1,400	736	564	32
Dec. 7	30	8.0	2,290	17	.04	214	92	239		312	975	111	.6	5.1	.30	1,810	913	657	36
Jan. 3, 1950	22	7.9	2,650	25	....	168	108	362		416	1,080	127	.6	6.3	....	2,080	863	522	48
Feb. 7	45	7.6	2,680	24	.02	235	64	367		312	1,160	124	.6	7.8	....	2,140	850	594	48
Mar. 2	90	7.8	1,560	20	.02	130	45	172		180	603	73	.4	4.7	.05	1,140	510	362	42
Apr. 6	258	7.7	1,830	19	.04	159	54	174		220	675	77	.6	4.5	.30	1,270	619	439	38
May 15	482	7.6	2,110	18	.10	182	53	262		166	1,010	37	.6	1.4	....	1,650	672	536	46
June 6	402	7.7	1,020	14	.04	95	28	90		160	355	31	.6	3.5	....	736	352	221	36
July 5	128	7.3	1,550	11	.04	173	52	147		150	760	34	.5	3.2	....	1,260	646	523	33
Aug. 3	6.0	7.6	2,320	12	.02	217	112	209		244	1,170	24	.3	1.2	.35	1,870	1,000	800	31
Sept. 28	21	7.2	2,690	14	.02	244	90	313		206	1,330	71	.8	2.8	....	2,170	978	809	41

Powder River near Locate, Mont.

Nov. 14, 1945...	125	8.0	1,760	8.4	0.07	162	65	178 5.2	302	717	42	0.3	3.2	0.04	1,410	672	424	37
Aug. 31, 1948...	58	7.6	1,910	14	.02	179	60	204	244	860	28	.6	.8	.18	1,470	693	493	39
Oct. 27.........	258	7.9	1,960	18	.04	176	62	245	238	924	48	.5	1.5	....	1,590	694	499	43
Dec. 21.........	80	8.0	2,220	18	.06	214	95	187	374	904	56	.5	3.9	.19	1,670	924	617	31
Feb. 27, 1949...	80	7.5	1,630	16	.02	151	62	134	304	580	46	.4	3.8	.00	1,150	632	383	32
Mar. 7..........	11,100	7.7	640	9.0	.02	56	16	55	147	182	7.0	.5	3.9	.17	433	206	85	37
Apr. 26.........	592	7.8	1,870	13	.02	146	63	199	238	776	35	.4	2.6	....	1,350	624	429	41
May 24..........	1,460	7.5	944	14	.02	88	26	76	168	312	18	.4	2.3	....	685	327	189	34
June 27.........	673	7.6	810	14	.02	72	18	75	130	276	14	.5	2.2	....	583	254	147	39
July 18.........	286	7.6	2,520	17	.02	219	75	272	236	1,130	52	.6	.6	....	1,880	855	661	41
Dec. 5..........	220	7.7	1,900	13	....	168	75	183	300	775	47	.4	4.8	....	1,410	728	482	35
Feb. 8, 1950....	.1	6.9	3,700	38	.02	322	145	512	685	1,710	116	.6	7.0	....	3,190	1,400	838	44
Mar. 3..........	50	7.5	949	12	.10	80	28	100	156	357	21	.2	2.9	....	730	315	187	41
Apr. 6..........	1,630	7.7	891	21	.10	69	23	96	170	305	12	.4	1.3	.20	678	267	128	44
May 2...........	1,000	7.7	1,120	14	.20	72	25	147	204	388	20	.6	1.4	....	834	283	116	53
May 9...........	1,510	7.7	1,610	14	.10	116	41	214	208	680	28	.5	4.0	....	1,200	458	287	50
June 6..........	870	8.0	856	16	.04	75	24	80	156	295	15	.6	1.5	....	600	286	158	38
June 26.........	1,030	7.6	767	13	.04	68	21	72	140	265	15	.2	1.4	.20	552	256	141	38
July 5..........	258	7.6	1,220	17	.04	103	30	147	199	485	22	.5	.7	....	948	381	218	46
July 17.........	288	7.5	1,430	12	.02	113	40	149	208	540	24	.3	3.6	.20	984	446	275	42
Aug. 2..........	87	7.6	1,930	17	.02	155	62	213	234	835	28	.4	1.0	.30	1,430	640	448	42
Sept. 4.........	10	7.5	2,220	18	.02	155	63	307	271	1,000	35	.5	.7	.30	1,710	647	425	51

Middle Fork Powder River near Kaycee, Wyo.

