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Geological Survey

Water Resources Division

Progress Report

on the

Investigations of Fluvial Sediments and Water Quality

Bighorn Drainage Basin, Wyoming and Montana

Compiled as part of program of
Interior Department for development of
Missouri River Basin

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ABSTRACT

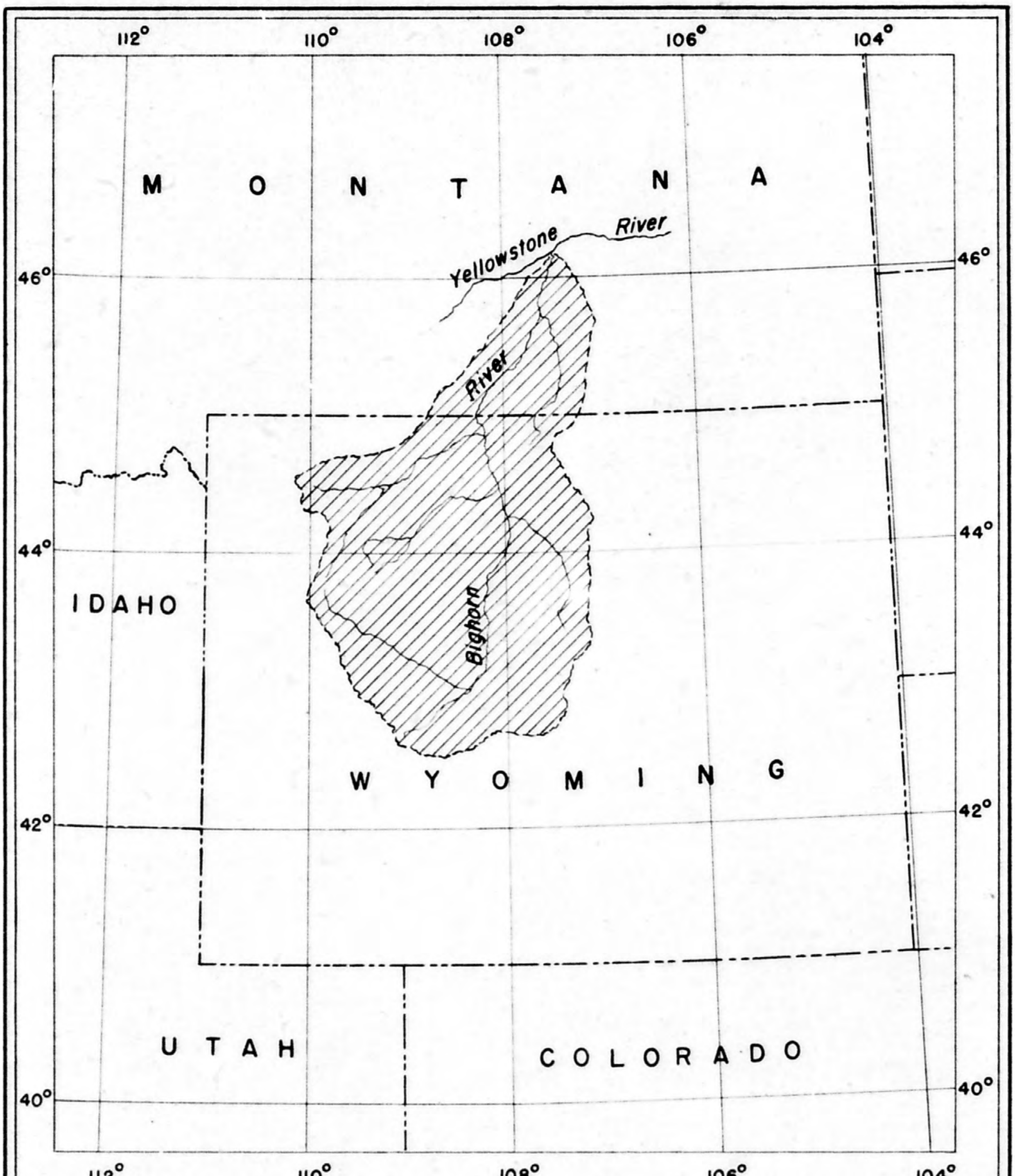
This report gives the results of progress to date in the investigations of fluvial sediments and water quality in the Bighorn River Basin, Wyoming and Montana. It comprises in part a discussion of the related surficial geology, an outline of the physiographic history of the area, results of quantitive measurements at selected locations of suspended sediments transported by the Bighorn River, and information regarding the water quality at these and other locations.

The rate of erosion in the irrigated areas (550 sq. mi. or 2.4 percent of the drainage area) is excessive and above the geologic norm. In some intermittent streams which are now fed by return irrigation waters and occasional cloudbursts, trenched channels have been formed as a result of erosion. Gullying has occurred wherever artificial drains enter the parent stream and is evident in other parts of the drainage basin. In the non-irrigated areas (22,450 sq. mil. or 97.6 percent of the drainage area) the rate of erosion is probably slightly above the geologic norm owing to other cultural activities. With respect to quantities, sediment contributions are made by the three geographic areas in the following order: Bighorn Basin, Wind River Basin and Bighorn Valley.

The composition and properties of the Bighorn River water vary considerably from head to mouth. Return flows from irrigated tracts contain high concentrations of salts which enter the river and cause progressive increase in the alkali and sulfate content of the water downstream. However present concentrations of dissolved solids and

results for percent sodium are not serious in the critical evaluation of the Bighorn River as an irrigation water assuming the soil is suitable and good irrigation and drainage practices are followed.

PLATE I



INDEX MAP
SHOWING LOCATION OF BIGHORN RIVER DRAINAGE BASIN

Scale in miles
50 0 50 100 150 200

INTRODUCTION

The purpose of this report is to summarize progress made to date in the hydrologic study of the Bighorn River Drainage Basin, Wyoming and Montana, with respect to fluvial sediments and mineral character of the waters. The information made available is for use in connection with the operation programs of federal, state, municipal, and private agencies engaged in development of the Missouri River Basin. The report covers the period from April 1946 to September 1948.

The investigation in the Bighorn River Drainage Basin is 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 is under the immediate supervision of Paul C. Benedict, District Engineer, Lincoln, Nebraska.

Measurements of suspended sediment transported by the streams is directly supervised by T. F.Hanly of the Worland Wyoming Office assisted by S. G. Heidel, K. H. Kroll and A. R. Robinson.

The geologic and physiographic studies of land forms and stream channels were made by C. H. Hembree and M. C. Boyer assisted by J. A. Adams who reviewed the literature on soils of the region.

Field surveys of the erosional characteristics of the Bighorn River Drainage Basin uplands were made by K. R. Melin, Technical Coordination Branch, who prepared the section of this report relating to this phase of the work.

The studies of the quality of surface waters were supervised by H. A. Swenson assisted by W. M. Barr, J. F. Bonebright, J. G. Connor, W. H. Durum, R. P. Orth, F. H. Rainwater, and L. L. Thatcher.

The report was typed by C. J. Harper and E. M. Gushard and the illustrations were prepared by L. L. Hull, R. W. Thrun, and F. L. Amato.

Acknowledgements are made to state and county officials for assisting with arrangements for laboratory space and for providing office space in the Washakie County Court House, Worland, Wyoming.

Records of water discharge were furnished by Robert Follansbee, District Engineer, Denver, Colorado and A. H. Tuttle, District Engineer, Helena, Montana.

Previous Investigations

Investigations of the amount of sediment transported by the Bighorn River were first made by the United States Geological Survey at a station near Custer, Montana during the period June 10, 1905 to June 8, 1906. _/ Some 23 years later another preliminary study was made by the Chief of Engineers, United States Army at a station near Hardin, Montana. This study was carried on during the period September 20, 1929 to November 30, 1930. _/

_/ Stabler, Herman Some Stream Waters of the Western United States: U.S. Geol. Survey, Water Supply Paper 274, 1911.

_/ U.S. Department of the Army, corps of Engineers, Yellowstone River: 73rd Cong. 2d sess., H. Doc. 256, 1934

Investigations were again undertaken by the Corps of Engineers, U. S. Army, in 1938 at three stations on the Bighorn River. _/ These stations and the periods or record are as follows:

_/ Silt Studies, Yellowstone River and Tributaries, U.S. Engineer Office, Fort Peck, Montana, December 1, 1946 (Mimeographed Report)

Bighorn River at Thermopolis, Wyoming, 1938-44
Bighorn River at Kane, Wyoming, 1940-44
Bighorn River near St. Xavier, Wyoming, 1938-44.

Some additional information was also obtained at other points in the Basin.

The investigations of the amount of sediment in transport were all conducted at gaging stations operated by the United States Geological Survey.

GENERAL FEATURES OF THE BIGHORN RIVER DRAINAGE BASIN

Location and Extent

The Bighorn River Drainage Basin is situated in northwestern Wyoming and south-central Montana. It has a total area of 23,000 square miles, 19,000 of which are in Wyoming and 4,000 in Montana. The basin extends from latitude 42°30' to 46°10' and longitude 107° to 110°10' at point of greatest lateral extent.

The Wind-Bighorn Rivers system is some 460 miles in length. The Wind River, rising on the easter side of the Wind River Mountains, which form a part of the continental divide, flows in a southeasterly direction to Riverton, Wyoming. The Popo Agie River, which also drains a part of the Wind River Range, flows into the Wind River just below Riverton to form the Bighorn River. The Bighorn River turns abruptly below Riverton and flows in a northerly direction to its confluence with the Yellowstone River at Laurel, Montana.

Other tributary streams, which contribute significant quantities of water, flow into the Bighorn River below Worland, Wyoming. From the west, the Greybull River enters at Greybull and the Shoshone River enters below Kane; both rivers drain areas adjacent to Yellowstone National Park. From the east, Nowood Creek, which rises on the western side of the Bighorn Mountains, enters at Manderson, Wyoming. The Little Bighorn River, which drains part of the northeastern slopes of the Rosebud Mountains enters just below Hardin, Montana.

In 1806 Captain Clark named the Bighorn River and in 1876 the Little Horn River became of national significance because of the Custer massacre which took place just south of the present Crow Agency. During the period 1901-1905, N. H. Darton made the first detailed investigation of geology and water resources of the Bighorn Mountains, and used the names Bighorn and Little Bighorn Rivers. Since that investigation several writers have used the terms Big Horn River and Little Horn River. In 1940 the Board of Geographical Names ruled that thereafter the name Big Horn would be written as one word, ie., Bighorn; and the name of the tributary stream Little Horn River would be changed to Little Bighorn River.

Topography

The Bighorn River Drainage Basin is an area of rugged mountains with deep canyons and extensive valley areas including bench lands. The highest point in the basin is Gannett Peak in the Wind River Range, elevation 13,785 feet; the lowest is at the mouth of the Bighorn River with an elevation of 2,666 feet.

On the basis of physiographic development, the Bighorn River Drainage Basin is easily divided into three distinctive regions; the Wind River Basin, and the Bighorn Basin in Wyoming, and the Bighorn Valley in Montana. In some reports, that section of the Bighorn River Drainage Basin in Montana has been designated as the Lower Bighorn Basin. However, as this part of the drainage basin is not a basin topographically it will hereafter be referred to as the Bighorn Valley.

Wind River Basin

The Wind River Basin comprises approximately one-fourth of the Bighorn River Drainage Basin. It is the headwaters of the Bighorn River and is bounded on the north by the Owl Creek Mountains and the eastward extension of the Absaroka's; on the west and southwest by the Wind River Mountains; on the south by Beaver Rim and on the east by a region of high relief which is a southward extension of the Bighorn Mountains.

The elevation of the basin varies from 4,500 feet at Boysen damsite to 13,785 feet at the top of Gannett Peak, the highest elevation in the Wind River Mountains and the State of Wyoming. The Owl Creek Mountains on the north rise to elevations exceeding 9,000 feet; on the south along Beaver Rim, the escarpment reaches elevations of 7,000 feet. On the east, along the divide between the Bighorn and Powder River drainage in the vicinity of Waltman, Wyoming, the area of high relief reaches an elevation of 6,000 feet.

The floor or interior of the basin is essentially a much-dissected erosional plain, the predominant topographic features being the mature valleys of the Wind and Popo Agie Rivers and their associated stream terraces. In many parts, particularly in the badlands, erosional remnants in the form of buttes are common. The highland areas are gently rolling remnants of an old erosional plain. Along the southwestern edge of the basin, the flank of the Wind River Mountains is characterized by a series of hogbacks formed by the removal of almost horizontal Tertiary sediments which once covered the steeply dipping older formations.

The Bighorn River flows from the Wind River Basin through the deeply incised Wind River Canyon in the Owl Creek Mountains. The anomaly in names between the river and its canyon is of interest. In the early days of western exploration, the Wind River Basin was entered from the east by way of the North Platte River Valley, while the Bighorn River Basin north of the Owl Creek Mountains was explored from the northeast by way of the Yellowstone River. The Wind River Canyon was almost impassable and such travel that did occur between the Bighorn Basin and the Wind River Basin was over mountain passes to the north and south of the Wind River Canyon. / This mutual isolation resulted in different

/ Hayden, F. V., Sun Pictures of Rocky Mountain Scenery, with a description of the Geographical and Geological features and some account of the Resources of the Great West: Julius Bien, New York, 1870.
Hayden, F. V., First, Second, and Third annual reports of the United States Geological Survey of the Territories for the years 1867, 1868, 1869, pp. 71.

names for the river and canyon. Darton in 1905 proposed extending the name "Big Horn" for the river upstream through the canyon to the confluence of the Wind and Little Wind Rivers. / A. J. Collier / attempted

/ Fanshawe, J. R., Road Log Shoshoni to Boysen: Wyoming Geological Association. Third Annual Field Conference Guide Book, p. 36, 1948.

/ Collier, A. J., Oil in the Warm Springs and Hamilton Domes near Thermopolis, Wyoming: U. S. Geol. Survey, Bulletin., 711, 1920

to remedy the situation by proposing the name "Bea Ogwa" for the canyon which is an Indian term for "Big Waters." This was approved by the Board of Geographical Names, but did not meet with the approval of local residents of the region. Locally the "Wedding of the Waters" is considered to be at the north end of the canyon with the stream designated

PLATE

Wind River Canyon at mouth. Note the dip slope formed on the Phosphoria formation.

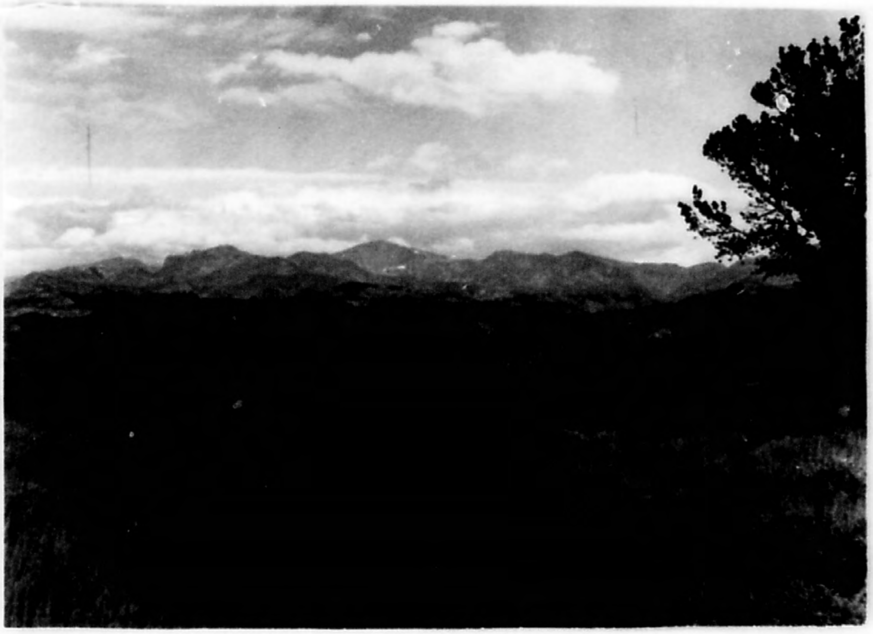
Red Canyon southwest of Lander, Wyoming. The flat-topped mountain in the background is an erosional remnant of Tertiary sediments which were laid down over beveled older sediments. Note the basinward dip of the Chugwater formation on the right. The alcova member appears as a white line at the first bench.

as the Wind River above and the Bighorn River below that point. In 1940, however, the Board of Geographical Names ruled that the Bighorn River begins at the confluence of the Wind and Popo Agie Rivers just below Riverton, Wyoming. The anomaly of the Bighorn River traversing the Owl Creek Mountains through the Wind River Canyon still persists.

Bighorn Basin

The Bighorn Basin is that part of the Bighorn River Drainage Basin between the Owl Creek and Absaroka Mountains on the south and southwest; and the northwestern end of the Bighorn Mountains and Pryor Mountains on the north. The Bighorn River enters the basin through the Wind River (Bea Ogwa) Canyon upstream from Thermopolis and leaves it through the Bighorn Canyon below the mouth of the Shoshone River near Kane, Wyoming. The Bighorn Basin covers an area of approximately 10,200 square miles, bounded on the west by the Absaroka Mountains and on the east by the Bighorn Mountains.

The average elevation of the basin floor is approximately 4,500 feet. The elevation of the Bighorn Mountains on the east varies from about 9,000 feet to a maximum of 13, 165 feet for Cloud Peak. On the west, Franks Peak in the Absaroka Mountains has an elevation of 13, 140 feet. Several other peaks have elevations in excessof 12,000 feet. Prominent hogbacks, scarps, and bench lands occupy parts of the basin. Polecat Bench in the northern end of the basin is the lowest of the confining highlands with an approximate elevation of 5,000 feet.



Cloud Peak, highest point in the Bighorn Mountains.

Sand dune area near Crow Mountain, Wyoming. Absaroka Mountains in the background.

Tatman Mountain, 8 miles south of the Greybull River and 1,230 feet above it, is the highest and oldest Tertiary erosional remnant in the basin.

The areas drained by Shell and Nowood Creeks consist of steep-walled canyons on the western side of the Bighorn Mountains with relatively narrow flat valleys after reaching the floor of the basin. On the western side of the basin, the areas drained by Owl Creek, Greybull, and Shoshone Rivers similarly consist of rugged canyons in the mountains. However, the valleys in the basin floor are fairly wide and less steep.

The Bighorn River below Thermopolis, Wyoming flows in a valley on the east side of the basin. Nine miles north of Greybull, Wyoming it cuts directly across Sheep Mountain Anticline through a vertical walled canyon about one mile long and 500 feet deep. On leaving Sheep Mountain Canyon, the river flows a meandering course in a narrow valley to the mouth of Bighorn Canyon below Kane, Wyoming. This Canyon is approximately 25 miles in length with a maximum depth of 2,800 feet at the apex of the Bighorn anticline.

Bighorn Valley

Bighorn Valley is considered in this report to be the area drained by the Bighorn River below Bighorn Canyon. It is bordered on the west by an area of high relief; on the south by the Pryor and Bighorn Mountains; and on the east by the Rosebud Mountains, the northern extension of which is an area of low relief. It is a wide flat valley with little change in relief except that part drained by the Little Bighorn River. The latter region consists of canyons on the northeastern side of the Bighorn Mountains and narrow valleys on the western side of the Rosebud Mountains. In some places in the Bighorn Mountains the Little Bighorn Canyon reaches a depth of almost 2,000 feet. Just above the confluence of the Bighorn and Yellowstone Rivers, the Bighorn Valley is quite flat and narrow and void of any distinctive relief pattern.

CLIMATE

The climate of the region is characterized by extreme dryness on the floors of the basins, but moist along the mountain ranges and uplands. The high elevations of the Wind River Range and Absaroka Mountains, which form the crest of the watershed to the west, trap much of the moisture from the Pacific storms as they pass over the region. The storms in passing across the basins, contribute little moisture to the valley floors. On striking the Bighorn Mountains, along the eastern edge of the watershed, the eastward-travelling storms again deposit moisture. The Owl Creek Mountains, which divide the Wind River and Bighorn Basins and trend east-west, trap some moisture because of their elevation, but the quantity is not as great as that which falls on the higher ranges to the east and west.

Frequent convection storms, which are characteristic of the region, occur during the summer months, caused by the upward flow of warm air and condensation along the mountain ranges. A study of U. S. Weather Bureau precipitation records for 7 valley stations shows that 66 percent of the total precipitation for the year occurs during the six months April to September (spring, summer, and early fall). This moisture falls principally as rain. The precipitation occurring during the remainder of the year is primarily in the form of snow.

Precipitation and comparative runoff data are illustrated in Plates __6__ and __7__.

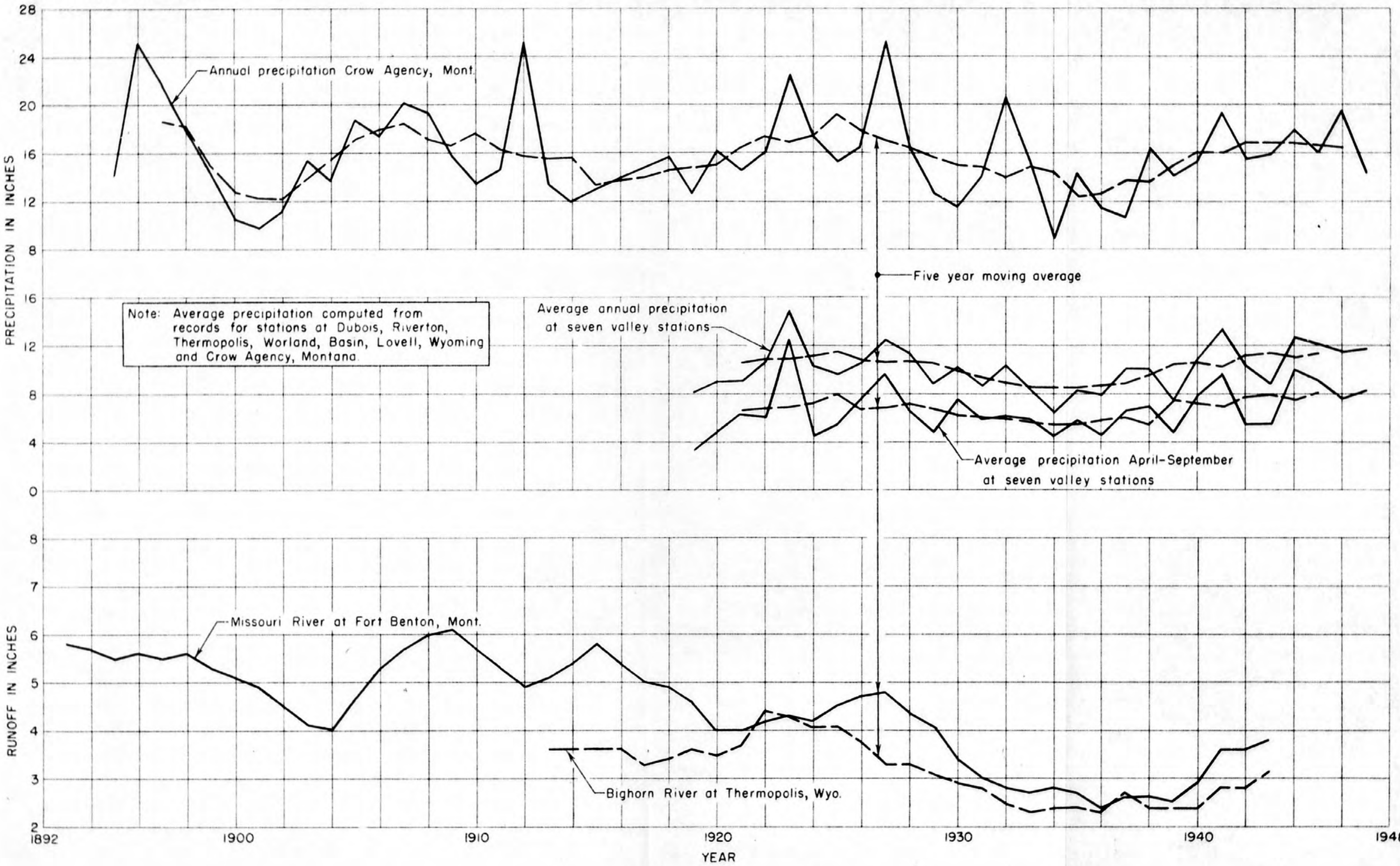


DIAGRAM SHOWING PRECIPITATION IN THE BIGHORN RIVER DRAINAGE BASIN AND RUNOFF, BIGHORN RIVER AT THERMOPOLIS, WYOMING AND MISSOURI RIVER AT FORT BENTON, MONTANA.

Wind River looking upstream from the highway bridge at Riverton, Wyoming.

Beaver Creek one mile above its confluence with the Popo Agie River.

View downstream in Wind River Canyon just above the old Boysen dam site. The wall of rock in the foreground is very resistant pre-Cambrian metamorphic rock; the cliff in the background is Paleozoic limestone.

Bighorn Canyon looking upstream from the mouth of Porcupine Creek near the Wyoming-Montana State Line. Note the resistant Paleozoic formations in the walls of the canyon.

The valley of the Bighorn River from Sheep Mountain anticline in the Bighorn Basin. Bighorn Mountains in the background.

View looking northwest toward the Absaroka Mountains from Circle Ridge anticline in the Wind River Basin.

View looking northwest from the front of the Owl Creek Mountains toward the Wind River Mountains showing typical basin floor topography of the Wind River Basin.

PLATE

Closeup of outcrop of the Bighorn dolomite showing the vuggy weathering distinctive of the formation.

View near Kane, Wyoming showing erosion of soft Cretaceous shales.

Close-up of the Red Peak member of the Chugwater formation.

View showing highly cross-bedded Nugget sandstone.

PLATE 7

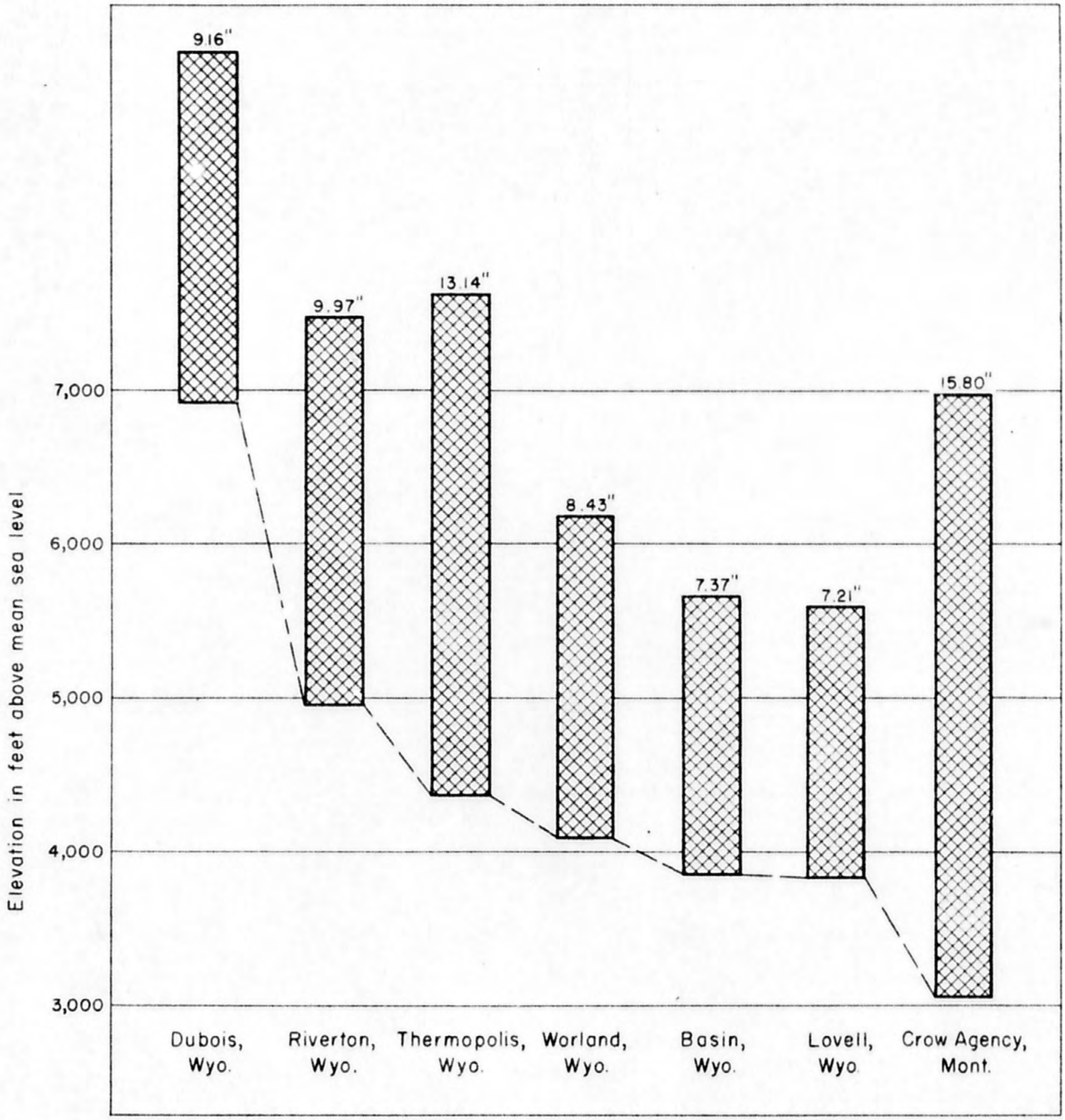


Figure Mean precipitation and elevation at U.S. Weather Bureau stations in the Bighorn River drainage basin, Wyoming and Montana.

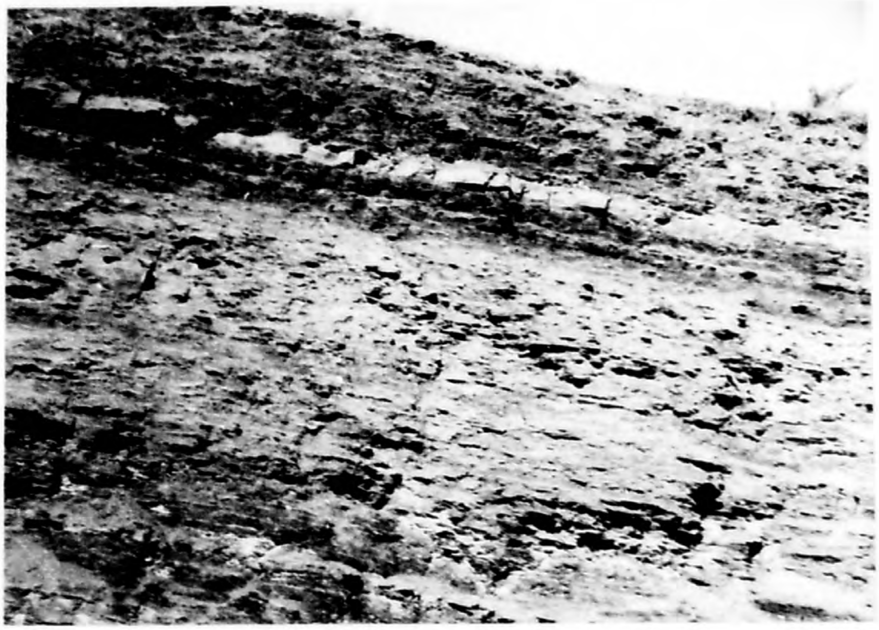
PLATE

View showing juniper covered dip slope of the Muddy sandstone.

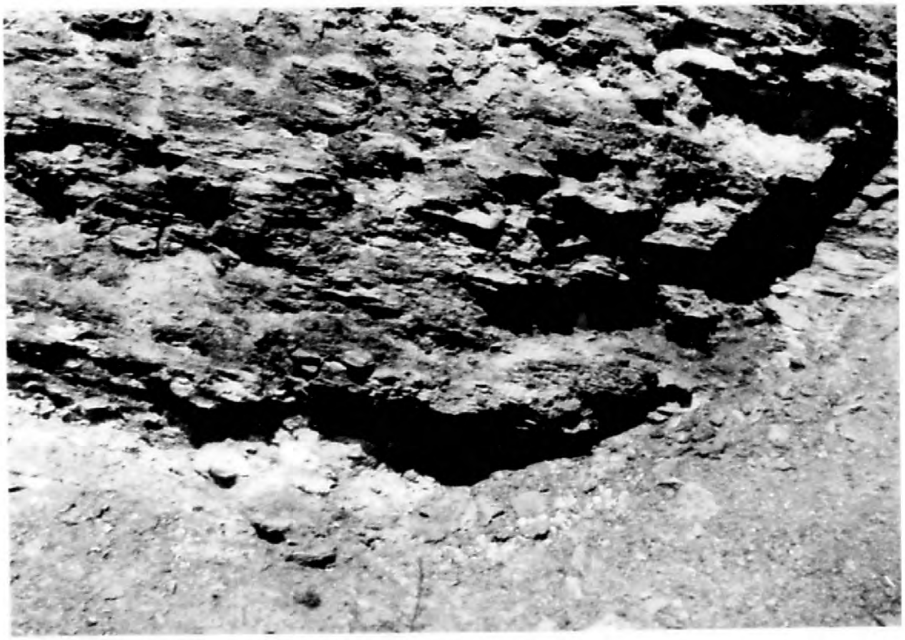
View showing an outcrop of the Mowry shale. Note the vegetational banding which is distinctive of the formation.

View looking west toward the Wind River Mountains from Circle Ridge.

View in Sheep Mountain Canyon. The anticlinal nature of Sheep Mountain is well shown by the arched strata.



View near Thermopolis, Wyoming showing north dipping strata of the Thermopolis formation.



Close-up of the Thermopolis formation.

PLATE

Cody shale near Hudson, Wyoming.

Close-up of the Cody shale.

View of drain into Five Mile Creek on the Riverton Project
This drain eroded to its present depth from its original
depth of not over four feet in less than three years.

View of drain on the Riverton Irrigation Project.

Five Mile Creek at falls. Note the dark shales capped by lighter colored massive sandstone.

View downstream on lower Five Mile Creek showing narrow channel confined by strata of the Wind River formation.

NATIVE VEGETATION

The native vegetation has adapted itself to the climatic characteristics of the region in which it grows. On the basin floors, where the precipitation is scanty, the summers very hot and dry, and the winters cold, dry and windy, the sages and greasewoods predominate, interspersed with cacti. During the favorable growing season in the spring, the basin floor is well clothed with range grasses valuable as feed for stock. Along the low slopes of the uplands the grasses become more prominent, the greasewoods and cacti thin out, and the sagebrushes persists. Sagebrush thins with elevation and disappears generally at about 9,000 feet. Juniper and cedar are found along stretches of sedimentary rocks favorable to their growth. Along the mountain slopes and on the peaks the range grasses predominate, together with the lupines and other flora typical of a sub-alpine habitat. Pines, firs, and spruce comprise the main species of coniferous trees covering the mountain slopes, with aspens and cottonwoods present in some areas. Timberline occurs at an elevation of approximately 10,000 feet.

GENERAL GEOLOGY OF THE BIGHORN RIVER DRAINAGE BASIN

Purpose and Scope of Geologic Work

The geologic work during the present investigation was undertaken to provide information that is essential to the understanding and interpretation of problems relating to fluvial sediments and to the mineral quality of both surface and ground waters in the Bighorn River Drainage Basin. The material carried by the streams, both in solution and suspension or as bed-load, was originally derived from the rocks which make up the mountain ranges and basins of the area. The investigation therefore involved a reconnaissance of the rocks and a review of pertinent published reports, considering especially the sediment producing properties and the relationship of the formations as the sources of sediment carried by the streams; and their relationship to the minerals in solution.

General Character, Stratigraphic Position, and Age of the Rocks

The igenous, metamorphic, and sedimentary rocks in the Bighorn River Drainage Basin range in age from pre-Cambrian to present with sediments of the Silurian and most of the Devonian being absent.

Pre-Cambrian

Rocks of pre-Cambrain age are exposed in the dissected cores of the Bighorn, Owl Creek, and Wind River Mountains. Of the three, the Wind River Mountains have by far the largest area of exposed pre-Cambrian

Popo Agie River Valley looking northwest toward the Wind River Mountains. The broad valley is the topographic expression of the Cody shale.

View along the east side of the Bighorn River 8 miles north of Worland, Wyoming showing bluffs carved in the Willwood formation of Eocene age.

PLATE

Bighorn River above the Manderson bridge showing an outcrop of the Fort Union formation. Note the black subbituminous coal seams.

Badlands carved in the Wind River formation near Lysite, Wyoming

PLATE

View north of Riverton, Wyoming showing two levels of terraces or benches.

Close-up of stream rounded terrace gravels near Riverton, Wyoming

The Owl Creek Mountains and head of the Wind River Canyon.

View downstream Midway in Wind River Canyon. Size of canyon can be judged by the car on the highway at the right.

rocks. The basement complex consists of chlorite schists, hematite schists, quartzmica schists, quartzite, other metamorphic rocks, and basic intrusions, which are in turn intruded by pink and gray granites. The granite is normally medium-grained, but there are pegmatitic phases.

Paleozoic

Rocks of Palezoic age crop out in a band along the flanks of the Wind River, Owl Creek, and Bighorn Mountains with a few small outcrops scattered elsewhere in the drainage basin.

The Cambrian formations of the Bighorn River Drainage Basin crop out high along the flanks of the mountains and are well exposed in transverse canyons such as Wind River Canyon. The formations of Cambrian age are made up of three distinct lithological types. The Flathead sandstone is a quartzitic red sandstone, the Gros Ventre formation is a sandy and micaceous shale, and the Gallatin formation is a limestone with interbedded shales.

The Ordovician of the area is represented by only one formation, the Bighorn dolomite. Areas of outcrop are best seen in the deep canyons formed by the rapidly descending mountain streams. The massive, buff colored, porous, and vuggy Bighorn dolomite forms prominent cliffs in the walls of the mountain canyons and stands as scallops above the Cambrian at the top of the dip slopes.

Formations of Devonian age occur in only a few limited areas in the region and there is still some question of their relationship. 1/

1/ Stipp, T. F., Paleozoic Formations near Cody, Park County, Wyoming: Am. Assoc. Petrol. Geol. Bull., vol. 31, pp. 274-281, 1947.

In Shoshone Canyon a series of shales, limestones and thin sandstones lying between the Madison limestone and the Bighorn dolomite has been correlated with the Threeforks formation of Montana. The underlying limestones and dolomites, formerly thought to be part of the Bighorn, are equivalent to the Jefferson formation of Montana. In the Wind River Mountains, the Darby formation wedges in from the north and pinches out in short distance. It is probable that the dolomites, sandstones, and shale beds of the Darby are equivalent to both the Jefferson and Threeforks formations.

Sedimentary rocks of Mississippian age, represented by the Madison formation and possibly in part by the Amsden formation, are present along the flanks of the mountains and, as is the case with most of the Paleozoic sequences, are best seen in the canyons running back into the highlands. The Madison formation consists of massive and thin-bedded gray limestone and dolomite with cherty layers.

The Amsden formation consists of a heterogenous series of red shales, white limestones, and cherty limestones, and occupies the stratigraphic interval between the Madison limestone and the Tensleep sandstone. _/ Some of the geologists who have worked in the area believe

_/ Darton, N. H., Comparison of Stratigraphy of the Black Hills, Bighorn Mountains and Rocky Mountain Front Range: Geol. Soc. Amer. Bull., Vol. 15. pp. 379-448, 1904.

the formation to be entirely Pennsylvanian in age. _/ Others believe the

_/ Thomas, Horace, D., Summary of Paleozoic Stratigraphy of the Wind River Basin, Wyoming: Wyoming Geol. Assoc., Third Annual Field Conference Guide Book, p. 87, 1948.

upper part of the Amsden is Pennsylvanian and the lower part is Mississippian.

However, the line of demarcation is difficult to draw. _/

_/ Branson, E. B. and Branson, C. C., Geology of Wind River Mountains, Wyoming: Amer. Assoc. Petrol. Geol., Bull., Vol. 25, p. 131, 1941.

Love, J. D., Geology Along the Southern Margin of the Absaroka Range, Wyoming: Geol. Soc. America, Spec. paper 20, 1939.

Weller, J. Marvin et al, Correlation of Mississippian Formations of North America: Geol. Soc. America, Bull., Vol. 59 pp. 91-196, 1948.

Along the lower canyon of Tensleep Creek, the type section of the Tensleep formation of Pennsylvanian age consists of massive, cross-bedded, yellow, buff, or white sandstone. _/ Elsewhere in the Bighorn River

_/ Darton, N. H., Comparison of Stratigraphy of the Black Hills, Bighorn Mountains and Rocky Mountain Front Range: Geol. Soc. Amer. Bull., Vol. 15, pp. 379-448, 1904.

Drainage Basin, it is usually white or buff, massive cross-bedded sandstone, made up almost entirely of quartz grains of fine to medium texture.

The Paleozoic-Mesozoic boundary is not well marked in the Bighorn River Drainage Basin. The formation name "Embar" is in common usage and as generally understood includes both the Phosphoria formation of Permian age and the Dinwoody formation of Triassic age.

The Permian Phosphoria is the most lithologically complicated series of any of the Paleozoic formations. It consists of limestones, red shales, sandstones, cherts, and phosphate rock. The lithologic characteristics vary greatly from one locality to another. _/

_/ Thomas, Horace D., Phosphoria and Dinwoody Tongues in Lower Chugwater of Central and Southeastern Wyoming: Am. Assoc. Petrol. Geol. Bull., Vol. 18, pp. 1655-1697, 1934.

King, Ralph H., Phosphate Deposits Near Lander, Wyoming: Wyoming Geol. Survey, Bull. 39, 1947.

Mesozoic

Formations of Mesozoic age crop out in a broad band around the margins of the Wind River and Bighorn Basins and over two-thirds of that part of the drainage basin lying north of the Montana-Wyoming border. Mesozoic formations are also exposed in the eroded anticlinal structures on the floors of the basins.

The Triassic in the region is represented by a thick sequence of "red beds" which have been divided into two formations. There is some difference of opinion as to the division of the "red beds" in regard to age and members. _/ The Dinwoody formation consists of yellow-brown

/ Branson, E. B. and Branson, C. C., Geology of Wind River Mountains, Wyoming: Am. Associ. Petrol. Beol., Bull., Vol. 25, p. 134, 1941.
Love, J. D., Geology Along the Southern Margin of the Absaroka Range, Wyoming: Geol. Soc. American, Special Paper 20, 1939.
Love, J. D., Mesozoic Stratigraphy of the Wind River Basin, Central Wyoming: Wyoming Geol. Assoc., Third Am. Field Conference Guide Book, pp. 98, 99, 1948.

sandy shales, thin-bedded dark gray shale and gypsiferous slabby dolomites and limestones. The Chugwater formation is divided into the Red Peak, Alvova, and Popo Agie members. The Red Peak member is a reddish siltstone; the Alcova limestone member is a thin crinkly light-gray limestone; and the Popo Agie member consists of ocher-colored claystone, purple to red siltstone, and limestone conglomerates.

The Jurassic in the area is represented by marine, shallow marine, and terrestrial sediments. These sediments have been divided into the Nugget sandstone, Gypsum Spring formation, Sundance formation, and Morrison formation. The Nugget sandstone has been included in the

Chugwater group by some writers under the name "Wyopo." / Love, however,

/ Branson, E. B., and Branson, C. C., Geology of Wind River Mountains, Wyoming: A,. Assoc. Petrol. Geol., Bull., Vol. 25, p. 136, 1941.

prefers the name Nugget for the red and gray massive to coarsely bedded sandstone overlying the Popo Agie member of the Chugwater formation. /

/ Love, J. D., Mesozoic Stratigraphy of the Wind River Basin, Central Wyoming: Wyoming Geol. Assoc., Third Ann. Field Conference Guide Book, pp. 100, 101, 1948.

In some areas of outcrop, the formation is highly cross-bedded. The formation wedges rapidly from about 500 feet in thickness at the southwestern margin of the Wind River Basin to extinction north of the Owl Creek Mountains. Until very recently, the Gypsum Spring formation was thought to be the upper part of the Chugwater and some geologists still believe it to be Triassic. It consists of red siltstone with interbedded gypsum of irregular thickness and distribution. The basal part of the Sundance formation consists of gray and greenish-gray calcareous shales with interbedded limestone. The upper part is made up of sandstone, sandy shale, sandy limestone, and limestone. The fluviatile and lacustrine sediments of the Morrison formation are easily separated from the underlying marine Sundance. The formation consists of variegated shale and claystones, siltstones, silty sandstones, and conglomerates. The Morrison formation is overlain by the Cloverly formation of Lower Cretaceous age and because of the rapid horizontal and vertical changes in the two formations, no sharp dividing line can be made when the conglomerate of basal Cloverly is absent.

The Cretaceous sediments in the Bighorn River Drainage Basin are divided into the Cloverly and Thermopolis formations of Lower Cretaceous age and the Muddy sandstone, Mowry shale, Frontier formation, Cody shale, Mesaverde formation, Meeteetse formation, and Lance formation of Upper Cretaceous age. The Cloverly formation consists of Conglomerates, gray sandstone, gray silty shales, lilac claystone with limestone concretions, variegated silty shales and siltstones. Love [9] and other investigators believe the boundary between the Cloverly and Morrison formations is marked by the quartz crystal sandstone and conglomerate zone some 200 feet above the glauconitic Sundance. The Thermopolis shale is a remarkedly persistent lithologic unit throughout Wyoming. This formation of black shale commonly has thin bentonite beds present as well as gray shaly sandstone. The Muddy sandstone overlies the Thermopolis shale and the sharp lithologic contact makes the separation of the two very easy in the field. The formation consists of coarse sandstone which forms cliffs and juniper covered hogbacks. The Mowry shale as recognized by Love [/] directly overlies the Muddy sandstone and underlies the Frontier formation. The lower part of the Mowry consists of soft black non-siliceous shales which grade up into hard gray siliceous shale. Thin beds of bentonite and quartzitic sandstone are present. The Frontier formation consists of interbedded gray and black sandstone and shales. Thin coal

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[9] Love, J. D., Mesozoic Stratigraphy of the Wind River Basin Central Wyoming: Wyoming Geol. Assoc., Third Ann. Field Conference Guide Book, pp. 104-105, 1948.

[/] Love, J. D., Mesozoic Stratigraphy of the Wind River Basin Central Wyoming: Wyoming Geol. Assoc., Third Ann. Field Conference Guide Book, p. 107, 1948.

beds are present near the center of the formation. The Cody shale is made up of 2,500 to 4,500 feet of shaly sandstone, dark gray marine shales, calcareous shale, and a few thin beds of bentonite. The Mesaverde formation consists of alternating white to buff massive cross-bedded sandstone, thin-bedded sandstones, shales and coal. The Meeteetse formation is made up of interbedded light-gray shaly sandstone, sandstone and carbonaceous shale. Thin seams of coal are present in the upper half of the formation. The Lance formation is composed of light gray and brown sandstones and interbedded gray shales, claystone, and carbonaceous shale. The yellowish-brown to gray basal sandstone of the Lance contrasts markedly with the lighter color of the underlying sandstone of the Meeteetse and the basal red beds of the overlying Fort Union. _/

_/ Rogers, C. P. et al, Geol. of the Worland Hyattville Area, Bighorn and Washakie counties, Wyoming: U.S. Geol. Survey, Oil and Gas Invest. Prelim., map 84, 1948.

Cenozoic

The Cenozoic is represented by Tertiary sediments which cover the larger part of the floors of the Wind River and Bighorn Basin and by Quaternary sediments along the Bighorn River and its tributaries.

The most complete exposures of Tertiary sediments in the area are along Beaver Rim and in the Lysite-Lost Cabin areas. Recent investigations in the Wind River Basin indicate that much work needs to be done before the Tertiary sequence will be satisfactorily known.

The Fort Union formation of Paleocene age consists of gray and buff sandstone, shale, thin interbedded, sub-bituminous coal, and carbonaceous shale. Most of the carbonaceous deposits are found in the lower part of the formation. Some of the sandstones are cemented with iron oxides and are rusty colored in outcrops. The basal red-colored beds of the Fort Union easily differentiate it from the underlying light brown sandstone of the Lance.

The Eocene in the Bighorn River Drainage Basin is represented by a thick sequence of continental sediments. These sediments are recognized as the Willwood and Tatman in the Bighorn Basin and as the Wind River formation in the Wind River Basin. The Willwood and Wind River formations are of lower Eocene age and the Tatman of middle Eocene age. The name Willwood was first applied by Van Houten _/ to the 2,500 feet of beds that

_/ Van Houten, F. B., Stratigraphy of the Willwood and Tatman Formations in Northeastern Wyoming: Geol. Soc. American. Bull., Vol. 55 pp. 165-210, 1944.

lie between the Fort Union and Tatman formations. The names Willwood and Tatman were proposed to replace the name Wasatch formation formerly used in the Bighorn Basin, because of the difference in age and lithology between the so-called Wasatch of the basin and the type Wasatch in Utah. The Willwood formation is composed of red, purple, and gray claystone, and gray and yellow sandstone. The Wind River formation has been divided by Tourtelot _/ into two members on the basis of lithologic differences.

_/ Tourtelot, H. A., Tertiary Rocks in the Northeastern part of the Wind River Basin, Wyoming: Wyoming Geol. Assoc., Third Ann. Field Conference Guide Book, pp. 112-124, 1948.

The Lysite member is composed of interbedded yellowish-brown sandstone, red, tan, and gray sandy siltstones, and claystone. Beds of conglomerate are commonly associated with the sandstone near the mountains, but become less numerous away from the mountains. The Lost Cabin member consists of gray and green siltstone and claystone with yellowish-brown to orange sandstones with some variegated beds present; and in beds of the Wind River formation of Lost Cabin age found in other parts of the Wind River Basin volcanic material is present. As in the Lysite member, the sandstones in the Lost Cabin member are more conglomeratic near the mountains. The Tatman formation consists of alternating fine-grained sandstone and laminated brown carbonaceous shale. Remnants of the Tatman formation occur in only a few places in the basin. The type section is at Tatman Mountain, a mesa south of the Greybull River.

In general, the sediments of undivided middle Eocene, upper Eocene, and Oligocene have not received sufficient attention to adequately place them in their proper age relationships. The sediments are composed of green, brown, and white andesite tuffs; light-colored fossiliferous fresh-water limestones; drab grayish-green and dull brown, sandy and gravelly claystones; sandy, clayey, fine-grained conglomerate; and soft, tan, ashy siltstone with irregular beds of conglomerate.

Sediments of Miocene and Pliocene age have not been clearly distinguished. The Pleistocene and Recent are represented by typical glacial deposits in the mountains and by terrace and flood plain deposits of gravel and sandy silt along the Bighorn River and its tributaries.

Structure

The Wind River, Owl Creek, and Bighorn Mountains are essentially asymmetrical anticlines with northwest trending axis.

The Wind River Basin is a large synclinal fold with minor flexures lying between the Owl Creek and Wind River Mountains.

The western edge of the Wind River Basin is limited by the Wind River Mountains, one of the major archs of the region. The structural pattern of the Wind River Mountains is repeated in the series of anticlines lying a few miles to the east of the foot of the Paleozoic dip slopes. This line of anticlines, starting from the north, includes Winkleman, Sage Creek, Hudson, Dallas, Derby, Hidden, and Sheep Mountain anticlines. All of the folds north of Hidden anticline have been eroded into the Chugwater.

The southern margin of Wind River Basin is a southward retreating erosional scarp, carved, for the most part in almost horizontal Tertiary sediments. This scarp is little affected by the underlying gently northward dipping strata. In front of the erosional scarp is a line of plunging anticlinal folds which includes Beaver Creek, Sand Draw, Alkali Butte, Conant Creek, Muskrat, and Dutton Basin, and the Rattlesnake Hills.

Along the eastern edge of Wind River Basin is a line of folds which separates the Wind River and Powder River drainages. The northwest trend of these anticlines is roughly the same as most of the other folds of the Wind River area. The Circle Ridge, Maverick Springs, and Little Dome line of folding in the northwest part of the basin follows the same trend and passes beneath the Wind River sediments in muon the same trend and passes beneath the Wind River sediments in much the same manner as do the folds in the southern part of the basin.

The northern margin of Wind River Basin is limited by the Owl Creek Mountain uplift; a complex anticline which includes two low areas of synclinal nature in which Mesozoic strata extend almost completely across the axis of the anticline. _/ The southern margin of the uplift

_/ Blackstone, D. L. Jr., The Structural Pattern of the Wind River Basin, Wyoming: Wyoming Geol. Assoc., Third Ann. Field Conference Guide Book, P. 74, 1948.

has apparently overthrust the basin margin to the south, _/ but the

_/ Fanshawe, J. R., Structural Geology of Wind River Canyon Area, Wyoming: Am. Assoc. Petrol. Geol., bull., Vol. 23 p. 1452, 1939.

interpretation is difficult because of the overlapping Wind River sediments along the foot of the uplift.

It seems likely that the structural pattern of northwest trending anticlines similar to those exposed in various parts of the basin continues beneath the Tertiary sediments which cover the greater part of the basin. There is at present no reason to believe otherwise.

The Bighorn Basin structural pattern follows in general that of the Wind River Basin. It is a large synclinal basin between the Bighorn and Owl Creek uplifts. The large downward fold is modified by numerous smaller folds.

Lying along the northern edge of the Owl Creek uplift is a series of anticlines that follows the same northwestward trend of the Owl Creek Mountains. This line of anticlines includes Shoshone, Horse Center, Oregon Basin, Spring Creek, Pitchfork, Sunshine, Fourbear, Buffalo, Gooseberry, Grass Creek, Walker, Enos Creek, Embar, Owl Creek, Wagonhound, Hamilton, Waugh, Golden Eagle, Sand Draw, Gebo, and Thermopolis. Almost all of these structures are eroded to the Cretaceous and a few at the south have even older sediments exposed in the center.

The northeast margin of the Bighorn Basin is limited by the Bighorn Mountains; a complex anticlinal arch which, like the Owl Creek Mountains, is thrust to the southwest for an unknown distance.

Bordering the basin along the southwest side of the Bighorn Mountains is a line of anticlines parallel to those along the southwest edge of the basin. This line of anticlines includes Red, Black Butte, Elk Basin, Frannie, Sage, Gypsum Creek, Big and Little Polecat, Garland, Byron, Little Sheep Mountain, Rose, Goose-Egg-Alkali, Spence, Crystal Creek, Sheep Mountain, Shell Creek, Cherry, Greybull, Lamb, Torchlight, Manderson, Paintrock, and Bonanza. Almost all of the faults associated with the structures strike perpendicular to their axis.