May 4, 1946.....	464	8.1	506	......	0.10	63	12	33	144	134	13	0.1	3.0	....	362	207	89	26
June 2..........	354	8.1	505	......	.10	64	10	50	182	131	16	.1	1.5	....	396	201	52	35
July 19.........	49	8.4	1,010	......	.10	111	27	106	d 248	355	30	.3	1.5	....	759	388	185	37
Sept. 10........	92	8.1	1,230	......	.10	160	29	94	232	494	46	.4	2.0	....	985	518	328	28
Oct. 31.........	118	8.3	1,130	......	.05	110	37	116	a 242	409	38	.3	1.5	....	870	427	228	37
Mar. 30, 1947...	169	8.0	972	19	.05	115	39	72	207	368	34	.5	2.3	.28	790	447	277	26
May 16..........	730	8.4	502	14	.05	70	19	21	a 157	144	13	.4	.4	.18	398	253	124	15
June 27.........	384	8.2	506	15	.05	62	22	24	155	140	16	.4	.6	.24	368	245	118	17
July 15.........	98	8.4	737	11	.04	77	34	51	b 185	228	36	.4	1.4	.18	548	332	180	25
Aug. 12.........	29	7.9	928	12	.05	104	41	72	215	311	59	.4	.1	.21	760	428	252	27
Mar. 2, 1949....	330	7.7	1,060	13	.04	91	33	87	158	360	31	.3	2.7	.09	751	362	232	34
May 31..........	246	7.7	707	13	.02	74	23	35	164	178	23	.3	1.8	....	491	279	145	21
July 8..........	16	8.1	1,250	13	.02	108	42	110	226	390	62	.4	.7	....	922	442	257	35
Aug. 2..........	.2	7.7	1,630	15	.05	130	49	189	231	520	144	.4	2.6	....	1,160	526	337	44
Sept. 20........	39	7.8	891	11	.02	103	35	49	146	353	13	.2	1.5	.30	682	401	281	21
Nov. 30.........	100	7.8	1,200	12	.04	120	51	92	244	408	58	.4	1.9	....	920	509	309	28
Jan. 6, 1950....	100	7.8	1,530	39	....	144	58	103	280	468	72	.5	4.0	....	1,030	598	368	27
Jan. 31.........	100	7.8	1,370	14	....	138	51	102	280	437	62	.4	4.3	....	947	554	324	29
Mar. 3..........	110	7.9	1,260	26	.02	136	44	96	244	433	54	.4	2.2	.10	974	521	321	29
Apr. 6..........	145	7.6	1,380	14	.02	120	43	131	222	483	51	.6	2.9	....	955	477	295	37
May 6...........	356	7.6	1,330	18	.04	108	37	133	186	493	28	.6	4.1	....	914	422	269	41
June 7..........	339	7.8	600	14	.10	60	20	40	154	154	21	.2	1.7	....	404	232	106	27
July 6..........	38	7.6	1,260	11	.10	110	44	128	221	471	43	.3	.8	....	982	456	275	38
Aug. 2..........	2.5	7.9	1,570	5.8	.06	134	54	141	219	555	73	.3	.4	.35	1,070	556	376	35

See footnotes at end of table, p. 90.