To the north of the Bighorn Mountains and south of the Yellowstone in the Bighorn Valley are a few minor folds that parallel the axis of the Bighorn Mountains.

Erosional Characteristics of the Rocks

The agents of erosion are constantly working to destroy the rocks of the earth's surface. Whether the agents are in motion such as the waters of the rivers, the wind, and moving glaciers or essentially motionless such as ice in the cracks of rocks and the solvents around mineral particles, all are engaged in the process of erosion. When the destruction of the rocks is accomplished by the mechanical wear of rivers, wind and moving ice, it is destruction by corrasion; if the destruction is by chemical wear, it is corrosion. Weathering is the breakdown of rocks by essentially motionless agents. The breakdown of rocks accomplished by chemical action is decomposition and that accomplished by mechanical action is disintegration.

Practically all fluvial sediments are of terrigenous origin resulting from the disintegration or decomposition of rocks on the surface and the outer part of the earth's crust. The characteristics of these source rocks determine the makeup of the sediments derived from them.

The rocks comprising the earth's outer shell are igneous, sedimentary, and their metamorphic equivalents. The igneous rocks have been estimated to cover 25 percent of the surface. The sedimentary rocks constitute only 5 percent of the crust, but veneer 75 percent of the surface._/

_/ Twenhofel, W. H., Principles of Sedimentation, McGraw-Hill Book Co., New York, pp. 132, 133, 1939.

The rock forming minerals of the igneous rocks are feldspars, quartz, amphiboles, pyroxenes, micas, magnetite and ilmenite, olivine, apatite, and a few rarer substances. Physical destruction of these rocks yields rock particles of the parent. Chemical decomposition of igneous rocks results in sediments which when lithified consist of 82 percent siltstone, claystone, and shale, 12 percent sandstones, and 6 percent limestones.

The clastic sediments include clays, silts, sands, and gravels. All are transported by running water. Each, if indurated, results in a particular lithified product. The coarse gravels after induration are termed conglomerates; sand become sandstones; silts become siltstones; and clays become claystones and shales.

In contradistinction to the clastic sediments are the calcitic and dolomitic limestones, products of chemical deposition.

If the sedimentary rocks, shales, siltstones, sandstones, and limestones are physically destroyed, the products are merely the unindurated equivalents. With the exception of limestone, chemical decomposition is not an active process as these rocks are in large part already the procusts of chemical decay, so that the products are not unlike the parents. Hence, sandstones will contribute sand, while siltstones and shales will produce silt and clay respectively.

Inasmuch as most of the source rocks in the Bighorn River Drainage Basin are clastic sediments, the great part of the unconsolidated material which they produce will, of necessity, be sands, silts, and clays.

Pre-Cambrian Rocks

The pre-Cambrian sequence is composed of metamorphic and igneous rocks which are especially resistant to erosion. The mineral composition and small amount of pore space of both the igneous and metamorphic rocks give them a resistance to erosion far above that of the average sedimentary rocks. Although the pre-Cambrian rocks are exposed high in the mountains where they are subjected to the more severe agents of erosion, the total products of erosion, which are for the most part sand and gravel, are very slowly transported down the streams to regions of deposition. While it is true that the original source of most of the material now being carried by the streams of the drainage basin was pre-Cambrian rocks, their present primary contribution is practically negligible.

Paleozoic Rocks

Because of its quartizitic composition, the Flathead sandstone furnishes very little sediment to the streams of the area. The Gros Ventre formation weathers into a micaceous clay from which steep grass covered mountain slopes have been formed. The native grass on the slopes prevents rapid erosion and consequent sediment supply to the streams except in a few areas where the production of sediment from the Gros Ventre shale is of importance. The Gallatin formation is composed of resistant limestone which weathers very slowly. Most of the products of erosion of this formation are carried from their source in solution.

The Bighorn dolomite, like all compact lime rocks, weathers very slowly into mostly water soluble products, and furnishes very little sediment to the streams of the area.

The shaly series of the Devonian formations furnishes some sediment to the streams, but because of the small area of exposure the Devonian formations are of little consequence as sediment producers.

The Madison limestone erodes very slowly and most of the products of its weathering are carried away in solution. The residual material consists primarily of cherty material. The red shales of the Amsden formation are easily eroded but because of the small areas of exposure and protection from weathering furnished by the interbedded limestones, this formation is a small contributor of sediment to the streams of the drainage basin.

The Tensleep formation composed of massive sandstone cemented with calcareous material is relatively resistant to weathering and while it does furnish large quantities of sand to the rivers of the area its share of the total sediment contribution is very small. Its resistant nature is shown by the almost vertical cliffs along the canyon walls near the base of the mountains.

The limestones, red shales, sandstones, cherts, and phosphate rock of the Phosphoria formation as a group are extremely resistant to the agents of erosion. The shales of this formation if by themselves would rapidly be carried away. However, as in the case of the shales of the Amsden, they are protected by overlying and underlying beds of limestone and chert. The Phosphoria formation has more area of outcrop than any other Paleozoic formation yet its resistance to erosion is such that it remains as large dip slopes on the north flanks of the Wind River and Owl Creek Mountains.

Mesozoic Rocks

The Dinwoody formation in those localities where it is not protected by the overlying Chugwater is easily eroded. On the north flanks of the Owl Creek and Wind River Mountains, the soft shales which compose most of the formation have been almost completely stripped from the underlying Phosphoria formation. At the present time, the Dinwoody formation is not an important contributor of sediment to the streams of the area. The siltstones of the Chugwater formation weathers into a red silty loam which is easily carried into the streams in times of heavy rainfall. However, the exposed area of this formation is of a size that prohibits it being a major source of the sediment carried by the streams of the Bighorn River Drainage Basin.

Under the attack of the agents of weathering, the Nugget Sandstone breaks down into a quartz sand which can be transported to the streams where, because of the size of the sand particles it is, for the most part, carried as bed load. The comparative slowness of weathering and rather small area of outcrop precludes this formation from being important as a source of stream sediment. The Gypsum Spring formation weathers into a red silty loam, but it is not a prime contributor of sediment to the streams. The interbedded gypsum in the formation acts as a deterrent to the normal processes of mechanical weathering. The chemical weathering of the gypsum beds of the formation undoubtedly is important in its effect on the mineral character of the streams draining the area. The calcareous shales and sandstone of the Sundance formation weathers down into a sandy clay soil which can be carried into nearby streams. However, this formation is not a major contributor of sediment. The shales, claystones, and siltstones of the Morrison formation are subject to rapid weathering and are important locally as contributors of sediment, but because of their limited area of exposure, the contribution to the total sediment load of the rivers is small.

The shales and claystones of the Cloverly formation like those of the Morrison formation are especially susceptible to erosion by water and in localities of outcrop this formation contributes substantial quantities of sediment to the streams in the form of silt and clay size particles. The black shale comprising the Thermopolis shale weathers into a black to gray clay which is easily picked up and transported by running water. The Muddy sandstone is very slowly weathered into sand. Its resistance to weathering in comparison to the overlying Mowry is shown by the cliffs and hogbacks formed by the Muddy sandstone. The lower part of the Mowry shale is rapidly eroded from the underlying Muddy sandstone unless it is structurally protected by the overlying hard siliceous shale of the formation. The Frontier formation weathers very slowly into a sandy clay loam. The shales of the formation would weather very rapidly were it not for the interbedded character of the formation. While the Frontier is not as resistant to erosion as the Muddy sandstone, it does form low hogbacks along the flanks of the anticlines. The shales of the Cody formation are eroded rapidly by the mechanical agents of weathering into silt and clay size particles easily carried by water to the major streams. The great thickness of this formation together with its comparative large area of exposure makes it a contributor of large quantities of sediment to the rivers of the drainage basin. The valleys and depressions which are a topographic expression of the Cody shale clearly indicate the importance of this formation as a contributor of sediment to the rivers of the area. The shales of the Mesaverde formation interbedded as they are with the massive and thin-bedded sandstones which make up the larger part of the formation are very slowly eroded. The resistance to erosion of this formation in comparison to the underlying Cody shale is very clearly shown by the differences in the topographic forms of each formation. The Mesaverde formation forms ridges bordering valleys and depressions representing the Cody formation. The poorly consolidated rocks of the Meeteetse formation are more easily eroded than the underlying Mesaverde and the overlying Lance. The interbedded sandstones and shales are eroded down into lowlands lying between the Meeteetse and Lance formations. The Lance formation, while containing much shale and claystone, is more slowly eroded than the underlying Meeteetse because of the interbedded sandstones which make up most of the Lance.

Cenozoic Rocks

The Fort Union formation consisting of sandstone, shale, and some coal is of importance as a producer of sediment in the Bighorn Basin where it has a large area of outcrop, but in the Wind River Basin where the formation crops out in only a small area, it is a minor producer of sediment.

The loosely consolidated sediments making up the formations of Eocene, Oligocene, Miocene, and Pliocene age are easily eroded into clay, silt, and sand sized particles and carried into the rivers draining the area. A measure of the production of sediment from these formations is given by the fact that nearly all of the streams of the drainage basin are clear until they enter areas of outcrop of Tertiary sediments when they become, in short distances, carriers of large quantities of sediment. Because of the low rainfall in the areas covered by Tertiary formations, streams rising in them are dry most of the year, but in the brief periods of run off from the torrential rainfall that is typical of these areas, enormous quantities of sediment are picked up and carried into the main streams. The large area of outcrop of the Tertiary formations, loosely consolidated sediments and subjection to rainfall of cloudburst intensities, make them the source of a large part of the sediment now carried by the main streams of the Bighorn River Drainage Basin.

The Pleistocene glacial deposits in the mountains are not important as sediment producers, but the Pleistocene and recent floodplain deposits along the Bighorn River and its tributaries are a major source of sediment in those localities where the natural regimen of the streams have been changed by irrigation developments.

Physiographic Development of the Bighorn River Drainage Basin

Formation of the Basins by Laramide Differential Movements

Most of the basin developments have occurred since the beginning of the Laramide Revolution in the closing stages of the Mesozoic era. This period of extended crustal unrest caused the floor of the great geosyncline, recently covered by the Cretaceous sea, to become the scene of folding and thrusting on a colossal scale, resulting in the Rocky Mountain System, of which the Bighorn River Drainage Basin is a part. / The Laramide Revolution covered a vast period and did not die out until in the Eocene or possibly in the Oligocene. It was characterized in the northern Rocky Mountains by thrust faulting of great magnitude. These orogenic movements, with attendant and subsequent erosion, determined the present-day physiography of the Bighorn region.

/ Schuchert, Charles, and Dunbar, Carl O., A Textbook of Geology, Part II - Historical Geology, p. 350, 1933, John Wiley & Sons, New York.

As the Laramide Revolution progressed, folds and faults were formed throughout the region which was to become the Wind River and Bighorn Basins. The mountains that now surround the basins began to rise. Concurrent with these movements and continuing after they died out, there was active erosion of the highlands and deposition in the intermontane basins.

Altitude of the Basin Floors at Culmination of Period of Aggradation

Aggradation of the Central Plains area culminated in later Tertiary time in the production of a vast, eastward-sloping alluvial surface, extending westward into the intermontane basins. A thick sequence of early Tertiary beds was laid down, reaching a depth of 3,500 feet in the Wind River and Bighorn Basins and almost completely burying the area in a sea of waste. This is confirmed by direct evidence to be observed in the basins. First, is the fact that all major consequent streams cut across structural barriers in positions that indicate superposition from a higher level. _/ Second, is the presence of extensive

_/ Fenneman, Nevin M., Physiography of Western United States, p. 147, McGraw-Hill Book Co., New York City, 1931.

deposits of stream-rounded gravel at elevations from 7,000 to 9,000 feet on the flanks of the Big Horn Range. These gravel surfaces on the Bighorn slope smoothly outward from the high axial peaks of the range, but end abruptly in a steep descending scarp at the range front; projections of the slopes across and above the present lowland define in a general way the form of the basin floor at the culmination of the period of aggradation._/

_/ Darton, N. H., Description of the Cloud Peak-Fort McKinney quadrangles, Wyoming: U.S. Geol. Survey Atlas, Vol. No. 142, pp. 8,9, fig. 21, 1906.

Drainage Pattern of the Wind and Bighorn Rivers

The Wind River flows to the southeastward along the approximate center line of the Wind River Basin. That position represents a balance between the large stream flows, but light sediment loads of the streams draining the northeastward slopes of the high and rugged Wind River Range and the small stream flows, but greater quantities of debris in the streams draining the southern slopes of the Owl Creek and Absaroka Mountains. Below the confluence of the Popo Agie and Wind River, the Bighorn River occupies a position to the east of the basin center, turning abruptly northeast and then north and leaving the Wind River Basin through the canyon of the same name.

Below the Wind River Canyon, the Bighorn River has been forced to the eastern margin of the Bighorn Basin by the outpouring of detritus from the Absaroka Mountains, no higher, but much heavier contributors of stream flow and sediment than the Bighorn Mountains to the east. The river cuts across a low anticline through Sheep Mountain Canyon, below Greybull, Wyoming, and leaves the basin and the state through the deeply incised canyon across the northern end of the Bighorn Arch.

Below the mouth of the Bighorn Canyon, the river emerges on to the wide, flat plains of its lower reaches in Montana. It flows thence in a meandering course through a region of low relief to its confluence with the Yellowstone River. The slope of Wind River from the foot of the Mountains to the confluence with the Popo Agie River is about 24 feet per mile. In contrast, the average slope of the Bighorn River is about 6.5 feet per mile.

Degradation of the Basins

The high silt content of the present Bighorn River and many of its tributaries clearly indicates that degradation of the region, which began in late Tertiary time, continues. The waste water from the irrigation projects and the runoff from the rainstorms which fall on the valley floors and lowlands gather up and transport large quantities of the soft, friable sediments that compose much of the land. Local temporary base levels have been established along the course of the Bighorn River at four points--at its confluence with the Yellowstone River, and by resistant rocks at the head of the Bighorn Canyon, near the Wyoming-Montana State Line, at the head of Sheep Mountain Canyon, and at the head of the Wind River Canyon--greatly limiting its downcutting. While the Bighorn River is itself apparently flowing at or close to grade between the local base levels, none of the tributaries ~~has~~ have approached that condition, with the possible exception of the Little Bighorn River in Montana. what is grade?

Stream Piracies in the Wind River and Bighorn Basins

Of interest in a resume' of the physiographic history of the Bighorn River region are the stream piracies which have occurred. The most noted of these piracies are the Wind River from its southeastward course to the Sweetwater River to its present course down the Bighorn; / the Grey-

/ Branson, E. B., and Branson, C.C., Geology of Wind River Mountains, Wyoming: Am. Assoc. Petrol. Geol. Bull., Vol. 25, p. 147, 1941.

bull River from its course across Emblem Bench and down Dry Creek to its present channel; and the Shoshone River from its former course through Polecat Valley and Pryor Gap to its present course. //

// Mackin, J. H., Erosional History of the Bighorn Basin, Wyoming, Geol. Soc. of American Bull., Vol. 48, pt. 1, p. 852, 1948.

The Wind River piracy probably occurred near the beginning of the present cycle of erosion, while much of the Wind River Basin was still filled to a high level with Tertiary sediments. The present Wind River flows southeastward through the Wind River Basin to a point near its center at Riverton, where the Popo Agie joins to become the Bighorn River.

The Bighorn turns sharply northward and leaves the basin through the Wind River Canyon. This peculiar bend of the stream is best accounted for by the assumption of its capture from the Sweetwater drainage by a headworking tributary of the Bighorn River. The former course is apparently delineated by a low gap in Beaver Rim, southeast of Lander.

The ancestral Greybull River in its sequence of degradation has left several erosional remnants to mark its prehistoric course. Of these, the oldest is Tatman Mountain, or more distinctively, Tatman Bench, the highest and oldest surface in the sequence of degradation. It lies 8 miles south of the river, and 1,230 feet above its present level. Its table-like surface, limited on all sides by steep erosional scarps, forms the divide between the Greybull Valley and an extensive badlands area drained by Fifteenmile Creek and minor streams. This bench is the highest and oldest gravel-capped erosion remnant in the Bighorn Basin. From its crest, the superb panorama includes almost the whole of the desolate waste of fantastically dissected badlands of the basin floor, interrupted by the perfectly smooth slopes of numerous highstanding lateral corrasion remnants and by the green valleys of the present streams, and surrounded on all sides, except the north, by snow-capped ranges.

Next, below the Tatman Bench are several discontinuous bench remnants, of which the Y. U. Bench is the largest. This is followed by the third stage of degradation, the Emblem Bench, which is approximately 360 feet lower than the Y. U. Bench and continuous for nearly 70 miles from the Greybull Canyon above Meeteetse to the confluence of the Greybull with the Bighorn River. In the western half of the Greybull basin, the remnants of the old Emblem Valley Floor are present as normal river terraces on one or both sides of the present valley, but near the center of the basin, the gravel-mantled surface, maintaining its smooth eastward slope, crosses a low divide and continues to the Bighorn River, in the valley now occupied by Dry Creek. /

/ Mackin, J. H., Erosional History of the Bighorn Basin, Wyoming. Geol. Soc. of America Bull., Vol. 48, Pt. 1, p. 828, 1948.

Much direct evidence points to the fact that the Shoshone River formerly flowed across the Polecat Valley and through Pryor Gap, to join the Yellowstone through what is now Pryor Creek. The capture of the Shoshone was accomplished by a head-working tributary of the Bighorn reaching the Shoshone River at a point about 40 miles upstream from the confluence of the capturing stream with the Bighorn and 70 miles upstream from the confluence of the Shoshone with the Yellowstone.

Glacial Action in the Basins

Two and possibly three, glacial stages have been recognized in the mountains bordering the Bighorn and Wind River Basins. / Moraines of the last, presumably Wisconsin, stage, stand near the present river levels at or near the mountain fronts in Rock Creek, Clark Fork, and Greybull Valleys and at the debouchment of the tributaries draining the Wind River Mountains to the Wind River along its upper reaches. While the glaciers

/ Bevan, Arthur, Glaciation northeast of Yellowstone National Park (abstract): Geol. Soc. of America Bull., Vol. 42, pp. 325-326, 1931.

themselves and the moraines which they formed were not great contributors to sedimentation from the basins, the greater precipitation during their period of existence must have caused heavy erosion over much of the basins and been responsible for the heavy valley deposits of floodplain material and incoherent alluvium in which the streams are flowing.

Wind Action

The action of the wind in effecting the erosion transportation and exportation of material comprises deflation. Deflation, therefore, is the counterpart of the term degradation as used in the discussion of streams. While the results of the action of wind are not usually as spectacular as those of mountain glaciers and rivers, the wind has in the past and is at present continually removing rock particles from those areas of the Bighorn River Drainage Basin that are poorly protected from its work by a dry land surface and a sparse vegetational cover. These areas, for the most part, are restricted to the semi-arid basin floors.

It is customary to associate the work of wind with the large sand dune areas in the desert regions of the earth. However, sand dunes are only a small part of the land formations resulting from wind action. In the Bighorn River Drainage Basin most of the rather small sand dune areas occur along the south flank of the Absaroka range and on the higher lands of the basin floor.

Perhaps the least noticed but one of the most numerous of the wind forms in the region are the depressions, found here and there on the basin floors. Most of these wind blown basins are small and locally are called "Buffalo Wallows" but many cover large areas and represent millions of tons of dust and sand that have been removed by the wind. One of the large depressions carved by the wind is now the site of Ocean Lake which is in the heart of the Riverton Irrigation Project.

As yet it has not been possible to estimate with any degree of accuracy the amount of material eroded each year by the wind, but it is evident that the amount is quite large in semi-arid regions such as is the larger part of the Bighorn River Drainage Basin.

The Canyons of the Bighorn River

Prominent configurations in the landscape of the Bighorn River Drainage Basin are the three major canyons which the river traverses in its course. These are the Wind River Canyon, cut for 12 miles through the Owl Creek Mountains which separate the Wind River and Bighorn Basins; Sheep Mountain Canyon, a mile in length, beginning at a point about 8 miles downstream from Greybull, Wyoming, and cutting across Sheep Mountain anticline; and the Bighorn Canyon, beginning at the Wyoming-Montana State line and crossing the plunging nose of the Bighorn Mountain Arch as a deeply incised trench nearly 30 miles in length. Each canyon is apparently the result of the superimposition of a river whoe present course was established on an old Tertiary erosional plain. The valley walls of the trenched Tertiary sediments held the river to its previously established course even after the valleys were downcut to the buried more resistant rocks of the anticlines.

The Wind River Canyon provides passage for a railroad and a highway. The Sheep Mountain Canyon accommodates a railroad, but the Bighorn Canyon, most spectacular of the group, provides no passage for either, though a road which is little more than a rocky trail parallels the upper two-thirds of the canyon on the high plateau along the west bank.

CHARACTERISTICS OF THE PRESENT-DAY BIGHORN RIVER AND TRIBUTARIES

The Bighorn River and its tributaries are continuing the cycle of downcutting and the removal of sediments which has been active with minor interruptions since its inception in late Tertiary times. The Bighorn River and the tributaries which feed it have certain characteristics of physiography and erosional activity. These are discussed in the following paragraphs, that a better understanding may be had of the role each plays in the contribution of sediment.

Streams tributary to the Wind River from the south and draining the northern end of the Wind River Mountains originate in the pre-Cambrian heart of those mountains, but flow through Paleozoic and Mesozoic sediments along practically their entire courses. The flow of these clear mountain streams is derived mainly from snow melt and springs. The beds of the streams are of heavy glacial and stream gravels which are being very slowly eroded.

Streams tributary to the Wind River from the north are in large measure antithetic to those which enter from the south. These streams, except for those downstream from Sand Coulee, originate in the Tertiary volcanics of the Absaroka Mountains, cross on to Tertiary sedimentary formations at the base of the mountains and flow thence through those sediments to their mouths. The Tertiary sediments are easily eroded and have in places been dissected into fantastic shapes, as the badlands between Crow Creek and Dubois. The streams generally carry little flow, though cloudburst floods resulting from convection storm activity along the slopes of the mountains produce occasional high discharges, usually of short duration. The lower stream valleys are irrigated and most of the summer flow of the streams is thus consumed.

The North and East Forks of Wind River head in the high areas of the Absaroka Mountains and have generally similar characteristics to the streams tributary to Wind River from the south. Below their confluence they flow through Tertiary sedimentary formations which they are eroding.

Below the diversion dam of the Bureau of Reclamation the Wind River is flowing in a mature valley, over a bed of heavy stones and gravels with little erosion. Diversion of a large part of the river's flow at the dam also reduces the opportunity for erosion below that point.

The Popo Agie River together with its tributaries drain the southern part of the Wind River Mountains. The tributaries, except for Beaver Creek, head in the pre-Cambrian core of the range and traverse early sediments through narrow, vertical-walled canyons. Beginning a few miles to the east of Lander, the river traverses a mature valley over heavy gravels which are being slowly eroded. Most of the water is used for irrigation. Stream flow is principally from snow melt and springs.

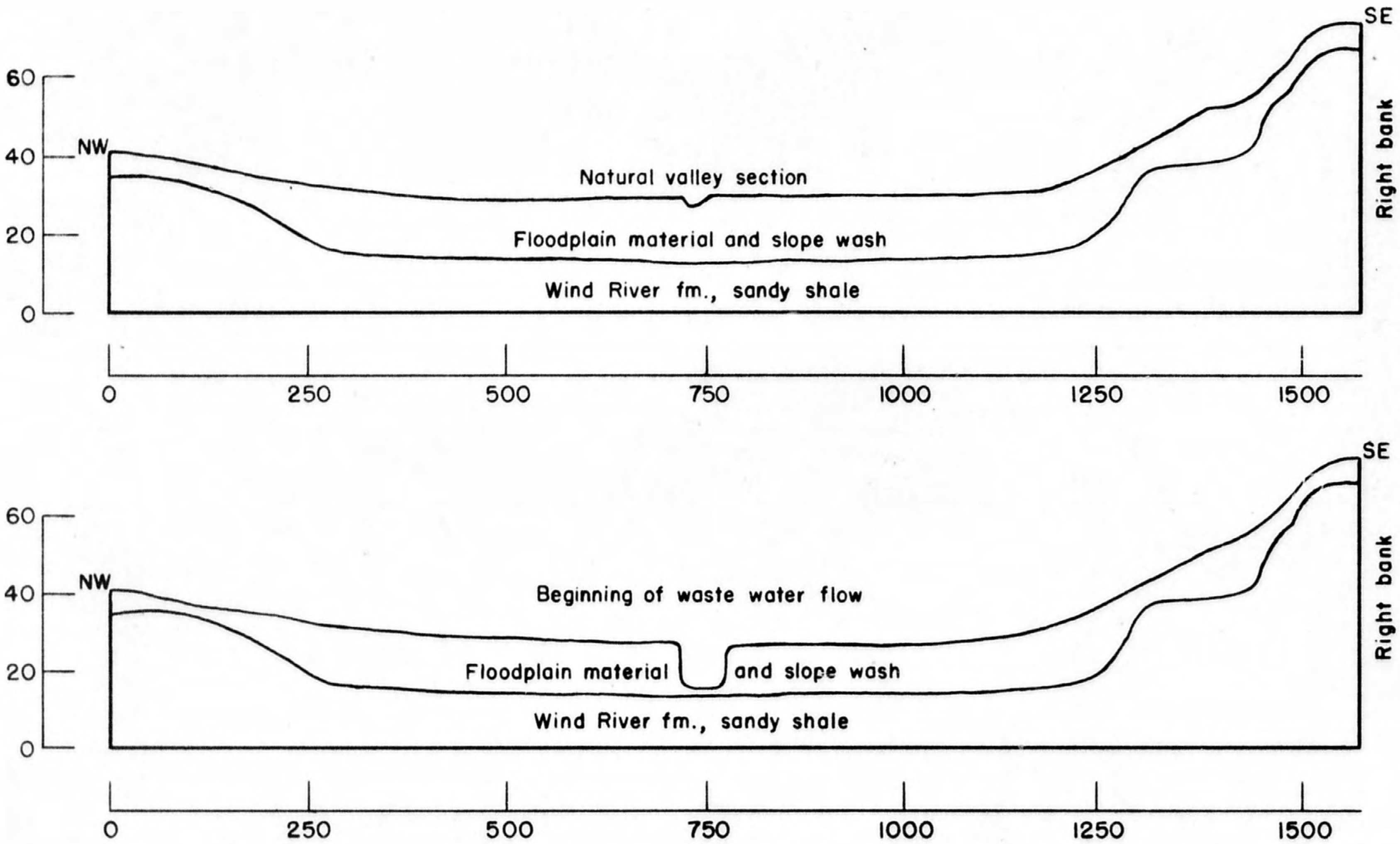
Beaver Creek rises in pre-Cambrian metamorphics of the Wind River Mountains north of Atlantic City. On leaving the mountains it flows over later Tertiary formations, drops rapidly down from Beaver Rim through Paleozoic sediments and thence flows across Tertiary sediments to its mouth south of Riverton. There is little erosion along the stream valley above the crossing of the Paleozoics, but below that point erosion is very active, being limited only by the light precipitation from convection storms on the valley floor and consequent runoff. Stream flow in the upper reach originates from snow melt and springs, most of which is taken out for irrigation along the middle reaches.

The Bighorn River, which is formed by the confluence of the Wind and Popo Agie Rivers, continues the meandering course of the latter streams with the characteristics of a mature stream flowing at or only slightly above grade. Its bed is composed of heavy gravels which inhibit downcutting. Some lateral corrasion is apparent, though such action is limited.

The Bighorn River, in passing through the Wind River Canyon, crosses pre-Cambrain and Paleozoic rocks which, with one or two minor exceptions, are not easily eroded. Little sediment is gathered by the stream in this reach.

The first major local base level along the Bighorn River has been established over the metamorphic pre-Cambrian rocks at the head of the Wind River Canyon. This has greatly slowed downcutting in comparison to

PLATE 23



Section across Fivemile Creek at wide section, SE1/4 section 18, T3N, R6E
Showing progressive stages of erosion

lateral corrasion in the Wind River Basin resulting in the mature valley characteristics of that region.

Fivemile Creek rises along the lower slopes of the Owl Creek Mountains to the northwest of Pavillion, Wyoming. Except for its extreme upper end, the stream flows across Tertiary and Quaternary sediments that are easily eroded. Much of the stream course is bordered by incoherent alluvium, flood-deposited during wet cycles in the past, which is now being eroded. Rainfall is slight and intermittent along the stream valley. Little snow runoff occurs, because of the low elevation of the headwaters. Convection storms cause occasional flash floods of short duration but are accompanied by heavy sediment movement.

Prior to 1923, Fivemile Creek has been described as an ephemeral stream with a channel considered to be normal for that area. During that year, a flood of 3,500/ second-feet (estimated) occurred which

/ Follansbee, Robert and Hodges, Paul V., Some Floods in the Rocky Mountain Region: U.S. Geol. Survey Water-Supply Paper 520-G, p.111, 1925.

caused extensive channel scour and some gullying in headwaters of minor tributaries.

In 1928, a part of the Riverton Irrigation Project of the Bureau of Reclamation was completed. The irrigation of lands on this project resulted in a rise in the water table which in turn made drainage imperative in some areas adjacent to Fivemile Creek. The drainage waters flow into Fivemile from a series of drains beginning at a point about 25 miles above its confluence with the Bighorn River. The stream is no longer intermittent, but continuous in flow, carrying between 100 and 200 second-feet at its mouth/ during the latter part of the irrigation season

/ Parker, Glen L. et al, Surface Water-Supply of the United States 1941, Part 6, Missouri River Basin: U.S. Geol. Survey Water Supply Paper 926, p. 146, 1943.
Parker, Glen L. et al, Surface Water-Supply of the United States 1942, part 6, Missouri River Basin: U.S. Geol. Survey Water Supply Paper 956, p. 148, 1944.

and dwindling to a few second-feet during the winter period. This large discharge, coupled with that from summer rains, has resulted in extensive erosion of the bed and banks.

The main canal of the Riverton irrigation project of the Bureau of Reclamation crosses Fivemile Creek north of Pavillion. After Fivemile Creek enters the irrigation project, the characteristics of the stream are greatly different than those above. Waste water leaving the irrigated lands of the project contributes flow into the stream, increasing in amount toward its mouth.

Fivemile Creek has deepened and widened its channel from the edge of the irrigation project to the confluence with Ocean Lake Drain. For some distance below that point, the downcutting has been delayed by a sandstone member of the Wind River formation which ends abruptly in a 20-foot falls. From this falls to the mouth, the stream has both deepened and widened its channel, there being reaches where the formerly narrow, intermittent stream is in excess of 1,000 feet in width. In this reach resistant members of the Wind River formation have in one case held the stream from lateral corrasion by confining it to a narrow channel incised in sandstones and siltstones, while a short distance downstream the stream has worked laterally to a great width in flood plain deposits while downcutting to the top of the resistant layers.

Muddy Creek is an intermittent stream rising along the south slopes of the Owl Creek Mountains, flowing southeast essentially parallel to Fivemile Creek and 5 miles northeast of it. This stream receives a small flow in the spring from snowmelt along the foothills at its head and intermittent flood flows from convection storms in summer. Such a storm occurred in 1923 and resulted in a discharge of 16,300 second-feet./

/ Follansbee, Robert and Hodges, Paul V., Some Floods in the Rocky Mountain Region: U.S. Geol. Survey Water-Supply Paper, 520-G, p.111, 1925.

Throughout practically its entire length Muddy Creek flows over Wind River sedimentaries. Much of the valley has been eroded laterally and filled back with floodplain materials. At a road crossing near the mouth, the channel has filled several feet with alluvium, to the extent that a small iron bridge has been underfilled nearly to the floor beams and the channel passes around the left abutment, being bridged by a wooden trestle. It is interesting to note that the channel of Muddy Creek has filled in since the 1923 flood whereas the channel of Fivemile Creek has widened and deepened.

Muddy Creek is at present contributing sediment to the Bighorn River. Intermittent storm flows carry heavy sediment loads, but are usually of short duration, though occasionally of high intensity. The Bureau of Reclamation is now construsting an addition to the Riverton project, the waste water from which will enter Muddy Creek.

PLATE

View upstream of Muddy Creek three miles above the mouth. Note how the sandstones and siltstones of the Wind River formation, covered by terrace gravels and floodplain material, have been undercut.

Badwater Creek two miles above confluence with the Bighorn River. Note the dry channel.

Poison Creek enters the Bighorn River opposite the mouth of Fivemile Creek and drains an area of high plains and rolling topography to the south and east of Shoshone, heading approximately 20 miles to the southeast of Moneta. The valley bed and sides are composed of floodplain material and Tertiary sediments, with Paleozoic exposures for a few miles at the head of Canyon Creek, tributary from the south. As the drainage basin is some distance from the Owl Creek Mountains to the north, it is beyond the range of severe convection storm activity and the runoff is small. Little erosion takes place except during storm periods. Muskrat Creek, a companion stream to the south, has very similar characteristics.

Badwater Creek drains the southern slopes of the Owl Creek Mountains extended to the eastward of the Wind River Canyon, joining the Bighorn River opposite Muddy Creek. All but one of the tributaries drain areas to the north of the stream, the principal one being Bridger Creek, emptying in a short distance below Lysite. Alkali Creek, an intermittent stream from the east joins Badwater Creek at Lysite.

Above the point of debouchment from the mountains, the creek and its tributaries are relatively clear, as they flow through and over resistant Paleozoic sediments. Below that point, the flow is through Tertiary sediments and Quaternary floodplain material and the stream is very actively eroding its valley. It is interesting to note that this stream has been pushed to the south side of its valley by the alluviumal outpourings from the southern slopes of the Owl Creeks. Lateral corrasion to the southward continues.

Flow in the upper reaches of the stream and its tributaries results from snow melt, but below the flank of the mountains convection storms cause cloudburst activity. An intense storm of this type in 1923 did $1,800,000 damage in the basin, principally to the C.B.&Q. Railroad. /

/ U. S. Department of the Army, Corps of Engineers, Yellowstone River: 73rd Cong., 2d sess., H. Doc. 256, 1934.

Most of the water along the upper reaches is consumed in irrigation and for considerable periods there is no flow at the mouth. However, during periods of storm runoff, the stream transports heavy sediment loads with alternate degradation and aggradation of the channel occurring.

The Bighorn River, on leaving the Wind River Canyon, enters the mature valley of the Bighorn Basin. The stream meanders through flood-plain terraces of low elevation, on which are the irrigated areas in the basin. The stream is performing some lateral corrasion, though not extensively, and is flowing close to grade. Some bank erosion is noted in most reaches of the river. Between Thermopolis and Worland, practically all of the summer flow is diverted for irrigation.

Buffalo Creek heads along the north face of the Owl Creek Mountains to the east of the Wind River Canyon, traversing Paleozoic sediments throughout most of its length. Some runoff results from snow melt, some from convection storms. The drainage area is small, producing little stream flow. Sediment concentration is rather high when flow occurs, but the total sediment load which the stream contributes may not be large.

Kirby Creek drains a low region through Cody shales. The lower reaches of the stream cut through considerable floodplain deposition and slump material, which erodes readily. There is flow throughout the year at the upper end of the stream, all of which is taken out for irrigation during the summer season. Flow along the lower reaches occurs primarily from convection storms and is intermittent, but may carry heavy sediment loads.

No Water Creek flows through a region of eroded early Tertiary sediments. It carries high concentrations of sediment when flow occurs, but the drainage is mainly from a region of low relief, away from the mountains, and runoff results only from occasional storms with the exception of some irrigation waste water which enters the stream near its mouth.

Owl Creek headsalong the northeast slopes of the Absaroka Mountains and the north slopes of the Owl Creek Mountains. The stream forms in two drainage basins, North Fork and South Fork, dominated at their western end by Washakie Needle, 12,495 feet above mean sea level. The flow above the confluence of the forks is derived primarily from melting snow and it varies little during the period of heavy snow melt in the spring. The streams leave their intermontane basins through deeply incised canyons and join in a wide valley at the foot of the Owl Creek Mountains. The North Fork rises in the Tertiary volcanics of the Absaroka Mountains; the South Fork in the pre-Cambrian and Paleozoic rocks of the Owl Creeks and below their confluence Mesozoic sediments are traversed. The valley bordering the lower stream is wide and flat, composed primarily of floodplain material, with terrace gravels as discontinuous remnants. Several irrigated ranches have been developed in this reach. Mud Creek joins Owl Creek, from the south, 6 miles upstream from the mouth of the latter. It heads along the north flank of the Owl Creeks and the name is descriptive, as considerable sediment is carried when stream flow occurs.

Below the confluence of the forks, Owl Creek is subject to convection storm activity and flash floods occur. Considerable sediment is transported at such times, as the stream is actively eroding its banks. The stream bed is covered throughout much of its length by heavy gravel and downcutting is inhibited. Some return flow from irrigation enters near the mouth.

Cottonwood Creek and its principal tributary, Grass Creek, drain a region of medium relief east of the Absaroka Mountains. The stream is cut off from mountain drainage by the headwaters of Owl Creek, Wood River, and, to some extent, Gooseberry Creek. The flow is intermittent, occurring as the result of melting snow or foothill storms. The stream flows through Mesozoic and earlier sediments along its upper course, entering Tertiary material 15 miles above its mouth. When flow occurs, considerable sediment is transported.

Gooseberry Creek drains a region similar to that of Cottonwood Creek, but flows over Tertiary materials for more than 30 miles. The valley floor is covered by floodplain deposits, a mile or more wide, and sufficiently level for irrigation. Flashy, intermittent flow primarily from convection storms is conducive to heavy sediment transportation.

View upstream near the mouth of Cottonwood Creek. Steel revetments now on inside of meander were placed on the outside of the meander in 1937.

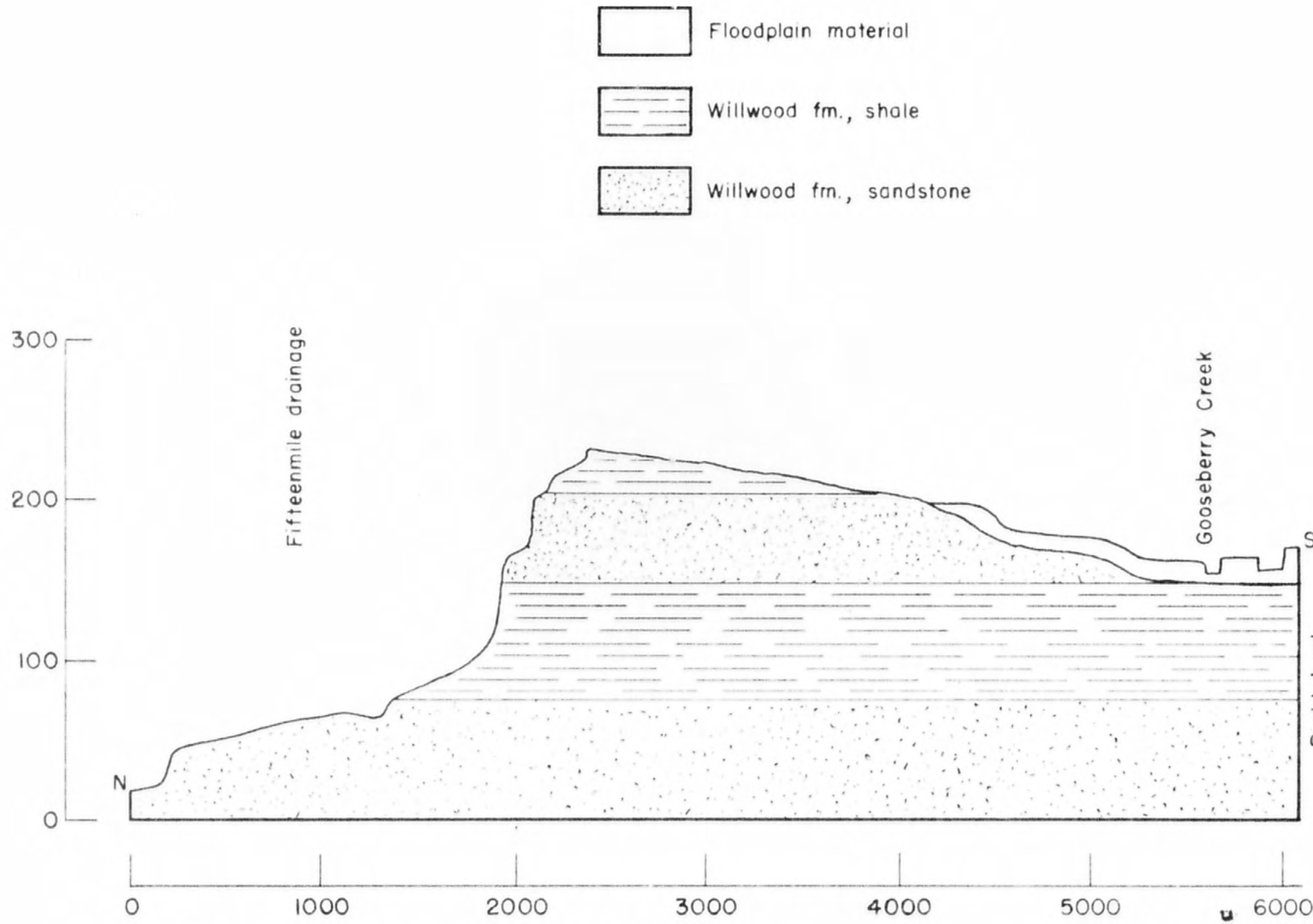
Bighorn River and valley looking downstream from Sheep Mountain Canyon.

Fifteenmile Creek drains a broad, fan-shaped area of fantastically eroded Tertiary sediments, bounded on the south by Gooseberry Creek, on the north and west by the Greybull River. Tatman Bench lies along the watershed to the northwest. The basin of this stream contains several remnants of Quaternary gravel-capped terraces, the most southerly of which forms a low divide between Gooseberry and Fifteenmile Creeks. Flow results primarily from convection activity, and high concentrations of sediment obtain during periods of runoff.

Nowood Creek is the third largest tributary stream in the Bighorn Basin in point of flow, gathering in all drainage from the west slopes of the Bighorn Mountains northward from the junction with the Owl Creek Mountains to a point 10 miles northwest of Cloud Peak. It is second largest in drainage area, 1,900 square miles, being exceeded only by the Shoshone River, 2,700 square miles, and exceeding the Greybull, 1,200 square miles.

All tributary flow of consequence is from the east, the largest tributaries being Tensleep and Paintrock Creeks. Flow in these streams originates along the high slopes of the Bighorns and is from snow melt and springs.

Nowood Creek flows in a general northwesterly direction, in and parallel to a series of anticlines. It is cut off from the extensive Tertiary deposits to the west by the Nowood, Bonanza, and Manderson anticlines. Terrace gravels are prominent along the valley. Considerable floodplain deposit is present along which some irrigated ranches are situated. The stream flows continuously and is a heavy contributor



Section across Gooseberry and Fifteenmile Creeks, east line section 25, T47N, R3E

Direction North—South

Aug. 24, 1948

PLATE 28

of sediment, obtained by active erosion of the floodplain and the soft sediments of the valley sides.

The Greybull River is the second largest tributary in the Bighorn Basin in point of flow and third in drainage area, being exceeded by Nowood Creek and the Shoshone River. It heads along the northeast slopes of the southern portion of the Absaroka Mountains.

The stream begins in the Tertiary volcanics of the Absarokas, flows thence across a short stretch of Tertiary sediments, then across Mesozoic formations returning to Tertiary sediments and continuing through them to near the mouth, where for a short reach Mesozoic sediments are encountered.

The Greybull River is actively eroding the sediments over which it flows, particularly the Tertiary of its lower reach. During its history, it has formed successively several surfaces of planation, now represented by Tatman Bench, Y.U. Bench, Emblem Bench, and its present valley. During the Emblem Bench stage it occupied the lower 15 miles of Dry Creek to the north, from which it was captured and diverted to its present course.

The stream bed is heavily covered with gravels from the Absaroka Mountains and its cutting is now confined mainly to lateral corrasion. Flow is maintained by melting snows in the upper reaches of the drainage basin, augmented at times during the summer period by convective storm activity along the mountain front. The lower 20 miles of the river gathers considerable sediment from erosion activities and from waste waters from irrigation.

Shell Creek rises in the pre-Cambrian formations along the top of the Bighorn Mountains to the east of Greybull. It plunges off these mountains through a deeply cut canyon across all the sedimentary rocks from the Cambrian to the Cretaceous. It flows over the latter in a broad, mature valley from the foot of the mountains to its mouth. The stream flow is primarily derived from snow and rainfall on the Bighorns at the streams head. Most of the water is taken out for irrigation of several ranches at the foot of the range. Little sediment is transported by this stream.

Dry Creek, in contradistinction to Shell Creek, is an intermittent stream draining the Tertiary formations to the west of the Bighorn River through a region of low relief, between the Greybull and the Shoshone Rivers. It receives little precipitation except from occasional convection storms and light snows. However, waste water from the irrigated lands on the Emblem Bench to the south contributes a material flow to the stream along its lower reaches. This flow is causing considerable erosion of the Tertiary sediments and the floodplain alluvium along the stream channel. This stream is a major contributor of sediment to the Bighorn River.

The Bighorn River between Sheep Mountain Canyon and Bighorn Canyon crosses the Sheep Mountain Arch, 6 miles below Greybull, through a narrow canyon, a mile long and over 500 feet deep, with vertical walls approximately 300 feet apart. On emergence the river flows through a region of complex geology, characterized by much folding and faulting. The river, is meandering, but gives indication of flowing above grade, with consequent active erosion of its beds and banks. At one point, about midreach, a large island was removed during the spring of 1948 and cottonwood trees at least 40 years old_/ were undercut and dropped

_/ Statement of local resident.

into the river. In all likelihood a considerable amount of sediment is contributed by this erosive action.

The Shoshone River is the largest tributary stream in the Bighorn Basin, both as to drainage area and as to stream flow. It heads along the eastern slopes of the Absaroka Mountains in the region east of Yellowstone Park. Above their confluence in Buffalo Bill (Shoshone) Reservoir, the North and South Forks flow through the Tertiary volcanics which form the Absaroka Mountains. Below the reservoir, the stream is in a deeply incised canyon across the Rattlesnake Mountain anticline. As it leave that gorge, it drops at the rate of 25 feet per mile. This rapid fall represents nice adjustment to the transportation of a great load of coarse waste._/ The river, on leaving the canyon through the

_/ Mackin, J. H., Erosional History of the Bighorn Basin, Wyoming, Geol. Soc. of Am. Bull., Vol. 48, pt. 1, p. 828, 1948.

anticline, flows through Tertiary and Mesozoic sediments and is laterally planing its valley, being inhibited from downcutting by the heavy gravels in the bed.

Beginning at the foothills of the Absaroka Mountains and extending to the mouth of the river along its north side is a high, level bench, up to 15 miles in width. Much of this bench is now under irrigation by the Shoshone project of the Bureau of Reclamation and canals for the irrigation of additional land are being constructed. Waste from this irrigation is returned to the Shoshone River through Alkali, Sage, and Dry Creeks. The flow is appreciable during a part of the year resulting in excessive erosion in certain areas.

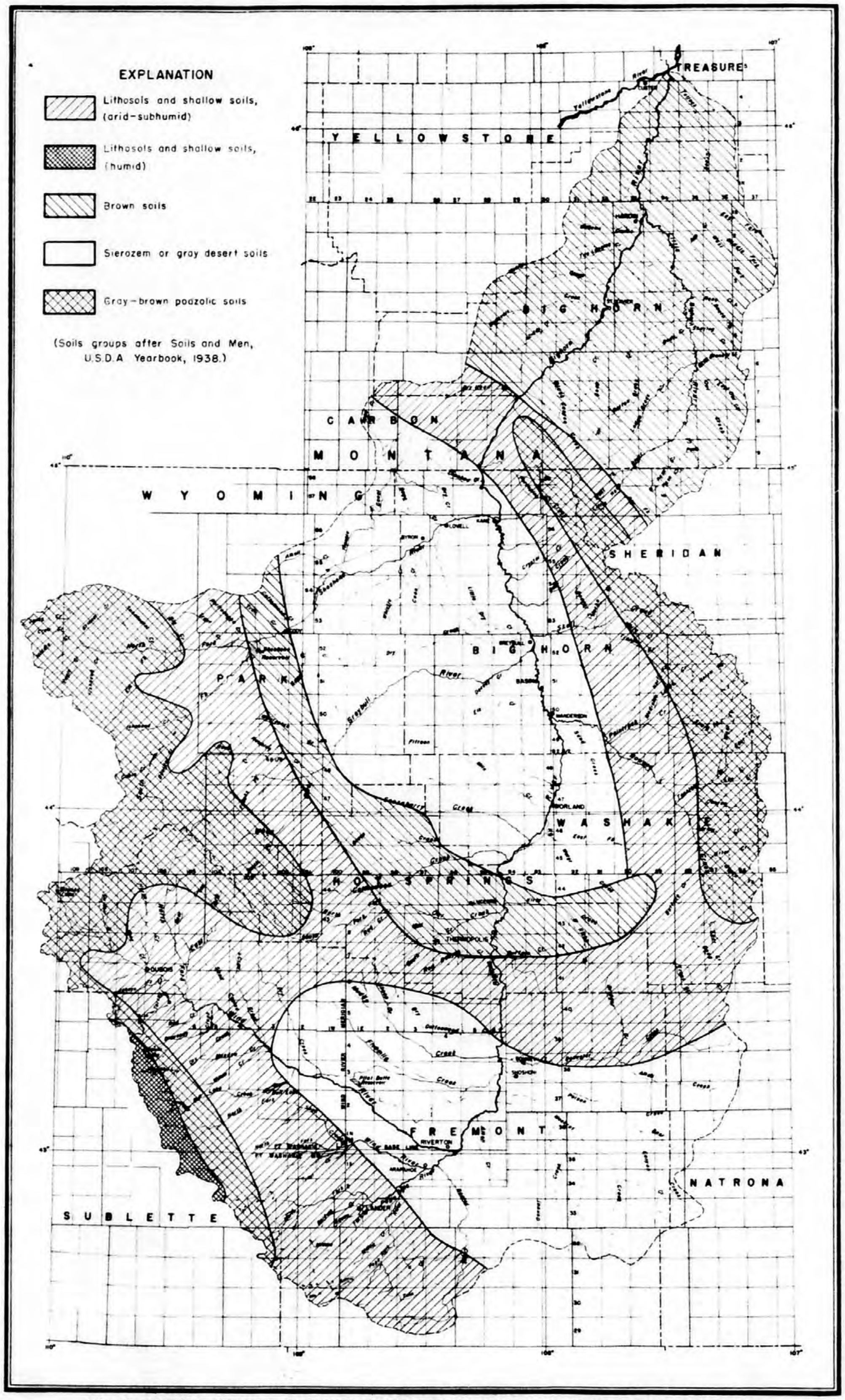
Only two tributaries of consequence enter between Dry Creek and the Shoshone River. These are Crystal Creek and Bear Creek heading in the Bighorn Mountains and traversing pre-Cambrian, Paleozoic, and Mesozoic rocks. The flow of these streams is small and is used for irrigation.

The Bighorn River leaves the Bighorn Basin through the north end of Bighorn Arch in a narrow, deep canyon. The river in this reach is flowing practically at grade, but the several small tributary streams are far above grade. Little sediment is produced in the reach, as the canyons of the river and the tributaries are in Mesozoic and Paleozoic formations which are not easily eroded.

Below Bighorn Canyon, the river enters a wide, gently rolling region of mature age, across which it meanders widely. Some lateral corrasion is occurring, but the stream is close to grade and downcutting is slow.

The Little Bighorn River heads against the northeast slopes of the Bighorn Mountains along the north edge of Wyoming and flows generally north to its confluence with the Bighorn River at Hardin, Montana. Except near its head, this stream also is flowing close to grade in a mature valley, through floodplain and Tertiary material. Stream flow is derived from snow melt and springs in the upper reaches of the basin and convection storms below the mountains. Much of the water is used for irrigation. Little sediment is carried by the stream except during

49-83



SOILS GROUPS OF THE BIGHORN RIVER DRAINAGE BASIN, WYOMING & MONTANA

SCALE 1/1,000,000

MILES

PLATE

flood periods resulting from snow melt or summer storms, when the load may be heavy for short periods.

SOILS OF THE BIGHORN RIVER DRAINAGE BASIN

Soil is a natural body on the surface of the earth in which plants grow, and is composed of organic and mineral materials. It is the product of the action of living organisms and the effect of climate upon the parent rock material conditioned by the local relief over a period of time. The principal factors of soil formation are: (1) parent material; (2) climate; (3) biological activity (living organisms); (4) relief; and (5) time._/ These soil factors are interdependent,

_/ Soils and Men, U.S. Department of Agriculture, Yearbook, 1938.

each modifying the effectiveness of the others. The effect of relief on climate which in turn effects the soils and vegetation is quite evident in the Bighorn River Drainage Basin. The soils range from desert soils, typical of an arid region on the basin floor to podzol soils, typical of a humid region on the upper slopes of the mountains. Thorp_/ observed that

_/ Thorp, James, The Effects of Vegetation and Climate Upon Soil Profiles in Northern and Northwestern Wyoming, Soil Sci. 32, pp. 283 to 302.

differences in climate in northern and northwestern Wyoming, due to the great variation in elevation, brought differences in vegetation and soils that were closely allied with those of climate. In this study, he divided the soils of this region into 6 major classes corresponding to 6 of the major soil groups.

The soils of the Bighorn River Drainage Basin are those which might be expected in a mountainous arid region. Soils on the basin floor are desert soils while those on the slopes of the mountains are Lithosols or rock soils. Gray-Brown Podzolic soils occur on the upper slopes of the mountains which is the region of highest precipitation and Brown soils occur on levels at intermediate elevations and in the Bighorn Valley. Desert soils cover the greatest area of the region followed very closely in area by the Lithosols. Brown soils and Gray-Brown Podzolic soils cover nearly equal areas, but their total area together probably makes a third or less of the total area of the drainage basin._/

_/ Soils and Men, U.S. Department of Agriculture, Yearbook, 1938.