Table 33.—Analyses of water in the Powder River drainage basin in Wyoming and Montana—Continued

[Analytical results in parts per million except as indicated]

Date of collection	Daily mean discharge (cfs)	pH	Specific conductance (micromhos/cm at 25 C)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$		Percent sodium
																	Total	Noncarbonate	
Middle Fork Powder River near Kaycee, Wyo.—Continued																			
Sept. 8, 1950...	1.7	7.7	1,830	10	0.02	149	57	200		210	658	130	0.4	0.1	....	1,310	606	434	42
Crazy Woman Creek near Arvada, Wyo.																			
Dec. 7, 1949....	....	7.8	2,290	14	0.02	224	120	171		330	1,080	19	0.4	2.2	0.40	1,790	1,050	779	26
Mar. 2, 1950....	13	7.8	1,490	28	.02	148	75	105		244	663	10	.2	3.0	.05	1,150	678	478	25
June 6..........	137	7.8	842	15	.10	76	32	63		148	313	5.0	.4	2.0	.20	638	321	200	30
July 5..........	57	7.4	1,080	11	.20	97	47	83		171	445	7.7	.1	1.3	....	848	436	296	29
Sept. 28........	12	7.9	1,810	7.0	.04	162	92	147		216	870	13	.3	.8	.33	1,400	782	605	29
Clear Creek near Buffalo, Wyo.																			
Dec. 7, 1949....	5.0	7.5	130	17	.04	16	3.4	10		72	13	1.0	.2	1.6	.15	94	54	0	29
Mar. 3, 1950....	2.3	7.4	113	22	.02	11	1.9	12		62	3.0	4.0	.1	2.0	.00	88	36	0	42
June 6..........	332	6.6	42.0	11	.04	6.0	.8	3.7		20	7.0	1.0	.2	.8	.30	38	19	3	30
Sept. 8.........	7.8	7.0	87.9	15	.02	9.5	1.8	5.5		45	5.0	.5	.1	.2	.20	68	31	0	28
Clear Creek near Arvada, Wyo.																			
Dec. 7, 1949....	86	8.0	1,380	12	....	135	62	113		308	553	2.6	.3	6.3	.20	1,040	592	339	29
Mar. 2, 1950....	64	7.4	916	6.4	.02	83	44	66		208	335	5.0	.1	5.5	....	722	388	217	27
June 6..........	417	7.8	494	14	.04	46	19	29		120	147	1.0	.2	1.8	.20	336	193	95	24
July 5..........	303	7.3	545	8.6	.02	46	23	32		119	170	1.0	.1	2.3	.10	366	208	110	25
Sept. 6.........	3.9	7.5	1,820	7.4	.02	157	88	171		282	845	7.0	.4	5.7	.30	1,420	754	523	33

a Includes equivalent of 6 ppm of carbonate (CO_3).
b Includes equivalent of 5 ppm of carbonate (CO_3).
c Includes equivalent of 10 ppm of carbonate (CO_3).
d Includes equivalent of 14 ppm of carbonate (CO_3).

Table 34.—Powder River drainage basin salinity study, Sept. 10 to 14, 1949

[Analytical results in parts per million except as indicated]