The Gray-Desert soils occurring on the floor of the Bighorn and Wind River basins vary in color from gray to red depending on the parent material._/ Under natural moisture conditions of 5 to 10" of annual

_/ Dunnewald, T. J., and others. Soil Survey of the Shoshone Area, Wyoming, U.S.D.A. series, 1927 No. 38.
Thorp, James and others. Soil Survey of the Basin Area, Wyoming, U.S.D.A. series 1928, No. 27.

rainfall, these soils are but slightly leached and are rich in mineral plant nutrients, but low in organic matter. Under natural conditions, this land is useful only for livestock range, but with irrigation the soils are highly productive except where high concentrations of soluble salts and poor drainage produce alkaline conditions. The parent material of the Gray-Desert soils is the alluvial debris, largely from sandstones, siltstones, shales, and limestones, which composes a series of gravel terraces laid down in Tertiary and Quaternary times. These terraces range from 20 to several hundred feet above the levels of the chief river courses of the region and constitute a large portion of the high lands of the basin floors. Native vegetation of the desert soils consists of desert shrub such as shadscale, saltbrush, rabbitbrush, sagebrush, and a thin growth of grasses in places. Greasewood and seepweed occur in land of high salt content.

Lithosols and shallow soils occur on the slopes of the Wind River, Absaroka, Owl Creek, Bighorn, and Pryor Mountains. Lithosols are a group of soils which have no well developed profile characteristics and consist of a highly and imperfectly weathered mass of rock fragments. The Lithosols of this region are largely confined to steeply sloping land and are mostly of the arid, subhumid type except for a small area of Alpine Meadow Lithosols of the humid type on the upper slopes of the Wind River mountains. These soils vary greatly in color, texture, structure, depth, stoniness and relief in short distances, but are mostly shallow, stony and lacking in very definite profile development. Lithosols on the ridge tops and south slopes have brown to dark brown subsoils, but on the north slopes where the timber is heavy, the soils below the dark leaf mull are light brown and leached. Parent materials of the Lithosols in this area are a great variety of igneous, sedimentary, and metamorphic rock, either in place or in the form of talus slopes, outwash fans, or terraces. Native vegetation on the mountain slopes consists of open stands of conifers with undergrowth of sagebrush and other shrubs, bunch grass and flowering herbs. Other places have small rather dense groves of aspen or lodgepole pine with open areas of sage-

View across erosional plain north of Riverton, Wyoming.

View along the south flank of the Owl Creek Mountains near Boysen Dam site, showing dissected Wind River formation overlapping the steeply south dipping older formations in the background. Note the table-like pediment remnant in the center.

brush and grass. Native vegetation on the soils on the plateaus consists of sagebrush and open juniper woodland, with a scattered growth of bunch grass.

Brown soils occur in the Bighorn Valley and on the south and west sides of the Bighorn Basin. Brown soils exist in a temperate or cool semi-arid climate under a vegetative cover of short grasses, bunch grasses, and shrubs. The mean annual precipitation for areas of brown soils in this region ranges from 10 to 18 inches. The surface soil to a depth of 7 to 10 inches is grayish-brown or gray. The subsoil is grayish-brown or brown to a depth of 12 to 16 inches, below which the soil is under lain by light-gray, very calcareous material, which is in turn under lain at 24 to 30 inches by the parent material of shale or sandstone.

The Gray-Brown Podzolic soils of this region, probably of the Helmer-Santa-Benewah association of soils, occur on the upper slopes of the Bighorn, Absaroka, and Wind River Mountains. The average annual rainfall for this area is 20 to 40 or more inches. The summers are comparatively dry with a short growing season while the winters are severe and snowfall is heavy. Native vegetation is coniferous forest consisting mainly of species of pine, fir, hemlock, and spruce. Parent materials of this area are mainly bedrock of granite, schist, quartzite, argillite, basalt and rhyolite. The Gray-Brown Podzolic soils of this area are light-brown to brown with a thin to thick surface layer of forest litter, and feebly-developed ashy gray podzolic layer in the sheltered and more heavily forested areas. They usually have a granular or single-grain floury structure.

The factors which largely govern the rate of erosion of soils are precipitation, relief, and the amount of vegetative cover present. The Gray-Desert sails which cover the floor of the basins offer the minimum resistance to erosion because of the sparseness of native vegetation and friableness of the soil. The Gray-Brown Podzolic soils which occupy the upper slopes of the mountains, offer the greatest resistance to erosion as they are the most consolidated and developed and have the most natural cover.

EROSIONAL FEATURES OF THE BIGHORN RIVER UPLANDS

General Statement

Under this heading there are considered the processes and progress of erosion away from the main streams--chiefly the gullying and sheet erosion that are a cause for so much concern in this area as well as other parts of Western United States. The studies in connection with this phase of the erosion-sedimentation investigation are being conducted under the soil and moisture program of the Water Resources Division, which is concerned chiefly with the lands administered by agencies of the Interior Department. This work was started under sponsorship of the Office of Land Utilization and is being continued under both the Soil and Moisture funds and other departmental funds allotted for investigations in the Missouri Basin. As has been stated earlier in this report lands of the Interior Department, contained in Grazing Districts and Indian Reservations, occupy a large part of the Wind River and Bighorn Basins. The land except for a small fraction along the main streams on the Indian Reservation is leased or allotted for grazing of livestock. Consequently, consideration of the effects of grazing operations is of prime importance in the area.

The work of the Geological Survey in this area has been closely allied with the land classification and conservation activities of the Bureau of Land Management and Office of Indian Affairs. The land agencies under their Missouri Basin Investigational program, have, in general, assembled an inventory of the extent and severity of erosion on their lands as well as having made soil and vegetation surveys. Incidentally, most of the information concerning vegetation in this report has been obtained from the land classification reports of the land agencies or through the joint work with the staffs of these agencies in the field. The Survey not to duplicate these activities, but to supplement them--to fill the gap between land classification and the investigations of sediment movement in the main streams--is studying the causes and progress of all forms of erosion with consideration of the factors involved. The ultimate aim, of course, of these studies is to determine if possible, the prospects of controlling or retarding current erosion and to obtain information relative to the type of control facility most adaptable for a given locality or set of conditions. The studies entail collection and correlation of data on a large number of erosional features, and the establishment of facilities for quantitative measurement on selected representative areas. In the course of this work, which has been in progress on a small scale for about 2 years, a number of observational plots have been established in the Wind and Bighorn Basins as well as in other parts of the Missouri Basin in Wyoming and Montana.

Factors Influencing Upland Erosion

The character and progress of erosion is dependent basically upon topography, physiography and geology, climate, soil, vegetation and land use. All these factors are more or less interrelated, although one or other may be outstanding in effect on the erosion in a given locality.

Topography--The area under consideration is diverse in Topography having features ranging from flats or gently-sloping surfaces on the valley floors and terraces to cliffs, badlands and rugged mountains. These features in themselves reflect in part the results of erosion and deposition in the geologic past. The fundamental of the erosion process probably simplest to comprehend is that material is continually being excavated from the higher and transported to the lower areas. Details of this process and correlation of the type and progress of erosion with respect to slope, however, are complex and in some places because of the influence exerted by other factors the basic relation between erosion and land slope may seem to be contradicted. It is a matter of common observation that major debris movements such as mud flows, landslides and rock falls occur chiefly in the mountains and other areas of steep slopes, also, that the eroding and carrying power of streams, other factors being equivalent, generally increase with increased gradient. Nevertheless, observations made so far in this study show that much of the silt contributed to the main streams in the Bighorn River area is derived, immediately at least, from the tracts of slight slope.

The drainage divides of the sub-basins throughout the Wind River and Bighorn Basins are characterized by a relatively rough and steep topography. Runoff from these steep slopes is rapid and quickly concentrated into small trunk drainageways where it is active in bank cutting or other excavation along the channels. Sheet erosion is most prevalent on steep slopes but the character of the soil and underlying rock seem to have as great an effect as the slope has on the severity of the erosion. The typical steep shale slopes of the Bighorn uplands are commonly marked by numerous rills, and it appears that erosion is rapid during storms. Part of this eroded material is transported to the main stream directly, whereas another part is deposited enroute where the slope decreases, but is there subject to removal by gullying.

In order to obtain further information on the relation of slope to the progress of erosion a number of erosion measurement ranges have been established in the Wind River Basin. As far as practicable the ranges were placed so as to sample differing slopes where other factors were equivalent. Also groups of ranges have been established successively along a drainageway to note the degradation or aggradation and the conditions under which changes from one process to the other takes place. In general, observations of this kind that have been initiated are not of sufficient length to permit drawing conclusions but they do suggest a trend at least in the relation of slope and erosion process. The available records are presented and discussed further under the Moneta study later in this report.

Influence of physiography and geology--The relation of physiography and geology to current erosion is well exemplified in the Bighorn River Area. The erosion-problem areas are confined essentially to the outcrops of certain rock formations and associated physiographic features.

The igneous rocks of the area are limited mainly to the high mountains. There, although disintegration of rock is comparatively rapid and there is continual excavation and movement of debris, the effect or product of erosion does not contribute greatly to the problem of land and water utilization of the area. The process of erosion in igneous rocks consists for the most part of a plucking or quarrying of rock along fractures and joints. The erosional product, is largely of coarse grain, and is transported by streams as bedload. It is deposited within the mountain reaches of the streams or within short distances of the mountain front. In some local areas as in the vicinity of Washakie Needle, there occur soft igneous rocks such as volcanic tuff and related types of rock that show relatively severe erosion--similar to that characterizing the fine-grained sandstone and shale, described below. Because of the small extent of their outcrop, however, these igneous rocks are not of great significance in the erosion problem of this region.

The older rocks of sedimentary origin in the area--the limestones, sandstones, quartzites and phyllites which also occur chiefly in the mountains--are generally similar to the igneous rocks in the grain-size of the material they supply and the influence they have on the erosion-sedimentation problem.

The injurious erosion and the production of sediments contributing to the siltation of reservoirs takes place chiefly in the foothill and the lower parts of the basins on the outcrop of the sedimentary rocks--the shales, siltstones, fine-grained sandstones and the unconsolidated alluvium, included in the group of formations from the Chugwater formation of Triassic age to those of Recent age. The outcrops of these formations are moderately to greatly dissected reflecting both current and past erosion.

Erosion of the Chugwater formation is probably the most obvious in the area. This may be due partly to the striking red color that characterizes the formation and the material derived from it, but undoubtedly the formation is moderately to highly erodible. It consists largely of soft, fine-grained sandstone, siltstone and shale and contains considerable gypsum. The gypsum is believed to have considerable influence on the erosional qualities; being soluble in water it dissolves when wet inducing slumping and breaking down of the shale or sandstone with which it is intercalated, thereby allowing for easy excavation by running water. The alluvium derived from the Chugwater is a fine textured incoherent powdery material that erodes very easily. Although a matter for consideration under erosion of the unconsolidated deposits, it may be stated at this point that the fills derived from the Chugwater are commonly severely gullied.

Parts of the Sundance and the Morrison formations are similar to the Chugwater in texture, lithology, and erosional characteristics. The great mass of black shales of Cretaceous age including the Thermopolis, Mowry and Cody shale--which have a wide distribution in the Bighorn area--are among the most erodible of the consolidated rocks. Being of fine texture they are relatively impervious to water and their runoff factor is comparatively high. They contain considerable alkali and salt consequently the mantle formed from weathering of these rocks supports only a sparse growth of plants of the most alkali-tolerant type. Thus the character of the rock exerts a control on the vegetation and indirectly is involved in the influence that the vegetation or lack of it may have on erosion. Contrasting with the black shales in surface expression and erosional characteristics are the medium- and coarse-grained sandstones interspersed among the shales. Most of these sandstones like the older sandstones and limestones are well cemented and relatively resistant to erosion.

The Wind River formation which occupies most of the lower part of the Wind River Basin and the Willwood and Tatman formations which occupy a corresponding part of the Bighorn Basin consist largely of clay-shale and siltstone with minor amounts of sandstone. On the whole, these formations probably are not as highly erodible as the Cretaceous shales. Their finger-grained constituents are not as fine-grained or as impervious as the Cretaceous shales and generally they contain somewhat less salt and alkali. Parts of the outcrops of these rocks are reflected by a gently rolling terrain on which the soil, though thin, contains both sand and material of finer grain and supports a fair stand of vegetation. In these places erosion does not appear to be severe. Because of the relative softness of the claystone and siltstone, which they contain, however, these formations form badlands, particularly near the main streams where opportunity for dissections have been the greatest. Also, the unequal resistance of the finer-textured materials and the sandstone has given rise to a steep broken terrain along the interstream divides.

Undoubtedly the badlands and other tracts of rough topography erode more readily than the smoother tracts, but there is some uncertainty as to whether they contribute as much silt to the main streams as their appearance would imply. Study of this part of the erosion problem is also being taken up in connection with the Moneta investigation.

Among the most significant of the erosion features in the Bighorn River area are those exhibited by the unconsolidated deposits--the terrace gravels and the alluvium along the stream channels. An appreciable part of the upland is represented by terraces capped by gravel. This coarse material is highly pervious and has an infiltration capacity that is rarely exceeded by precipitation. Consequently, its runoff factor is very low. Because of this and the fact that the gravel is not readily transported, erosion on the terraces is generally slight. Although rills and gullies advancing from adjacent erodible areas are attacking the steep slopes that bound the terraces, the terraces themselves are for the most part undissected. As will be discussed further the terraces are characterized also by vegetation of a different type and a greater density than that of adjacent bedrock areas.

The alluvial fills along the tributary streams are believed to be one of the main sources of sediment. All types of erosion occur on the fills, with a full transition from sheet erosion to gullying, but the gullying constitutes by far the greatest part of the problem. The fills in contrast to the terrace cappings are composed in large part of fine-grained material; their predominant constituent differs in texture from place to place, depending upon the source of material, but in most of the fills is fine sand. The alluvium, for the most part, is slightly to moderately pervious and permits infiltration of some water.

Despite the fact that the alluvium underlies the tracts of slightest slope, the alluvium is so easily eroded that its full thickness is trenched in many instances. In the Bighorn River Area, the alluvium of the fills is less resistant to cutting than any of the other rocks so that cutting, laterally downward or headward is retarded wherever other rock is encountered. Thus, meandering or swinging characteristic of some gullies in the area, and changes in gradient, at least in part, are due to the differing resistance of the alluvium and other rock.

Influence of climate--The influence of climate is reflected in erosion directly through the effects of precipitation and resultant runoff or infiltration; and indirectly through the effect of soil and vegetation.

In the Bighorn River area, most of the precipitation during the winter comes as snow, so that there is little runoff or erosion during that time. Infiltration of water derived from melting of snow and thawing of deeply frozen ground, however, may be significant in initiating erosion. Runoff resulting from melting of snow in the mountains during the spring and early summer, generally causes the highest stages of the year in the mountain streams. As this is also the time of greatest rainfall, there is some runoff from rainfall superimposed on the flow from snow melt so that in most years, flow in the major streams is then at a maximum. The accumulation of sediment derived by washing of the banks, and gathering of deposits lodged in the channels since the last high flow, in addition to that obtained directly from tributary streams, is also at a maximum.

Rainstorms of the early summer in the Bighorn area are generally of low or moderate intensity, although an occasional storm may have fairly high intensities for short periods. Consequently, high flash runoff is not common at that time of the year. However, rainfall of long duration, even though of low intensity and usually considered as the most beneficial type of precipitation, may be effective in promoting erosion. This is shown mainly in the valley fills where water passing into the ground seeps around the heads and along the sides of the existing gullies causing slumping and caving.

Surface runoff, which occurs from rainfall of moderate to high intensity, is the chief agent of fluvial erosion, nevertheless, and is necessary for continued erosion because the erosion caused by the other eroding agents could not proceed beyond a certain point unless the dislodged material were carried away. Few recorded data are available with respect to the range of rainfall intensities that have occurred in this area, but it is known from general observations and available short records that rainfall of moderately high intensity occurs in connection with thunderstorms almost every summer. Excessive rates of rainfall, so far as known are not as frequent in this area as they are in some other parts of Western United States but have been experienced in scattered localities, from time to time. It is believed from the observations that have been made that much of the apparent erosion is caused by the high flows resulting from such rainfall. The maximum progress takes place on storms in which total quantity of rainfall is great and intensities high; under these conditions the "softening up" of the ground by infiltration of water is effectuated and the loosened material is removed by surface water. Recurrent observation of gullies indicate that in some cases greater advance takes place as a result of one storm than occurs otherwise in a number of years.

In this connection, it is pointed out that much more information is needed respecting rainfall intensity and the runoff and erosion resulting from intense storms, particularly for small drainage basins. Data of this kind are urgently needed as a basis for design of proposed reservoirs for dentention of runoff and sediment as well as for general appraisal of erosion conditions.

Influence of soil, vegetation and land use--Because of their interdependence with each other and geology and climate, the soil and vegetation of the Bighorn Area shows a wide range from the one extreme in the areas underlain by shale in the arid lower parts of the basin to the other in the areas underlain by limestone or igneous rocks in the mountains. In much of the upland, except on the high mountains, the rocks are practically bare or are covered by a very thin mantle. Soil as an entity distinguishable by structure or profile is not continuous and may be absent over extensive tracts. This condition is due in part to the low average annual precipitation but probably more to the type of underlying rock. Shale bedrock which occupies a considerable part of the area, is so nearly impervious that it renders entry of water and roots of vegetation, necessary to evolution of soil very difficult; as a result the rate of soil formation is slow. The tightness of the soil and rock as well as the abundance of soluble salts is unfavorable for vegetation except salt sage, greasewood and a few other salt-tolerant plants which generally are widely spaced and supply little humus for progressive soil formation. Sandstone bedrock differing from shale produces by disintegration a highly pervious sandy mantle which drys rapidly. Again, mainly because of the paucity of precipitation the mantle decomposes and forms a soil slowly. The vegetation supported by such material consists predominantly of sage and grass. For the most part the density of vegetation is low.

Soils of the colluvial deposits reflect the characteristics of the rock from which the deposit was derived. In many places, because of the occurrence of alternating sandstone and shale, the colluvial deposits consist of a mixture of sand and fine-textured materials. The soil formed from these materials is intermediate in texture and permeability. Where the soil has been undisturbed for a considerable period of time, it supports a stand of vegetation, denser than that supported by the soil on the sandstone or shale. Soils on the alluvium forming the terrace capping and valley fills are variable in type, development and thickness, depending on the lithologic composition of the alluvium and the length of time it has been undisturbed. Most of the terraces have soils that are moderately to highly pervious, and although differing somewhat from one locality to another, these soils include some of the thickest of the area. Also, they bear vegetative stands among the densest in the area. Soils on the valley fills cover a wide range in development, thickness and texture. In certain places where deposition have recently occurred old soil is buried and no soil appears at the surface, whereas in other places the soil has been removed through scour by high water. However, in some tracts the soil is several feet thick. The vegetation varies with the soil—on soils that retain sandy or stony character and are well drained the vegetation consists dominantly of the sage-grass association whereas on fine-textured poorly drained soils it consists dominantly of the alkali-tolerant plants. With transition in soil there is an accompanying transition in vegetative type.

The interrelation of rock type, soil, vegetation and the character of the erosion is exceptionally well exhibited by a sharp change that occurs at the boundaries between the gravel terraces and shale outcrops. The terraces are characterized generally by a relatively-smooth undissected surface. They bear vegetation composed almost entirely of the sage-grass association.

On the other hand the shale areas are greatly gullied and rilled; and they bear only a sparse growth of the salt-tolerant shrubs. These differences in vegetation and erosion conditions appear on the two types of terrance consistently even though land use practices are the same and obviously the precipitation is the same. The land use being referred to in this connection is grazing. There is a possibility that equivalent grazing has a greater deteriorating effect on the shale areas than the other, but no recorded observations or specific information is available to confirm this. On the other hand, because of the consistency of the relations between the natural factors and the erosion shown over wide areas it is believed that the areas in which erosion is now most severe had that characteristic before they were subjected to grazing of domestic livestock. Although definite records are not available the Bighorn River has always been known as a muddy stream when in high water. The Powder River which carries silt in higher concentrations than the Bighorn was termed "too thick to drink but too thin to plough" by the scouts and pioneers who saw it before the land was used by white man.

It is generally believed that vegetation has an important effect on erosion progress through the binder provided by roots and the obstruction offered to runoff and silt movement. What this effect is in quantitative terms in an area such as the Bighorn however, is not known because, there are available no experimental results that are applicable. Comparisons of areas of appreciable size, as for example, drainage units of 1 to

10 square miles in which vegetation conditions are distinguishably different but other conditions equivalent would be highly desirable. Also to gain an index of the effects of grazing, comparisons of used and excluded areas would be desirable. Attempts are being made in the program now in progress to obtain such information, but areas where the land practices differ are rare. It is believed by those trained in range examination that injurious effects of overgrazing can be distinguished by current vegetative condition. Their conclusions are generally that overgrazing has contributed considerably to present conditions, and they strongly advocate grazing control. Certainly some examples can be cited where overgrazing obviously has resulted in deterioration of vegetation and has accelerated erosion. Moreover, inasmuch as proper control of grazing in the long run cannot result in loss in any way--even in the volume of forage harvested--it constitutes the one conservation practice that cannot be successfully contradicted. Nevertheless owing to the influence of the natural factors, it is questionable whether the problem areas can be appreciably changed by grazing control, artificial seeding or other land treatment practices. Conclusive information in this connection, can be obtained only by experiments, carefully conducted over a long period.

Erosion Processes

In an area having the relatively great diversity in topography, geology, climate and dependant characteristics, as the Bighorn Area has, it is to be expected that essentially all the forms of erosion are expressed to some extent. It is thought, however, from field examinations and study of all available information relating to the area that the types of erosion that constitute the greater part of the problem, with respect to both the destruction of land and to production of harmful sediment are gullying, including valley trenching and bank cutting, sheet erosion and associate transitional forms. Most of the erosion of these types occurs in the foothills and lower parts of the basins.

Other forms of erosion such as soil creep, landslides and mudflows generally associated with relatively humid climates and terrains of steep slope occur to some extent in the mountains of the Bighorn Area; but such forms of erosion, although they have not been appraised in detail, are known not to have been on such large scale, or so damaging as they have been in some other parts of Western United States. There is no record, for example, of mudflows having caused any destruction, and no evidence known indicating that such phenomena have been of large proportions and widespread. The reason for this is thought to be that the mountains in the Bighorn Area are not so greatly fractured, slopes are not so steep and storms are not so intense as they are in the other areas.

The coarse-grained debris carried by the mountain streams of the Bighorn Area, derived through the erosion that obtains in mountains, may be significant with respect to the sedimentation of reservoirs and other structures within the mountain reaches. The debris load is deposited, however, far upstream from the sites of the major reservoirs on the main streams.

Gullying--Gullying is the most conspicuous form of erosion, particularly in the tracts underlain by alluvium or other soft rocks. The formation of the deep axial gully, commonly called valley trenching, which is currently a feature of many major valleys as well as of small upland valleys of the west, probably more than any other type of erosion has directed attention to the erosion problem. The trenches advance headward by a process of caving, slumping and undercutting followed by movement of dislodged material by flood water. Although not generally realized, attrition by flowing water is only part of the process involved in gully development and may be rather small in quantitative effect.

Water passing into the ground acting both as a solvent and a mechanical agent tends to perforate the material adjacent to a cut bank causing it to lose its coherence and to slump and cave. Access to water is provided by both the granular interstices of the soil and rock and openings along cracks. The latter type of openings, particularly in fine-textured materials commonly are of considerable width and provide for greater intake than the former type. The movement of water underground is oriented along deep cracks, pervious layers of material and passageways provided by decay of deep roots and rodent and insect burrows. The effectiveness the water has in underground channeling and undermining is dependent upon the nature of the association of materials of differing textures and permeabilities and the pattern of the passageways.

It is to be recognized, of course, that the progress of the slumping and caving of banks thus caused is interdependent with the action of surface water. The action of ground water does not proceed ordinarily unless there is a surface channel providing an outlet; but the surface and ground water processes operate together beginning with a shallow cut, progressively increasing in scale.

The work of surface water consists chiefly of moving the material that has been dislodged and dropped into the channel, undercutting banks and scouring the beds of the channels. The first mentioned seems to be the most important action in most of the current gullying, because if the dislodged material were not carried out, it would tend to regain its coherence, reach a new angle of repose, and the dislodging of new bank by ground water would decrease. Undercutting of banks by surface water operates hand in hand with the action of ground water in causing caving and slumping.

Scouring of the bed of the channel in addition to the destruction connected with the deepening of the gully gives impetus to the caving and slumping at heads and sides of the gully by providing increased head for the water that enters the ground back from the gully rims. The depth to which the gullys are cut, in many if not most cases is determined by the occurrence of resistant rock. In others the depth is determined by the association of factors such as elevation of a downstream control--commonly formed of resistant rock--the magnitude of the streams and other factors which in themselves are changeable so that it is impossible to predict how deep a gully may cut at any place. A feature that is exhibited by gullies throughout the Missouri Basin is that the depth is nearly constant throughout their lengths.

A result of gullying that commonly is damaging and to some extent increases the opportunity for further progress is the lowering of the water table and consequently a decrease in vegetation.

It follows from the brief description of gullying processes given above that measures for retardation of gullying must include the control of both the water which enters the channel as surface flow and the water which penetrates into the ground near existing cuts. Some practices of gully control that have been tried have not been successful; for example, structures intended to induce ponding and infiltration of water where placed near active gullies have enhanced rather than retarded gully growth. Control of gullies, once they are well started is an exceedingly perplexing problem unless means can be found to entirely eliminate water from entering the site. As has been brought out the availability of water is the immediate necessity of gully advancement. Hence in seasons of little rainfall and no high-intensity storms, gullies generally make little or no progress; but when heavy precipitation occurs they may advance on an unprecedented scale.

For this reason, study of gullying to determine the current and potential silt production from this source necessarily must be continued for a term of considerable length including both wet and dry years. Measurements of gully growth have been established at a number of places in the Bighorn Area in the last 2 years. These are summarized in the table that follows. The change registered during this time, except where natural runoff has been augmented by artificial diversion of water, for the most part has not been great, in most places much less than would be expected from the appearance of the gully. The advances have generally corresponded with the rainfall and runoff that have occurred in the respective localities.

Table Observations of gully progress in Bighorn River Area

Designation and Location	Sub-basin	Character of Cutting	Depth of Cutting in Feet	Date Initial Survey	Date Check Survey	Progress in Feet	Remarks
Sec. 33, T46N R97W, near Thermopolis	Tributary of Cottonwood Cr.	Single headcut on main gully	14	Sept. 1947	Sept. 1948	Headcut advance about 80.	Headcut advance up axis of draw in medium textured alluvium derived from diverse rocks. Side-cuts terminate on bordering gravel terraces and bedrock. Vegetation on fill is of moderate density.
Sec. 16, T38N, R93W, nr Bonneville	Tributary of Badwater Cr.	Multiple headcuts	13	Aug. 1946	Sept. 1948	No appreciable change.	Headcuts on outwash plain between Badwater Creek and escarpment formed of Wind River formation. Material in cuts fine textured. Vegetation sparse. Although some headcuts are steep and appear active, aerial photos indicate very little change since 1936.
Sec. 18 & 18, T38N, R. 87 & 86 W, nr Arminto	E-K Creek Tributary to Badwater Cr.	Multiple headcuts	Headcuts 2 to 20. Main gully, downstream, 30.	Aug. 1946	Aug. 1947 & May 1948	No appreciable change.	Tributary headcuts in fine-textured alluvium derived from Chugwater formation. Vegetation sparse. Much caved material remaining in gullies.
Sec. 13, T34N, R91W, nr Moneta	Frazier Draw Tributary to Muskrat Cr.	Single headcut	Headcut 8. Gully downstream deeper.	Aug. 1947	Aug. 1948	About 180	Gully in broad alluvial flat. Alluvium is mainly fine sand. Slope of flat about 1 per cent. Vegetation sparse. Advance is believed to have occurred during one storm.
Tps 36 & 37 N, R 90 and 91W. nr Moneta	Moneta Draw Tributary to Poison Cr.	Headcut and bank cutting on network of gullies in drainage basin of stock-water reservoir.	Headcuts, 1 to 16. Maximum depth of gullies, 16.	July 1947	Sept. 1948	Widening--for most of gully length, 1 to 5 feet. Deepening--No change for most part; maximum 1.0. Headcuts--numerous cuts 1 to 8. Maximum 30.	Gullies generally cut full thickness of alluvium. Main gullies head on sandstone and shale of Wind River formation. Vegetation sparse. Intensive study of drainage basin of 3.3 sq. miles in progress.

Sheet erosion--Continued or recurrent erosion of surface material is evident in a large part of the Bighorn uplands. This type of erosion is commonly associated with more or less gullying and in areas where the sheet erosion is severe there is generally a full transition of the erosion forms represented. As has been implied the sheet erosion is very definitely related to the slope geology and interdependent factors of soil and vegetation. The erosion is most active on the outcrop of the shales, and siltstones and unconsolidated materials derived from them. These are the rocks which are generally the softest, have the finest texture, the highest runoff factor and support the least vegetation. Because runoff is the main influence involved, areas in which sheet erosion is severe contribute also greatly to gully erosion.

The product of sheet erosion, consisting in large part of fine-textured material contributes mainly to the suspended load of the streams, and part of it is conveyed directly from the place of origin through the upland gullies to the main streams. The remainder of the eroded material, however, is transported less distance and is deposited on the slopes or along the upland drainageways. This deposited material, of course, is subject to be taken out later by either gully or sheet erosion. The deposits derived from sheet erosion are not necessarily destructive in themselves. Generally, the fine-textured material is incorporated into the underlying material without causing a loss in fertility or in growth of vegetation. Under certain conditions, the intermixture of sandy and shaly material such as occurs on the colluvial slopes below the cliffs of the Wind River formation constitutes the better soils of the locality.

Determining the rate of sheet erosion in a given area is attended by difficulty and uncertainty. When it is considered that even relatively severe erosion, if expressed as an average annual depth for a drainage basin is as small as 0.1 of an inch or less, it is evident that direct measurement of the depth generally cannot be made in sufficient accuracy for an exact determination of average annual change. Measurements of reservoir siltation give the total sediment yield, including the amounts derived from both sheet and gully erosion; if the gully growth is then measured and adjusted for, the magnitude of the sheet erosion can be obtained. Under certain conditions, a determination of sheet erosion in a small tract can be made by measuring ground deposits derived from sheet erosion and tracing the path of movement of the material to its origin. Then by weighting indexes from a group of representative small tracts, an approximate index for the drainage unit can be derived.

Interpretation of Erosional History and its Applications

The summary of the geomorphic history of the Bighorn area presented in the first part of this report showed the profound effects of fluvial erosion and sedimentation as a factor in the evolution of the land forms during the geologic past. Of direct significance to the problem being considered herein, is the interpretation of erosional activity during Recent geologic time. Of particular interest is the tracing of events in the last few thousand years to determine how the erosion of the past--before the date of occupation by white man--compared with the erosion that has occurred since that date and with that currently in progress. Certain features of the gullies and of the sediment deposits making up the valley fills where erosion is now active indicate that the sites have been subjects alternately to erosion and deposition, and that the scale of activity of former periods may have exceeded that of the present period. Inasmuch as these features are remarkably consistent from one site to another they are believed to have resulted from a common cause, which if interpreted correctly might furnish a key to the causes of the current erosion and prospects of its control. Investigations, therefore, have been initiated involving examination of the channels and collection of historical accounts.

It is obvious that at one time the bedrock surfaces at the base of the alluvial fills were exposed and that some time later deposition occurred. Whether the first fills were subsequently entirely removed by erosion is not know but that they were trenched and again covered is shown by the presence of filled and buried gullies and buried soil horizons in the walls of the current gullies. Another characteristic of the gullies of the Bighorn area as well as of other parts of Wyoming and Montana is an inner alluvial terrace between the bottom of the gully and the surface of the valley fill. The terrace differs somewhat in position from one gully to another but most commonly it occurs about half way between the bed of the channel and the valley floor. In most gullies its relative position persists from the mouth to the head, and its gradient as well as that of the present gully bed is generally equal or nearly equal to that of the valley floor.

This surface represents either a level down to which a former channel was cut or the surface of a deposit laid in a trench that had been previously excavated. In any event, it indicates a reversal in erosion process which must reflect a change in the factors that influence erosion.

An attempt is being made to determine what the genesis of this surface may have been and what relation it bears to the current trenching. Assuming that the erosion of the past--before the country was settled by white man--could not have been due to misuse of land but must have been due entirely to natural causes, what were these causes and how do they enter into the present activity? Suggestions have been made that abnormal cutting of the past and the present period was initiated by uplift, but this hypothesis, in view of the fact that gullying is progressing in areas distributed throughout the West irrespective of direction of the drainage seems untenable. From what has been learned from the studies to date, the cause seeming most logical is change in climate with dependant changes in runoff regimen, soils and vegetation.

Great fluctuations in annual precipitation, such as have occurred in part of the Great Plains during the last 2 decades are accompanied by changes in vegetative conditions and seem to be accompanied also by changes in erosional activity. Although there are no confirmatory data available, erosion seems to be less active now, after a number of years of normal or greater precipitations, then it was during and immediately following the dry period of the 1930's. In the Bighorn Area, flustuations in precipitation were not so outstanding and changes in vegetative and erosion conditions were not noticeable. It is reasonable to expect, however, that the relations of precipitation, vegetative conditions and erosion would correspond more or less in all areas. Although not definitely confirmed some information is available indicating that climatic fluctuations that have occurred throughout the time since the settlement of the country have been attended generally by variations in erosion progress. It is conceivable then, that over a long period, as for example, several hundred or a few thousand years climatic variations of greater phase may induce changes in erosional activity, greater than those that have been observed directly.

Moneta Basin Erosion Study

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The Moneta study which was started in October, 1946 is a comprehensive study of the hydrology and the erosion-sedimentation characteristics of a selected small drainage unit (3.3 square miles) forming the catchment basin of a reservoir in the Wind River Basin. The study includes maintenance of records of water stage and silt level in the reservoir and observations relative to gully degradation or aggradation and the progress of sheet erosion. Supplementing the records of runoff and erosion are records of precipitation, recurrent observations relative to vegetative conditions and collection of data relating to the topography, geology and soil.

In general topographic and geologic character the Moneta drainage basin is representative of a large part of the upland area of the Wind River Basin. With respect to present vegetative conditions, the drainage basin perhaps does not present an average of the grazing lands in Wind River Basin, rather it reflects the "harder hit" areas. The drainage basin is composed of public land in Wyoming Grazing District 2 and is crossed by a major stock trail on which the reservoir is an important watering place. However, because such usage is an integral part of the stock operation on the public land ~~it~~ and constitutes one of the main problems in administration and conservation, quantitative study of the erosion conditions should have special value.

Description of Reservoir and Drainage Basin

Location.—Reservoir in NW $\frac{1}{4}$ sec. 14, T 37 N, R 91 W in Grazing District 2, Fremont County, Wyoming. On west side of Moneta--Lysite road about 1 mile north of Moneta which is on U. S. Highway 20 about

20 miles east of Shoshoni. The reservoir is on Moneta draw about 1½ miles above junction with Poison Creek (see figures 1 and 2).

Details of the Reservoir.—Formed by dam across main gully trenching flat, below 3 main forks. Major part of the capacity of the reservoir is formed by excavation below the level of the flat. An auxiliary dam separates the reservoir from a silt basin occupying the gully upstream. Spillway is a natural overflow on one side of the reservoir. No outlet except spillway. (Structural details of dams shown in figure 2). Flowline of reservoir: Area = 5.06 acres; capacity, (1947) = 19.2 acre feet; max. depth, (1947) = 6.0 feet.

Performance of the Reservoir.—Reported to have been built in 1940 and to have had an initial capacity of 48 acre feet. Reported to have overflowed infrequently; there is no evidence of large overflow having occurred prior to 1948. Reservoir appears to be leakproof. Maximum draft on reservoir occurs on watering sheep when trailing which is very small as compared to evaporation loss.

Drainage basin.—Rudely rectangular in shape about 2½ miles along its east-west axis and 1½ miles along north-south axis and had an area of 3.27 square miles (see fig. 1). When the study was started in 1947, the natural runoff from this area was received by the main reservoir. In the winter of 1947, a reservoir having a capacity of 2.3 acre feet was built on the West Fork. The area above this reservoir is 0.37 square miles. Adjustments thus must be made in the computations of silt discharge.

The drainage basin has a maximum relief of ~~425~~ 375 feet, having an altitude range of from 5275 to 5600 feet. The lower half of the basin is an outwash plain sloping gently upward to the north and having slight local relief. The upper part of the basin has a much more rugged topography. It is a dissected bedrock table-land, which although still retaining some relatively level tracts controlled by flat-lying beds of sandstone, it is characterized mainly by escarpments or steep slopes and box canyons. The boundary between the gently sloping alluvial area and the rugged bedrock area is relatively sharp, and forms a definite break in the drainage channels.

The drainage system consists of 3 main forks which unite in the silt basin, just above the main reservoir. Each of these forks in turn have a number of tributaries which are formed by the union of numerous rills descending the steep escarpments. The length of these forks from the base of the escarpment to their junction ranges from 1.6 miles along the West Fork to 2.4 miles to the Middle and East Forks. The total drop from the base of the escarpment to the reservoir is about 225 feet. The average gradient of the West Fork from the base of the escarpment to the junction of the Forks thus is 2.6 percent, whereas the average gradient of the Middle and East Forks is 1.8 per cent. On all three forks, however, there are marked changes in gradient from place to place. (see figure 4). For most of their length, the channels of these forks have the forms of steep sided gullies from 10 to 30 feet wide and from 5 to 10 feet deep. In certain places, however, the channels are relatively wide and shallow, their beds are a half foot or less below the general level. These changes in form of the channels have been given considerable attention with respect to the erosion and deposition (see profiles and location of erosion measurements shown on figure 4). In the deeper gullies, consolidated rock is exposed in the lower part of the bank, though for the most part the channels have a sand or gravel bed. The channels have flow only in direct response to rainfall or rapid snow melt.

Precipitation in the Moneta Basin, on the basis of records for nearest stations and the record for the last 2 years, obtained in the course of this study, averages about 8 inches annually.

The entire drainage basin is underlain by the Wind River formation which prevails throughout the central part of the Wind River Basin. This formation consists of shale (strictly siltstone) and sandstone. The material of the finer-texture predominates, but sandstone in lenticular beds attaining a thickness of 20 feet or greater occur in the Moneta Basin. The shale or siltstone is relatively soft and readily erodible whereas the sandstone is relatively resistant.to erosion. Thus, in the upper part of the basin, where the Wind River bedrock is exposed, the sandstone occurs as a cap rock surmounting steep shale slopes. In the tract of slight relief in the lower part of the basin the Wind River bedrock is covered to thicknesses of from 5 to 10 feet by alluvium derived from erosion of the upper area.

The soil in this basin, where precipitation is so little and vegetation is so sparse, has not developed to an appreciable extent. It lacks structure and profile and is hardly distinguishable from the underlying rock. Thus in the shale areas and in some of the alluvial area it is fine-textured and only slightly pervious, in the sandstone tracts it is relatively coarse, highly pervious and on part of the alluvial and colluvial slopes it is transitional in character.

Vegetation is generally sparse. As shown by a range-survey map of the Bureau of Land Management and a vegetative count made in the course of this study by a range-examiner of that bureau, density averages about .15. The vegetation varies in type with underlying rock and soil; in the tracts of fine textured soil or poor drainage it consists principally of salt sage (atriplex nuttalii) and a dwarf sage (artemesia pedatifida) whereas on the tracts of sandy or intermediate soil it consists principally of big sage (artemesia tridentata) and grasses including wheat grass, grama, poa and rice grass.

Details of the Investigation

Precipitation record--Standard non recording gage installed April 1947 at Moneta about a mile from the reseroir; observations are made by a local observer. Three seasonal non recording gages installed Nov. 1947 in the drainage basin; observations made ordinarily after each storm.

Record of water-stage and silt level of the reservoir--A staff gage installed on the reservoir in October, 1946; gage readings are made by a local observer. Initial survey of the flow line of the reservoir was made in 1946. Determinations of the stage of silt in the reservoir are made by sounding recurrently on established ranges each year or more frequently; initial sounding was made in May 1947. Gage-height and silt-level record is being maintained also on the reservoir on the West Fork.

Observation of erosion and sedimentation in the drainage Basin--Initial surveys by transit-stadia method were made of the silt basin and drainage channels in summer of 1947. Reference points were established so that progress of erosion or sedimentation could be checked. Check surveys are made once a year.

A system of erosion measurement ranges was established in October and November, 1947. These ranges were installed in an attempt to obtain an index of the relative amounts of sediment produced by sheet, gully and transitional types of erosion and to correlate the amount of erosion with the influencing factors. To observerthe disposal of the eroded material and to determine the channel gradients and other factors which contributed to a change from degradation to aggradation a group of ranges was established along a drainageway, the first range at the base of the cliff and others successively downstream at selected points--some at points of degradation, others at points of aggradation or where the change from one process to the other appeared to have taken place in recent years. Locations of these ranges appear on the map, figure , and their position with respect to the profiles of the drainage channels appear in figure . Profiles along the ranges showing the change from 1947 to 1948 are shown in figure .

Results of the study to date

Runoff characteristics--The fluctuations of water stage of the reservoir for the two-year term October 1946 to September 1948 together with the available precipitation record is presented by figure . Although the precipitation record is incomplete for parts of the term the observations for all storms which caused flow into the reservoir are available.

The graph shows that appreciable runoff from the basin as reflected by a rise in reservoir stage occurred three times in both 1947 and 1948, but was limited to the months from June to September. Although the rainfall-runoff relation differs somewhat between successive storms probably because of the effect of antecedent precipitation, it differs most widely with respect to the time of the year in which the rain occurs. As shown, a rain of 1.1 inches in October 1947 caused no runoff where all rain in excess of .5 inch during the summer resulted in runoff. These differences are believed to be due to variations in rainfall intensity. Rains occurring in the spring or late fall in this area, ordinarily are gentle, whereas the summer rains associated with thunderstorms commonly have moderately high intensities.

The reservoir overflowed 3 times during the summer of 1948. The quantity that overflowed in 2 of these events was not large and could be readily estimated, but the quantity that overflowed in response to the storm of July 14 was relatively large and the estimate for it is subject to some error. The silt that was carried over the spillway, however, was largely deposited on the flat adjacent to the reservoir and could be estimated with fair accuracy.

Incorporating the estimate for the overflow, the precipitation-runoff relations for the period of record are as follows:

Year	Precipitation Inches	Runoff Acre-ft. per sq. mile	Depth in inches
1946-47	9.0	3.8	.07
1947-48	8.4	16.0	.31

If the available record is accepted as an index, it is evident that the annual runoff in this area is very small. Inasmuch as records for other stations in the Wind River Basin show that precipitation for the 2-year term was somewhat above normal it appears that the average long-term runoff would be no greater.

Silt production of the drainage basin--Profiles along the sounding ranges showing the deposition of silt in the reservoir between the soundings of May 1947 and July 1948 are presented by figure . As shown the silt deposit was spread in a regular fashion over the bottom and sides of the reservoir. The thickness of the deposit on the flat bottom of the reservoir ranges from .8 foot at the upper end of the reservoir to 1.5 feet near the dam. This deposit consists almost entirely of fine-textured material. Although the material has not been analysed for grain size the predominant constituent is believed to be silt. The deposit in the silt basin upstream from the auxiliary dam ranges in thickness from a few inches to about a foot; it varies considerably in thickness from place to place but generally thickens with distance downstream. The deposit includes material ranging from silt to gravel; the material varies in texture from place to place, but is much coarser on the whole than that deposited in the reservoir.

The determinations of silt discharged from the drainage basin from May 1947 to July 1948 are summarized as follows:

Deposit in main reservoir (computed from cross sections)	2.9	acre-feet
Deposit in silt basin do	3.5	do
Deposited by overflow from reservoir (estimated in field)	.5	do
Total quantity delivered to lower end of drainage basin (without adjustment for probable differences in densities of deposits)	6.9	do
Deposit in reservoir on West Fork (computed from cross sections)	.3	do
Total including deposit in reservoir on West Fork	7.2	acre-feet
Unit silt production of drainage basin, May 1947 to July 1948.	2.2	acre-feet per square mile
Annual unit silt production of drainage basin (approximated on basis of number of runoff events between the sediment observations as compared to total runoff events during 2-year term).	1.3	acre-feet per square mile
Annual depth of erosion in drainage basin (converted from annual unit silt production without adjustment for difference in densities of deposits and material in place in drainage basin.)	.025	inch

The catchment of the reservoir on the West Fork introduces an uncertainty in the determination of silt production because the reservoir overflowed during the period of observation and therefore could not be treated as a separate unit. As shown, however, the quantitative effect of the regulation is slight.

Because the sedimentation observations were made later in the year in 1948 than they were in 1947 a factor of less than 1.0 must be used to compute the annual silt production. In this case it seems that the best index on which to base the factor is the ratio of the average number of runoff events per year to the number of runoff events between the sedimentation observations. In each of the 2 years of record, appreciable runoff occurred 3 times, whereas between the sediment observations, appreciable runoff occurred 5 times. Hence, the factor used to obtain the annual silt production is .6. It would be desirable as the study progresses to make the observations at the same time each year, preferrebly before or after the period of greatest rainfall.

To date, determinations of density of the sediment deposits or of the material in place in the drainage basin have not been made. The density of the eroded soil is greater than that of the deposits, however, and may be as much as 50 percent greater. The annual depth of erosion, accordingly may be considerably less than the unadjusted depth presented above.

During the period, May 1947 to July 1948, the volume of silt deposited was 12 percent of the runoff. This concentration as well as the unit sediment production for the period of record is considerably greater than that shown by suspended load records or reservoir-sedimentation surveys for large drainage bains. Corresponding results has been shown also by other measurements of small drainage unit. It is recognized, of course, that in keeping with the principles of sampling the variation among small basins would be greater than that among large basins. Nevertheless the relations of the results for small and large basins are not readily explainable. Although the Moneta Basin constitutes only a small part of the drainage basin of Poison Creek it is believed to be fairly representative of the larger basin, but during the last few years at least, Moneta Basin has shown a silt production much higher than that of the Poison Basin. Poison Creek has delivered very little if any sediment to the Wind River during this time. This means that the sediment being delivered by drains similar to Moneta, most of which are not controlled by reservoirs, is deposited above the mouth of Poison Creek. The significance this condition may have is not entirely clear, but it would appear that these deposits present a potential contribution of silt from Poison Creek when a flood occurs on that stream.

Erosion and deposition in the drainage basin--A description of the established ranges and the changes registered between observations are presented in the following table and profiles along the ranges are shown by figure .

Table Description of erosion ranges and changes shown by the ranges from November 1947 to August 1948.

Designation of range	Site	Change registered from Nov. 1947 to August 1948. Feet
Drainageway A:		
A-1	Crosses channel, locally wide and shallow, but is trenched above and below range. Channel gradient 1.5 per cent.	Deposit averaging .4 in channel, medium grained sand. No change on adjacent slope.
Drainageway B: West Branch		
B-5	Along base of shale cliff. Vegetation very sparse.	Cutting averaging 0.1 on 1/3 or range. Cutting .3 in 2 narrow rills.
B-4	Covers gully and side slopes. Vegetation sparse. Gradient of gully 1.8 percent.	Deposit 1.6 in gully; deposit 0.1 on side slopes derived from adjacent shale hill.
East Branch		
B-3	Along base of rilled shale cliffs in box canyon. Vegetation very sparse. Average gradient across range 10 percent.	Cutting averaging 0.1 on 1/4 of range.
B-6	Similar to B-3.	No definite change, alternate cutting and deposition less than 0.1.
B-7	Crosses draw diagonally between cliffs, a few feet above knickpoint of gully. Gradient across range 6 percent.	Deposit averaging .15, maximum .3, consisting of medium-grained sand.
B-8	Covers gully and part of side slopes. Vegetation sparse. Corresponds to B-4 on west branch. Gradient of channel 2 per cent.	No change in gully. No change on one sloping side; deposition of .1 to .2 (uncertain, suspect error in observation) on other side.

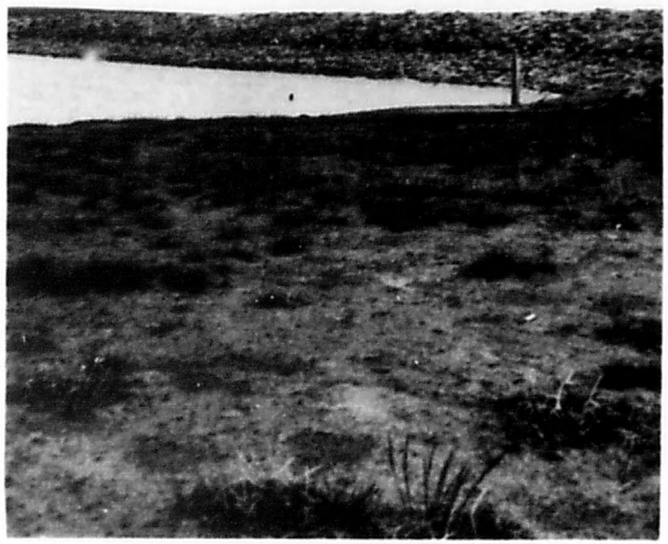
Description of erosion ranges and changes shown by the ranges from November 1947 to August 1948 continued..

Designation of Range	Site	Change registered from Nov. 1947 to August 1948. Feet
Drainageway B: Below junction east and west branch.		
B-2	Crosses channel, locally wide and shallow, but trenched above and below range. Channel gradient 1.8 percent.	Deposit .1 to .3 on about half the range. Narrow cut .6, in lowest part of channel. Deposit mainly medium-grained sand.
B-1	Crosses deposit in channel about 50 feet above old dam. Channel is trenched above and below range. Deposit downstream from range practically level. Gradient upstream 2 percent.	Deposit averaging 1.0, mainly fine- to medium-grained sand.
Drainageway C:		
C-1	Crosses drainage course comprising discontinuous, shallow trenches. Gradient 1.5 percent. Vegetation count on this range, density 14.2 per cent.	No definite change.
X	On hillside, no defined drainage course. Vegetation more abundant than at other ranges. Gradient across range averages 8 per cent.	No definite change.

The changes shown by the ranges may be summarized as follows: Of the 11 ranges 8, representing differing conditions, showed no definite change. Two ranges definitely showed cutting, but the cutting was not of great magnitude. Six ranges showed deposition, although on 1 of these the results are doubtful. All the 4 ranges crossing wide shallow sections of channels showed aggradation during the year. Most of the ranges covering the slopes adjacent to the stream channels showed slight deposition on the slope.

Although the observations for the year yielded little of conclusive nature they suggest some general trends. Sheet erosion was limited mainly to the steep shale slopes; and was relatively small in amount. As has been shown, 2 of the ranges at the base of the cliffs indicated slight cutting and it was found that the deposits occurring on the slopes adjacent to the stream channels had their origin on steep slopes nearby. Deposition whether in the channels or on side slopes seemed to be controlled mainly by breaks in gradient and the size of the stream transporting the material. Deposition of fine sand occurred in some channels on gradients of 2 per cent, if the gradients upstream were greater whereas inspection of material just above the silt basin showed that gravel was transported by the larger gullies on gradients of 1 percent. Because the vegetation throughout the basin is very sparse and shows little variation the influence of vegetation on the erosion or deposition was not well expressed in the observations for the year. The erosion range where vegetation was most abundant showed practically no change which suggests that the vegetation exerted some control, but because some of the other ranges also showed little or no change the results are not conclusive. To obtain further information in this connection it is believed that it will be necessary to establish comparative ranges in other drainage basins where there is a contrast in vegetative conditions.

Observations of gully progress made in addition to the observations on the numbered ranges indicated that the advances during the year, though not outstanding or conspicuous were widespread. Because of the great total length of the gullies in the Moneta Basin, moderate widening, if continuous, will account for a large quantity of sediment. Approximations made on the basis of the observations indicate that about 75 per cent of the sediment delivered to the reservoir and silt basin was derived by gullying. That a large part of the sediment was excavated by gullying is confirmed by the fact that much of the material deposited in the silt basin is too coarse-grained to have been derived by sheet erosion.

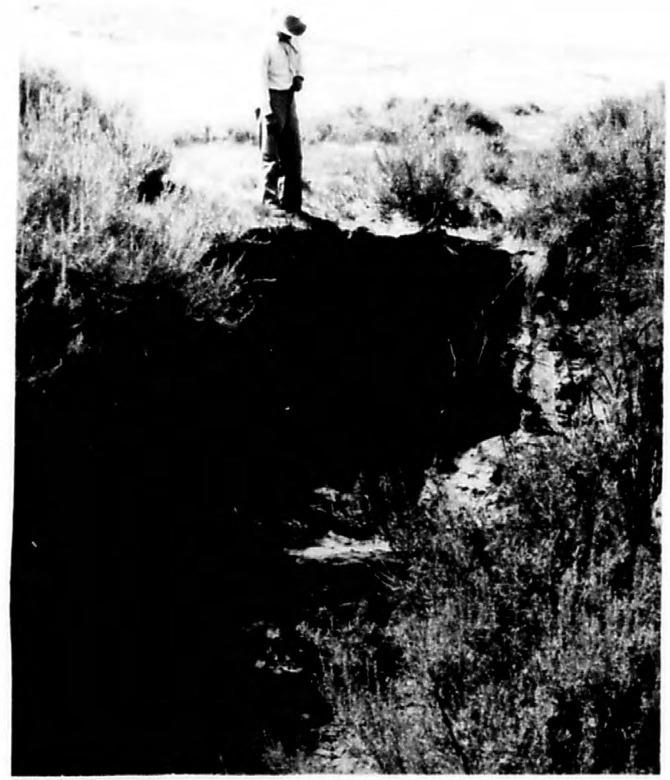


A. VIEW OF MONETA RESERVOIR SHOWING DAM AND GAGE. LOW STAGE--JUNE 1948.

B. VIEW OF MONETA RESERVOIR SHOWING METHOD USED IN SOUNDING. MARKED LINE STRETCHED BETWEEN REFERENCE STAKES ON ENDS OF RANGES.