Source	Daily mean discharge (cfs)	pH	Specific conductance (micromhos/cm at 25 C)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na) + potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$		Percent sodium
															Total	Noncarbonate	
South Fork Powder River near Kaycee, Wyo.	......	7.4	2,640	15	0.06	228	55	329	158	1,020	218	1.8	7.2	1,950	795	665	47
Powder River at Sussex, Wyo.	......	7.5	2,460	10	.06	228	77	256	198	960	195	1.0	2.0	1,830	886	724	39
Powder River at Arvada, Wyo.	2.0	7.6	3,100	4.4	.02	236	99	369	182	1,360	162	1.2	2.6	2,330	996	847	45
Powder River at Moorhead, Mont.	54	7.7	1,580	5.2	.02	126	84	115	262	656	6.4	.8	3.3	1,130	660	445	28
Powder River near Broadus, Mont.	......	7.7	1,630	7.2	.02	124	80	147	244	712	10	.8	2.0	1,210	639	439	33
Powder River near Locate, Mont.	44	7.4	2,010	10	.02	138	79	220	244	880	20	1.2	1.4	1,470	670	470	42
Powder River at mouth, Mont.	......	7.5	2,140	9.6	.02	154	71	261	240	968	25	1.2	1.4	1,610	677	480	46
Middle Fork Powder River near Barnum, Wyo.	......	8.5	293	10	.16	32	17	1.8	a 172	5.6	4.0	.1	.7	158	150	9	3
Middle Fork Powder River above Kaycee, Wyo.	40	7.9	1,030	10	.10	121	40	55	204	384	13	.2	1.3	754	467	300	21
Middle Fork Powder River at Kaycee, Wyo.	......	7.7	1,450	11	.06	128	53	127	206	504	84	.4	.0	1,010	538	369	34
Middle Fork Powder River near Kaycee, Wyo.	12	7.7	1,520	8.0	.04	135	53	148	222	560	79	.4	.0	1,090	555	373	37
Beaver Creek near Barnum, Wyo.	......	8.0	1,160	17	.12	125	59	58	236	460	3.5	.2	4.1	898	555	361	19
Red Fork near Barnum, Wyo.	......	8.2	643	9.8	.12	59	29	35	b 228	114	25	.2	.8	394	267	80	22
North Fork Powder River near Mayoworth, Wyo.	18	8.2	909	15	.10	83	40	63	c 264	288	1.5	.2	.3	638	372	156	27
North Fork Powder River near Kaycee, Wyo.	......	7.4	2,080	11	.04	156	86	253	282	984	26	.4	.5	1,660	743	512	43
Salt Creek near Sussex, Wyo.	......	7.8	4,410	7.6	.10	258	113	792	292	2,280	152	1.0	.0	3,750	1,110	871	61
North Fork Crazy Woman Creek above Billy Creek near Buffalo, Wyo.	9.8	7.7	252	15	.14	26	8.9	12	102	40	1.0	.2	.9	158	102	18	20
North Fork Crazy Woman Creek below Middle Fork near Buffalo, Wyo.	......	7.9	1,130	13	.14	95	56	67	222	406	4.5	.2	1.9	822	468	286	24
Crazy Woman Creek near Buffalo, Wyo.	......	7.9	1,770	6.8	.04	152	100	140	216	860	14	.6	.2	1,380	791	614	28
Middle Fork Crazy Woman Creek at Greub, Wyo.	10	8.1	492	16	.10	63	19	9.0	170	108	1.0	.2	.7	318	235	96	8
Poison Creek near Greub, Wyo.	......	7.8	3,710	15	.16	466	143	334	256	2,140	25	.6	.7	3,250	1,750	1,540	29
South Fork Crazy Woman Creek near Greub, Wyo.	......	8.1	1,220	14	.12	98	60	105	294	452	3.5	.2	1.6	906	491	250	32
Clear Creek near Buffalo, Wyo.	20	7.4	66.0	12	.06	10	1.0	.5	32	3.2	.4	.0	.2	46	29	3	3
Clear Creek near Arvada, Wyo.	62	7.8	1,620	6.2	.02	132	89	112	234	704	5.0	.8	7.2	1,170	696	504	26
Piney Creek at Kearney, Wyo.	14	7.6	200	11	.02	28	7.0	.9	104	14	1.2	.0	.2	126	99	14	2
Lake De Smet, Wyo.	......	8.0	1,020	10	.10	53	44	113	200	368	7.8	.2	1.8	816	314	150	44

See footnotes at end of table, p. 92.

Table 34.—Powder River drainage basin salinity study, Sept. 10 to 14, 1949—Continued

[Analytical results in parts per million except as indicated]

Source	Daily mean discharge (cfs)	pH	Specific conductance (micromhos/cm at 25 C)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na) + potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$		Percent sodium
															Total	Noncarbonate	
Little Powder River near Broadus, Mont.	2.4	7.4	2,690	6.2	0.02	137	77	408	329	1,210	9.6	1.0	2.0	2,020	659	389	57
Yellowstone River above confluence with Powder River, Mont.	......	7.5	867	12	.02	66	26	80	196	252	11	1.4	4.0	610	272	111	39
Yellowstone River at Terry, Mont.	......	7.5	853	14	.02	67	28	77	200	256	10	.8	3.4	616	282	118	37

a Includes equivalent of 12 ppm of carbonate (CO_3).
b Includes equivalent of 8 ppm of carbonate (CO_3).
c Includes equivalent of 6 ppm of carbonate (CO_3).