PLATE

A. HEADCUT OF GULLY NEAR BONNEVILLE, WIND RIVER BASIN, WYOMING. THE HEADCUT HAS NOT ADVANCED FOR A NUMBER OF YEARS. AUGUST, 1948



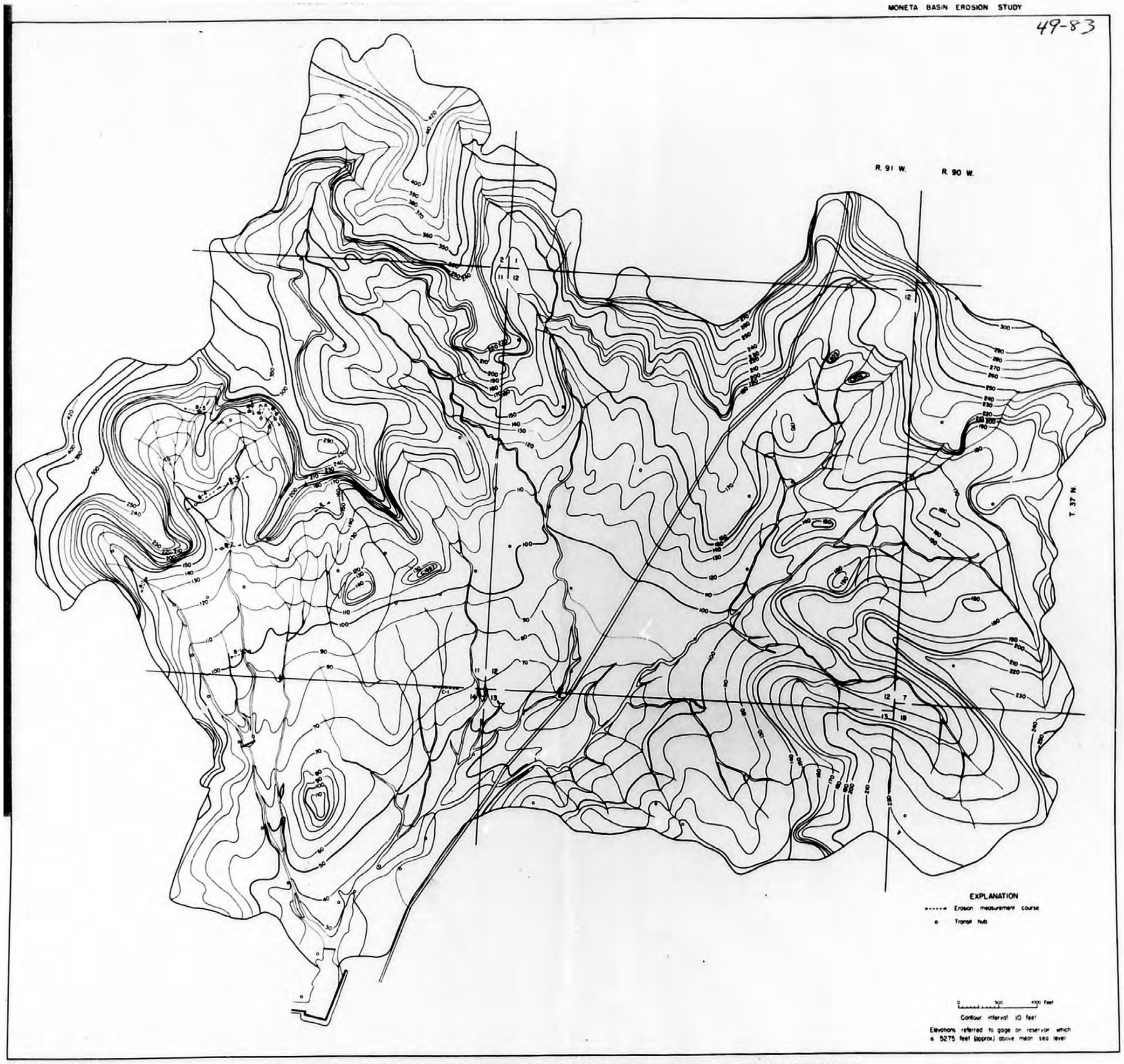
B. HEADCUT OF GULLY IN THE SUB-BASIN OF MUDDY CREEK, WIND RIVER INDIAN RESERVATION, WYOMING. SEPTEMBER, 1948

PLATE

PLATE

VIEW OF BURIED GULLY EXPOSED IN WALL OF
E K CREEK NEAR ARMINTO, WIND RIVER BASIN, WYOMING
AUGUST, 1947

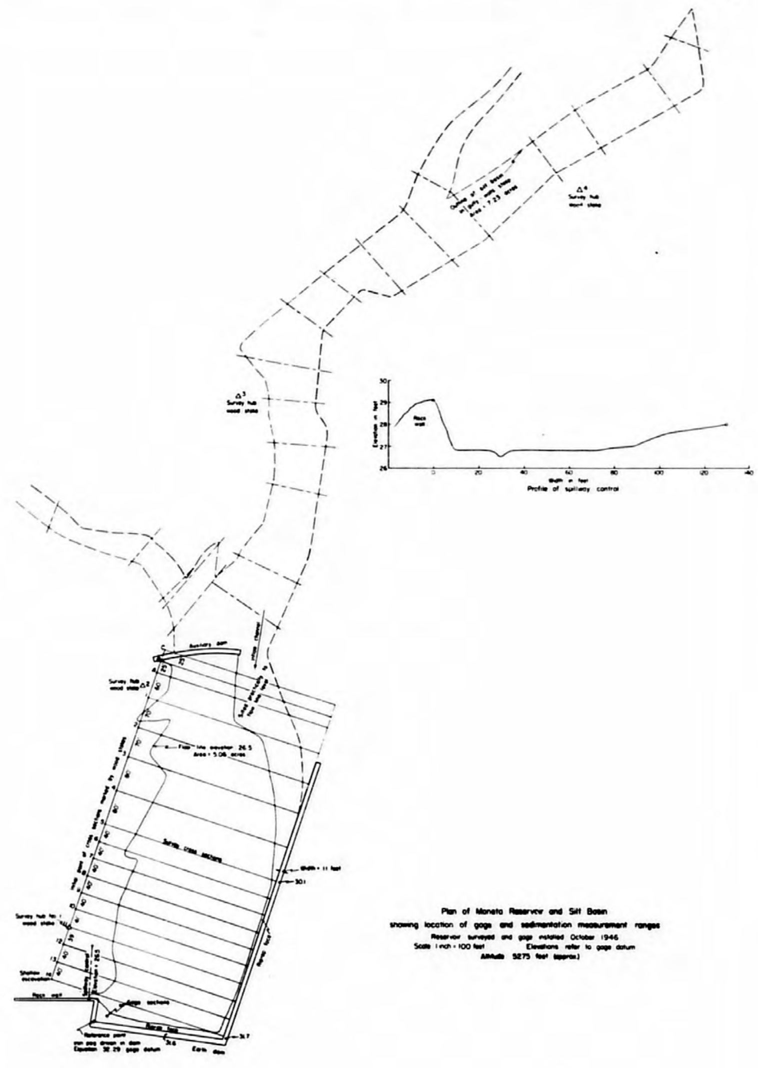
49-83



Base map prepared from aerial photograph and transit-stadia survey
Completed November 1948

TOPOGRAPHIC MAP OF MONETA RESERVOIR DRAINAGE BASIN, WYOMING, SHOWING LOCATION OF EROSION MEASUREMENTS

49-83



Plan of Moneta Reservoir and Silt Basin
showing location of gage and sedimentation measurement ranges
Reservoir surveyed and gage installed October 1946
Scale 1 inch = 100 feet   Elevations refer to gage datum
Altitude 5275 feet (approx.)

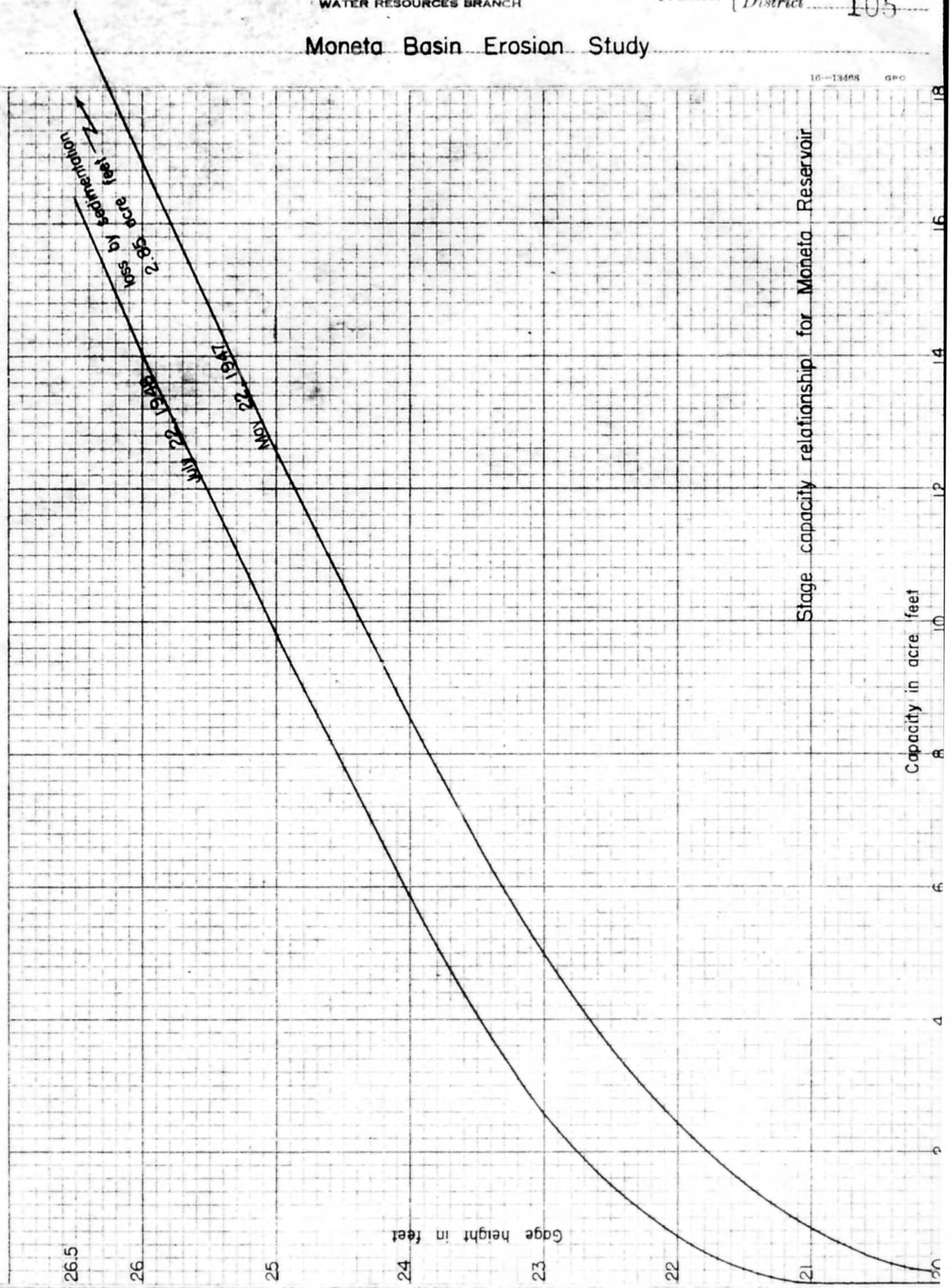
9-218-A
(November 1930)

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES BRANCH

File Number | Washington .... | District 105

Moneta Basin Erosion Study

16—13468 GPO



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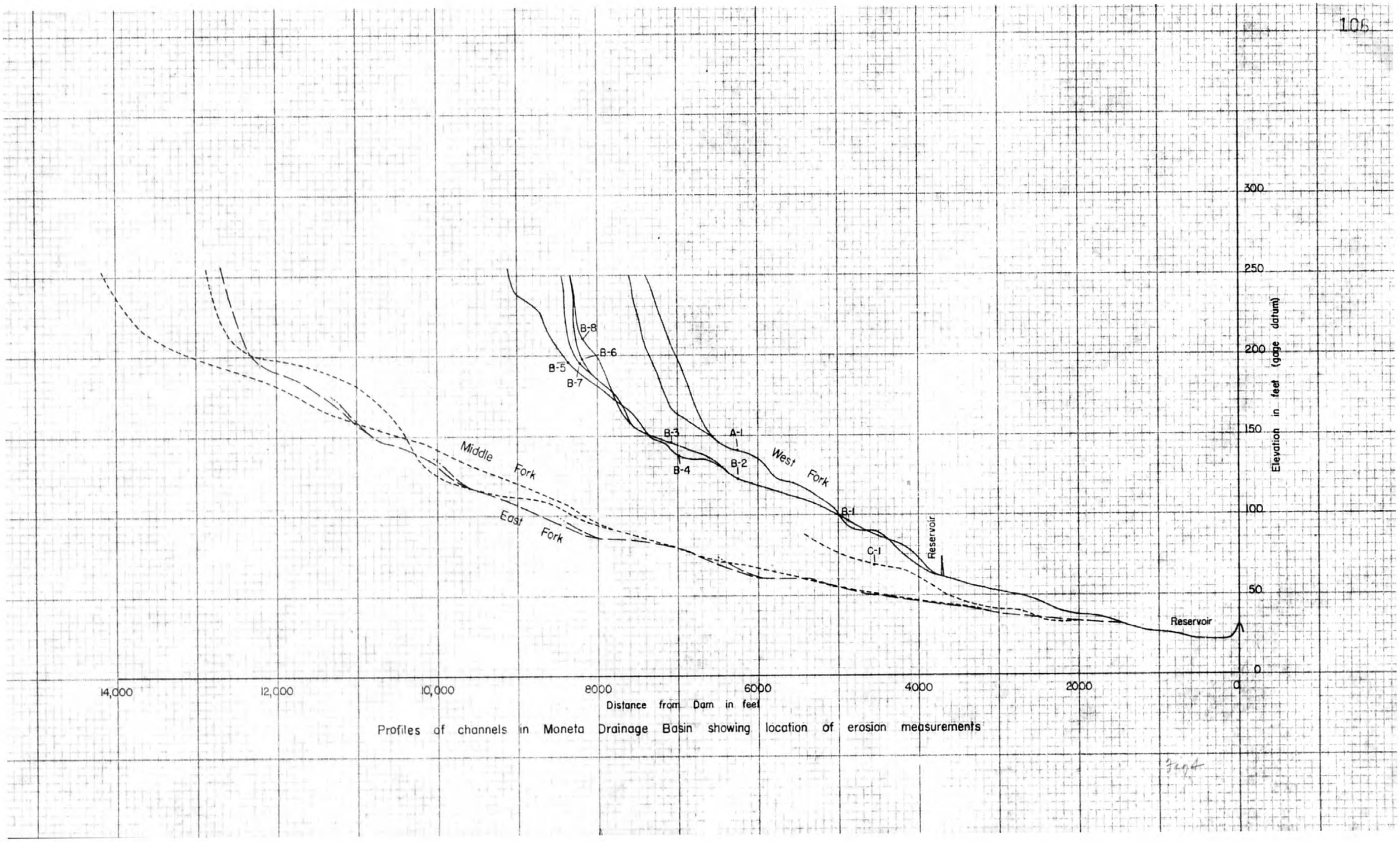
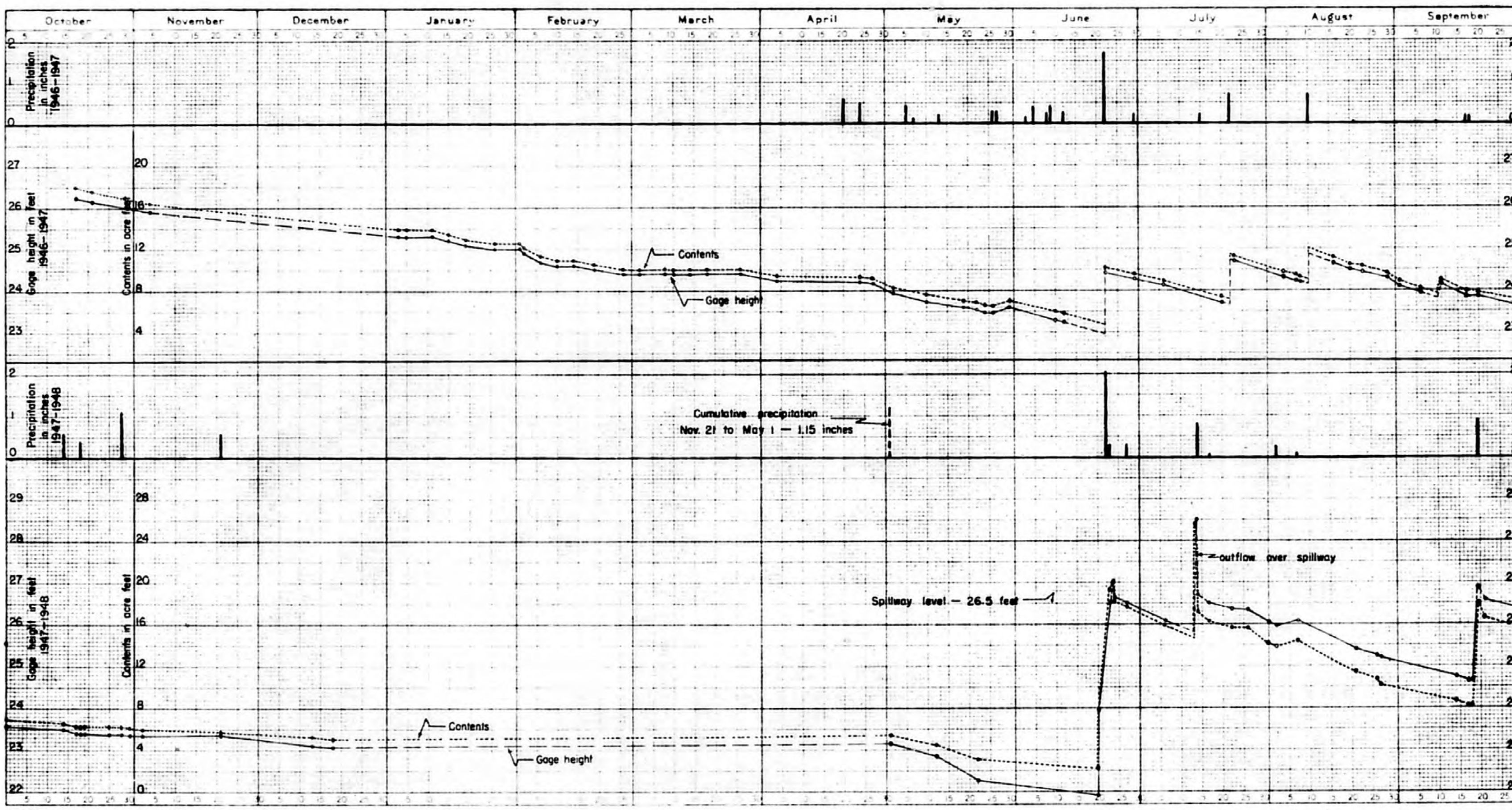


Profiles of channels in Moneta Drainage Basin showing location of erosion measurements

9-279-c Sept 1916

UNITED STATES DEPARTMENT OF THE INTERIOR GEOLOGICAL SURVEY (WATER RESOURCES BRANCH) HYDROGRAPH FOR Moneta Reservoir showing water-stage and precipitation

File No. Washington 49-83 Field 107



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(November 1939)

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WATER RESOURCES BRANCH

File Number { Washington .... District 108

Typical cross sections of Moneta Reservoir showing deposition

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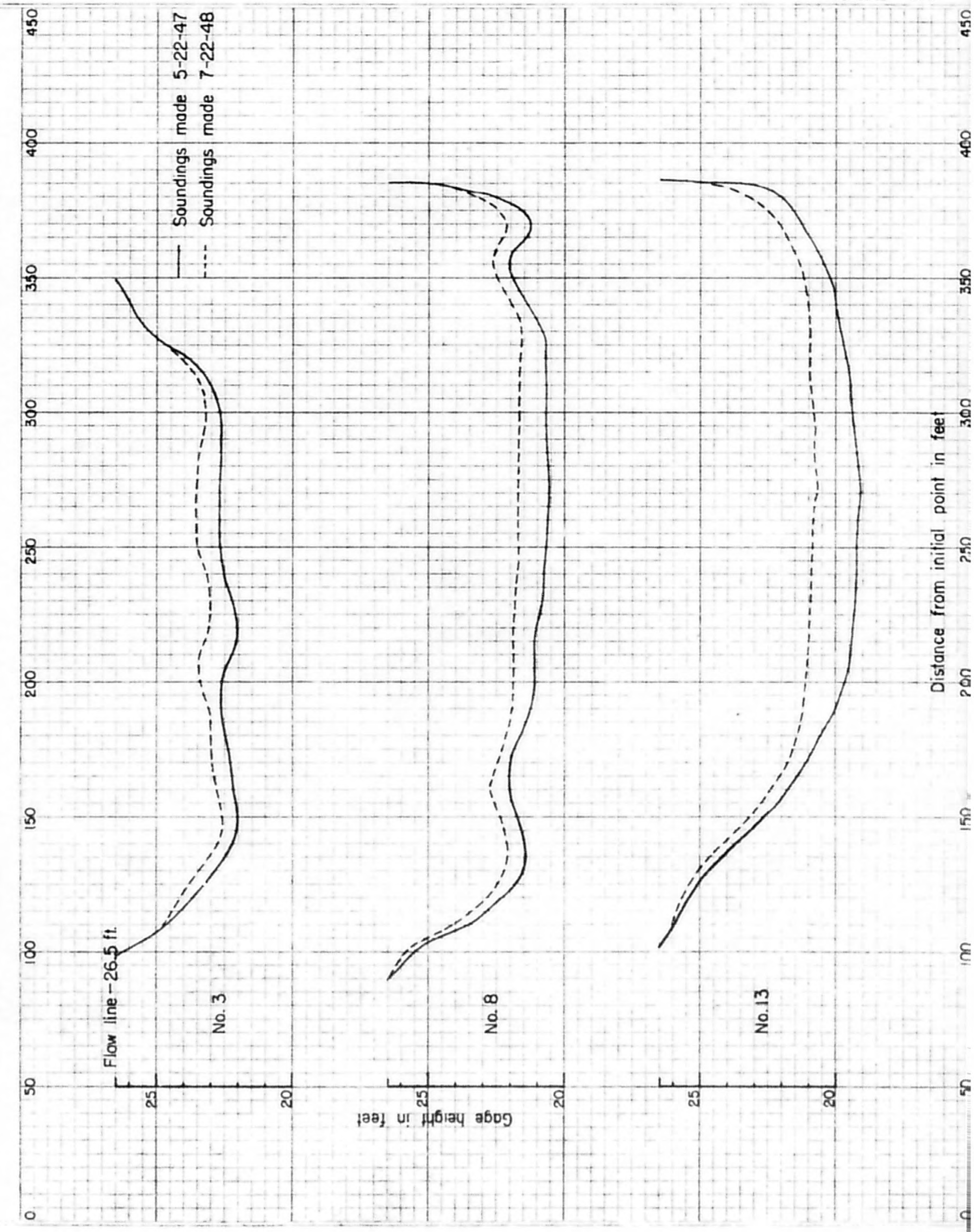

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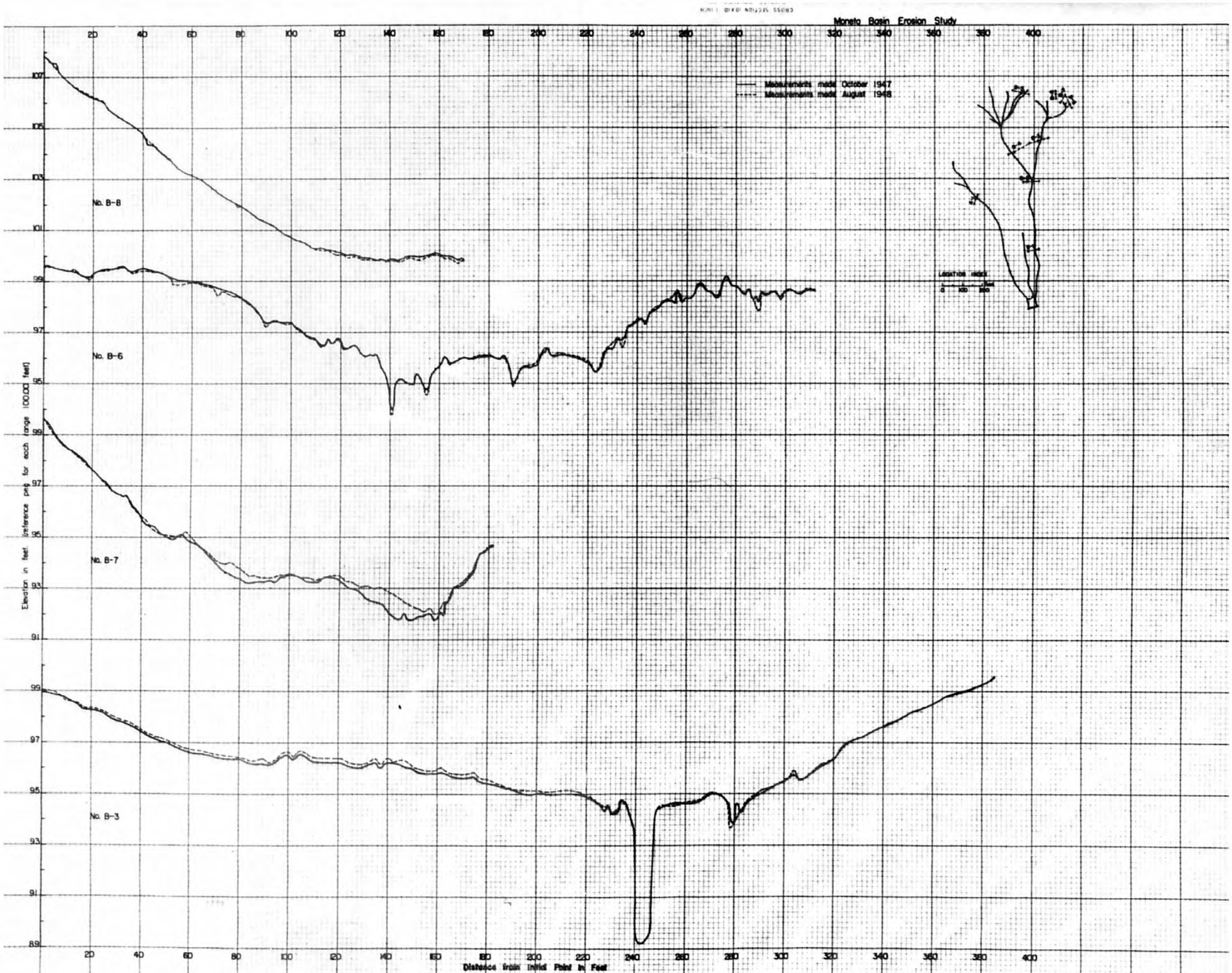
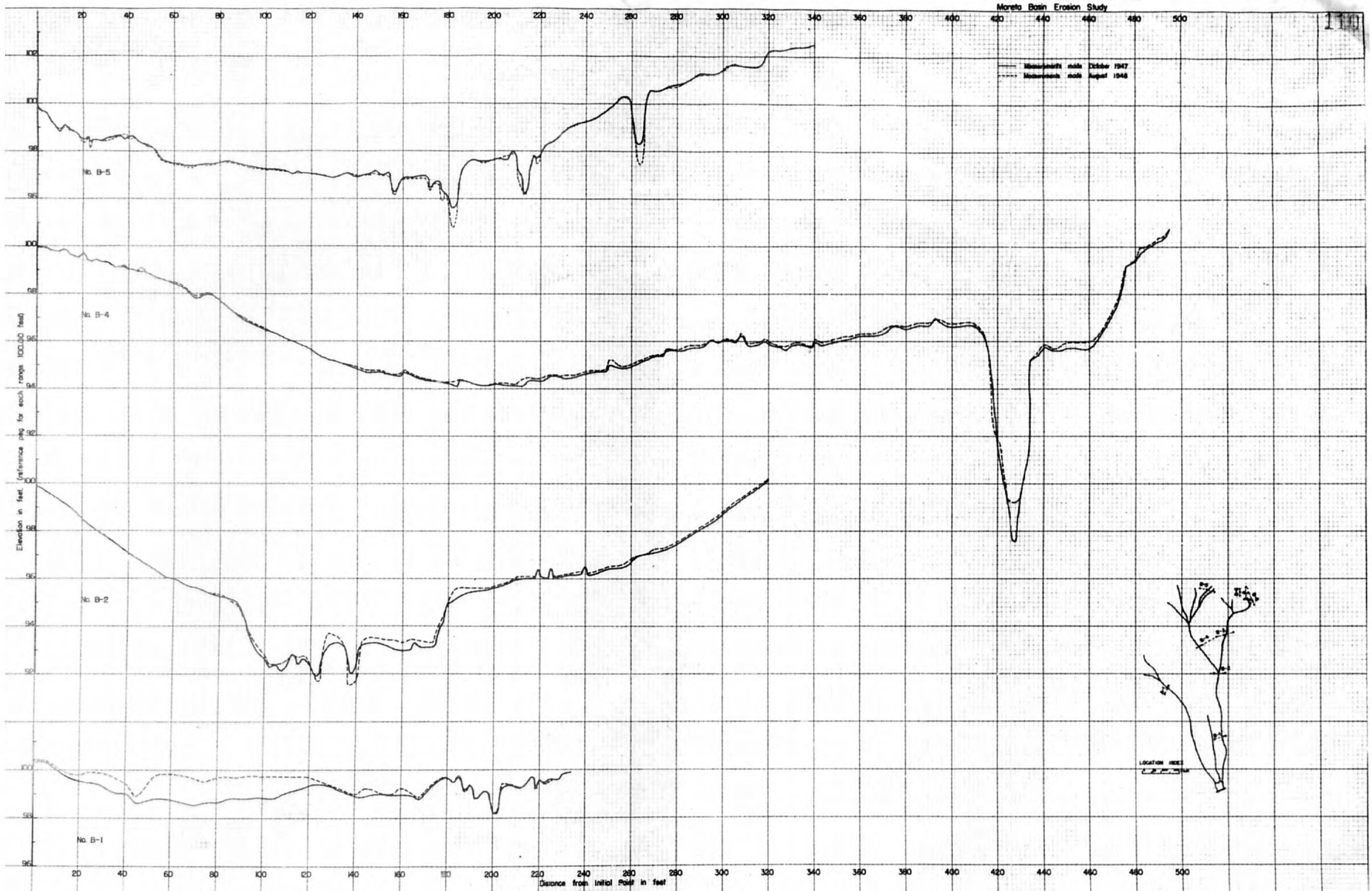
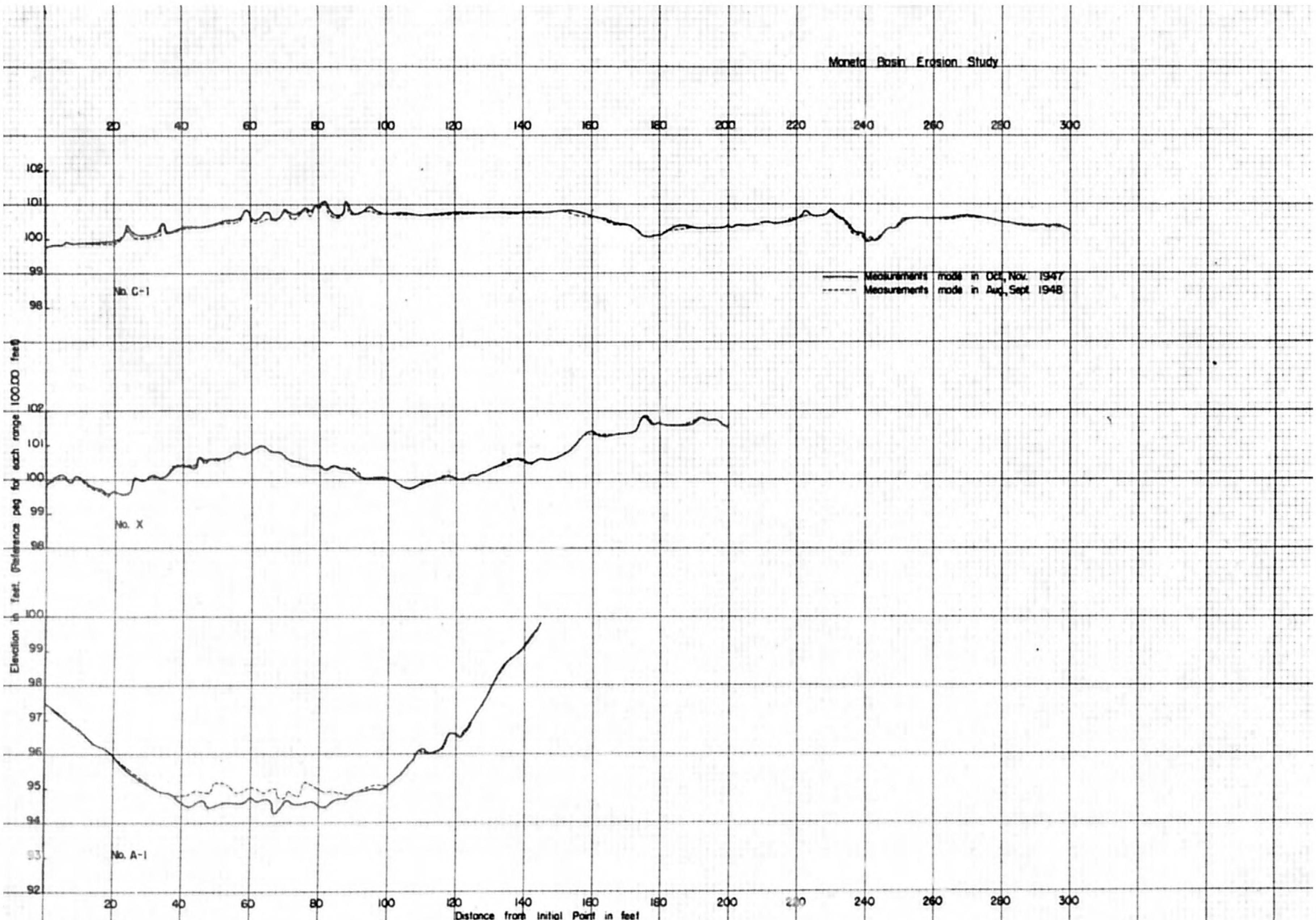


Profiles along measurement ranges showing rate of aggradation and degradation

Moreta Basin Erosion Study



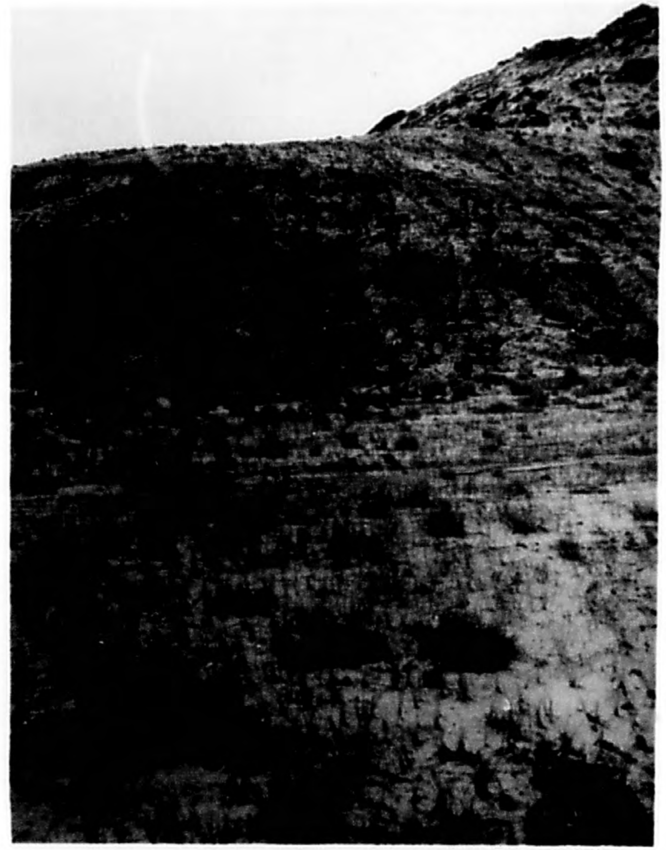
Profiles along measurement ranges showing rate of aggradation and degradation



Profiles along measurement ranges showing rate of aggradation and degradation

MONETA BASIN EROSION STUDY

A. EROSION MEASUREMENT RANGE B-6 AT BASE OF CLIFFS. PICKET IN FOREGROUND MARKS WEST END OF RANGE. THE MAN IS STANDING NEAR A ROD MARKING THE EAST END.



B. EROSION MEASUREMENT RANGE B-8. RANGE TRENDS ALONG THE BASE OF THE CLIFF. RODMAN IS STANDING NEAR THE MIDDLE OF THE RANGE.

PLATE

PLATE

MONETA BASIN EROSION STUDY

VIEW OF EROSION MEASUREMENT RANGE C-1. THE RANGE RUNS FROM THE MIDDLE FOREGROUND TO THE TRANSIT. THIS RANGE IS TYPICAL OF THE LOWER PART OF THE MONETA DRAINAGE BASIN.
NOVEMBER, 1947

Studies of Five-Mile Creek

Five-Mile Creek in the Riverton Project

Study of the erosional features of the Five-Mile Creek was first taken up to obtain information concerning the current and potential silt contribution of that stream as compared to that of the streams traversing public lands of the Grazing District, mainly Badwater, Poison and Muskrat Creeks. In the course of a preliminary examination of Five-Mile Creek in the Riverton Project, however, it was recognized that features displayed there afforded an excellent opportunity to study correlations of the extent and type of erosion with respect to influencing factors. Because much of the erosion has occurred in a relatively short time and is attributable in large part to irrigation waste water entering the channel, more data relative to the magnitude of runoff and the progress of erosion are available for Five-Mile Creek than for most gullies. Although systematic measurements have not been made, the general observations made by residents and others concerned with the area are of significance in this connection.

The influence of geology also, is well displayed. The Five-Mile Creek valley is floored by alluvial deposits which rest on bedrock, consisting mainly of shale and sandstone. The contact between the alluvium is uneven. The rapid erosion of the last few years has progressed to the extent that the alluvial fill has been cut to its base in long reaches of the channel and the underlying bedrock exposed. The differing resistance of the fill and the bedrock is reflected by the alternating wide and narrow sections and the sinuous course of the channel. Where the bedrock surface is near or projects above the valley floor, the channel is confined in a narrow bedrock gorge, whereas at other places the channel is several hundred feet wide. In general, the channel progressively widens until it reaches bedrock on the side. Flow in the channel is deflected by projecting bedrock points so that it swings from side to side alternately attacking one bank or the other, excavating the alluvium and progressively exposing more bedrock. The recurring bedrock outcrops, in the lower part of the gully walls, now make up a large portion of the channel length. This condition is believed to be highly significant with respect to the type of control measure that would be effective in reducing the bank cutting. Therefore, next to the study of measures for reducing inflow of irrigation-waste water, consideration of the geology of the channel is of prime importance in planning an erosion control program.

Some information relative to the progress of bank cutting is shown by measurements made on 4 cross sections of Five-Mile Creek on the Riverton Project during the last 2 years. The sections are distributed from the upper to the lower ends of the Project. The sections were selected primarily in connection with the sampling of sediments, consequently the measurements do not necessarily reflect the average progress throughout the Project but they demonstrate the difference in progress between the bedrock and alluvial banks. The measurements are presented by the table that follows:

Table . Progress of widening of the Five-Mile Creek channel in Riverton Project since Nov. 1946.

Location of cross section.	Width in feet between rims of gully (1946)	Progress of widening	Remarks
SE¼, sec. 3, T3N, R2E. About ½ mile above uppermost waste drain	175	To July 1948-No change, either bank.	Channel dry at time of observations. Flow only during storms; maximum flow 1946-48 estimated 300 second-feet. Bedrock at channel level both banks.
On section line, sec. 30/29 T3N, R4E. About 1 mile below Ocean Lake Drain.	300	To July 1948- Left bank-no change Right bank-about 5 feet sloughed and fallen to terrace below but not carried out.	Perennial flow in channel. Bedrock on left bank. Alluvial terrace between channel bed and right gully wall.
On section line, sec. 32/33 T3N, R5E. About ¼ mile below Sand Gulch	220	To July 1948. Left bank--no change. Right bank-about 10 feet sloughed and fallen to terrace below but not carried out.	Perennial flow in channel. Bedrock on left bank, alluvium on right. Low part of channel against left bank, sandy bed. Deposit of gravel in high-water channel. Bedrock exposed in both walls and in floor of gorge immediately downstream.
240 feet east of section line. sec. 18/17, T3N, R6E. About a mile above mouth and below all waste drains.	770	To Sept. 1948. Left bank-no change. To June 1947-Right bank widening 32 feet. To May 1948-Right bank widening 54 feet. To Sept. 1948, right bank widening 59 feet.	Perennial flow in channel, shifting from side to side on sand bed. Bedrock on left bank. Alluvium in vertical bank on right.

Another characteristic of the Five-Mile Creek that is expressed on the Riverton Project as well as throughout its reach upstream is the succession of alluvial surfaces along the channel. The most extensive of these in the Riverton Project stands about 20 feet above the channel and constitutes the level tract occupied by the irrigated farms. Another is an inner terrace that occurs about 10 feet above the bed of the channel; it is not now continuous but is represented by remnants of varying extent occurring intermittently throughout the channel in the Project. Extensions of these surfaces are discussed in considerable detail later in the report in connection with the work done in Five-Mile Creek above the Riverton Project.

The alluvium exposed in the walls of Five-Mile Creek, consists largely of fine-textured material but contains some lenses of coarse sand and gravel. Locally, it is fairly well stratified, but individual layers commonly do not persist for more than a few hundred feet. Thus, the alluvium is of the type deposited ordinarily by a fluctuating stream, such as Five-Mile Creek under normal regimen is at present. The question arises, however, as to what prompted the streams to deposit the fills at one time and later trench them, which action now seems to be the rule.

The first step in attempting to answer this question consisted of examination of the sediments in the gully walls and the bed of the channel on the Riverton Project for the purpose of comparing the material in the old deposits with that being worked by the present stream. The 4 cross sections of Five-Mile Creek mentioned earlier were sampled in detail, and the samples analyzed for grain size.

Results of this study, though attended by some departures from the general trend showed that the sediments of the upper part of the fill were consistently of finer-grain than those in the bed of the channel, and furthermore, that the upper sediments as well as those of the channel bed showed no consistent change from upstream to downstream points although it would normally be expected that they would decrease in grain size. The sediments in the lower part of the gully walls at the downstream end of the creek were about equal in grain size to those of the channel bed and showed a slight decrease in size in downstream direction. It appears from these results that the sediments near the surface of the fill were deposited by a stream of lower velocity than Five-Mile Creek had at the time of the sampling. Since the gradients of the old surfaces are about equivalent to that of the present channel bed it seems that a difference in velocity can not be ascribed to difference in gradient, which would be the first supposition, but must be ascribed some other factors. Vegetation in the old channels or flood plains for example, possibly could have been effective in retarding velocity and inducing deposition. Studies are being continued therefore, to obtain more detailed information as to the correlation of climate, vegetative conditions and runoff with the scouring and deposition of sediments. Some of the methods of attack are discussed in the following paragraphs covering investigations made upstream from the Riverton Project.

Five-Mile Creek above the Riverton Project on Wind River Indian Reservation.

General features--During the 1948 field season, an intensive study of the characteristics of Five-Mile Creek on the Wind River Indian Reservation was started. In this area Five-Mile Creek is an ephemeral stream but is reported to have had large floods at times. A flood in 1923--presumably the highest since the area was settled--is often cited as instrumental in initiating the rapid channel erosion which has been taking place in the Riverton Project during recent years. The channel of Five-Mile Creek here is generally not so wide as it is in the Project and does not meander quite so sharply or extensively; nevertheless, it is one of the major gullies of the Wind River uplands and has the physical appearance of one on which cutting is active. For much of its length in this area it traverses alluvium-filled valleys, where as has been discussed, the erosion potential may be very great. To evaluate this potential one phase of the work taken up consists of determining the relations of the alluvium and bedrock and mapping the bedrock outcrops along the channel. Although the bedrock occurring here is not invulnerable to erosion it erodes so much less rapidly than the alluvium that where bedrock is encountered the silt production through bank cutting is not a serious problem. A system of controls has been established for noting the progress of erosion. Another phase of the work consists of study and mapping of a series of 4 erosional surfaces that occur in this area for the information that might be obtained toward deducing the erosional history.

A reach of Five-Mile Creek about 12 miles long--from the Wyoming Canal siphon in sec. 24, T4N, R1E, upstream to a bridge in Sec. 16, T5N, R1W, about 5 miles below the extreme head of the creek on Maverick Springs Dome--was mapped in detail by plane-table and alidade. This reach includes essentially all the major channel and the valley portion of Five-Mile Creek above the Riverton Project. The part of the drainage basin above the upper end of this reach is characterized by bedrock hills and narrow drainageways cut for the most part in bedrock and therefore not so critical with respect to erosion potential. The mapped reach is not uniform throughout but is divisable into 3 units having differing geologic and topographic conditions. In the upper 5 miles--from the bridge in Sec. 16, T3N, R1W to the Barquin Coal Mine--the stream traverses a valley aligned along the upturned Cretaceous sandstone and shale formations composing the structural feature known as Little Dome. In the next 1½ miles the creek is confined in a canyon cut into the sandstone of the Mesaverde formation. From the mouth of the canyon downstream for about 5 miles to the lower end of the mapped area the creek crosses the flat lying beds of sandstone and shale of the Tertiary Wind River formation and broad alluvial flats.

Details of the map--The map shows by symbols the extent of bedrock cropping out above channel level, the height the outcrop attains and the total height of the cut bank. It also shows by patterns of cross-hatching the extent of the 4 mapped surfaces.

By reference to the map the form of the cross section of the gully at any point can be determined approximately (generally within 2 or 3 feet in any dimension). As is shown, the mapped surfaces are relatively flat; they have slight local relief due to hummocks of wind-blown sand and water-torn rills, but the relief from across each of the mapped surfaces is commonly no more than 2 or 3 feet.

Description of mapped surfaces and associated alluvial deposits--The surfaces S_1, S_2, S_3 and S_4 shown by the map are displayed very well in this area and could be traced with considerable assurance. Although the surfaces are not absolutely continuous, their relative elevations are quite consistent from place to place, and their other characteristics are sufficiently distinctive that they can be readily identified.

Surface S_1, the highest of the mapped surfaces, stands at a height of from 25 to 30 feet above the present stream channel. It is a gravel capped surface, apparently controlled by bedrock. It represents the lowest of a series of gravel terraces that occur in the Wind River Basin, probably considerably older than the lower surfaces with which this investigation is concerned, and differs from them in that it consistently is underlain by coarse gravel. This surface is believed to correspond with the Lenore terrace of Blackwelder[1] series of terraces in the Wind River Basin. The gravel as revealed by exposures in the gully walls ranges in thickness from 5 to 20 feet but for the most part has a thickness of less than 10 feet. It is composed chiefly of pebbles derived from quartzite, limestone and chert but includes some derived from volcanic rocks. It is relatively uniform in lithology and texture throughout the mapped area. The materials at or near the land surface are rather maturely weathered; as a matter of fact, in some tracts the soil that has developed is relatively fine-textured and completely conceals the gravel. The vegetation on this surface consists predominantly of grass--mainly grama--but includes some sage brush.

Surface S_2 stands at a height of from 18 to 20 feet above the channel. This surface is believed to correspond with the broad valley floor downstream on the Riverton Project. It is underlain

1. Blackwelder, Eliot, Post Cretaceous history of the Mountains of central-western Wyoming: Journal Geology Vol. 23, p.321, 1915.

by an alluvial deposit that rests on an uneven surface of bedrock. The deposit differs considerably in thickness from place to place and has a range in thickness generally of from about 5 to 20 feet. In a few places its thickness may be greater than 20 feet but is not known because the base of the deposit is not exposed. The alluvium consists chiefly of sand, with fine sand as the most abundant single component but also contains some silt and gravel. Bedding is not absent but is erratic and lenticular in nature. The materials at or near the land surface are noticeably weathered, and soil development is evident. The soil seems relatively tight and in most places the vegetation is supports consists only of salt sage. Some sheet erosion is evident on this surface. As is typical, the salt sage plants grow on hummocks.

Surface S_3 standing at a height of from 8 to 10 feet above the present channel is underlain by alluvium consisting principally of sand and gravel, coarser in texture on the whole than that beneath surface S_2. The surface materials are only slightly weathered. This surface, especially, has drawn attention to the significance of erosional history, because its genesis represents an event that may be related to the conditions responsible for the current erosion. The question as to whether this surface reflects the level down to which a stream trenching surface S_2 had scoured or the surface of a deposit that was laid in a trench formerly incised in S_2, as yet has not been determined conclusively. Available data, however, strongly favor the latter. It is believed that systematic sampling of the deposits beneath the surface, accompanied by intensive examination of the relations of deposits associated with surface S_2 and S_3 where they are exposed in the gully may answer the question.

Surface 4 which stands at a height ranging generally from 2 to 4 feet above the channel bed is an irregular surface, representing the present flood plain. As such it is in transitional stage of formation and subject to change, alternately to deposition, scour or lateral cutting. The deposits associated with this surface range in texture from silt and clay to gravel and are erratically distributed. As would be expected there is no noticeable surface weathering in this unit. In some of the places where it has not been recently disturbed by flood waters this surface supports a thick stand of sweet clover. Whether this was introduced artificially is not know. There are also a few Russian Olive trees in scattered groups on this surface. These trees were planted for bank controls about 10 years ago.

Occurrence of bedrock--Detailed mapping of the channel brought out some significant features that would otherwise not have been recognized. Recurrent bedrock outcrops in the walls of the gully make up about one third of the length of the channel in the mapped area. In the canyon reach the presence of bedrock in the gully wall or nearby is quite obvious, but there are many places in the valley tracts also where although alluvium appears continuously across the valley floor and adjacent to the rims of the gully, bedrock outcrops are continuous for several hundred feet along the gully walls. In a few places along these tracts outcrops are continuous for half a mile. It was found that Surface S_1 generally is underlain by bedrock at relatively shallow depth, and that in practically all the areas where Surface 1 forms the rim of the gully, bedrock appears in the gully wall. On the other hand, the depth to bedrock beneath surface 2 was found to vary considerably from place to place. In some places where surface 2 forms the gully rim bedrock does not appear at channel level, whereas at others it comes to within 5 feet of the rim.

Bedrock outcrops beneath surface 3 are rare. Thus, it is likely that the top of the bedrock beneath surface 3 generally is not higher than the bed of the present channel. Consequently, the alluvial deposit beneath surface 3 is subject to removal by flood water. As a matter of fact, this unit has been largely removed in the Riverton Project where there is continuous flow of water.

Conditions from the upper to the lower end of the mapped area are summarized briefly in the following paragraphs. As shown by sheet 1, which covers the upstream 4 miles of channel, bedrock appears in the gully walls or crops out near the rim of the gully at only a few points. Along most of the 4 miles of gully the bedrock outcrop at the base of Little Dome is about 1,000 feet from the rim of the gully. Surface 2 is continuous on the north side of the channel. Because of the proximity of Little Dome, the absence of bedrock in the north gully wall in most of this reach seems rather inconsistent. It may be that bedrock occurs a short distance back of the wall of the gully and is concealed by slumped alluvium. Nevertheless the position of the bedrock between the gully wall and the exposure can be determined definitely only by drilling or probably by resistivity surveys. It is believed that through a program of systematic, progressive drilling the location of the bedrock can be determined quite rapidly.

On the south side of the channel in this area bedrock appears in the gully wall along recurrent short reaches. In a few places it appears beneath surface 2, but more commonly it appears beneath surface 1. Here surface 1 is continuous and either forms the gully rim or is adjacent to it. Inasmuch as surface 1 is shown by numerous exposures to be underlain by bedrock generally at shallow depth, it is believed that bedrock occurs above channel level in much of the area represented by surface 1. A few drill holes properly placed should indicate positively the existing conditions. The localities on the south side of the channel in which the erosion potentials are greatest are those in the tracts represented by surface 2. The largest is at the extreme upper end of the mapped area and two others are near the lower end of the area shown on sheet 1. Drilling would also be required in these tracts.

In most of the area shown by sheet 2 which includes the canyon downstream from the Barquin mine, bedrock appears continuously or recurrently at short intervals in the gully walls. For about 2 miles at the upper end, however, bedrock does not appear in the right or southwest wall. Here surface 2 is as much as 1,000 feet wide, and ascertaining the depth of bedrock would therefore, require systematic test drilling. A few test holes would also be necessary between bedrock outcrops at other points in this area.

In the area shown by sheet 3, bedrock appears continuously in the gully walls for long distances in several places and small exposures occur locally at others. Nevertheless, there are a few reaches where no bedrock crops out and drilling would be required. For a distance of more than a mile in the reach including cross sections NN' and OO' there is no bedrock in the left or east wall. Exposure of bedrock, however, is relatively near the rim of the gully, and it is likely that bedrock occurs above channel level a short distance from the rim. The same condition appears on the east gully wall in the vicinity of cross section PP'. Some drilling would be required in these localities. From cross section QQ' to a point about 800 feet above the Wyoming Canal, no bedrock appears in the left wall; and from a point about 2500 feet upstream to a point about 2500 feet downstream from cross section QQ' no bedrock appears in the right wall. In this locality surface 2 appears on both sides of the gully and is relatively extensive on the left side. A number of drill tests may be necessary here. In the area shown by sheet 8 the relations of surface 1 and the bedrock are well brought out. At every place that it forms the gully rim, bedrock is exposed in the gully wall.

Gradient of the channel--A profile of the channel in the mapped area is shown in figure . The horizontal distance was measured along the course followed by the recent storm flows, thus it takes into account the meanders and is considerably greater than the distance along the general trend of the gully. As shown, the gradient throughout the mapped area, except for local irregularities, is quite uniform. The concavity of profile or steepening of gradient upstream, commonly found in streams of this kind, is not evident except at the extreme upper end. In the uppermost 2 miles, the gradient is 0.62 per cent or 33 feet in a mile, whereas in the next 3 miles downstream it is .46 per cent. For the remainder of the area it fluctuates from .49 to .56 per cent. The gradient through the canyon is .55 per cent thus is not appreciably greater than in the valley areas above and below the canyon. The profile presented shows a number of local irregularities. Some of these are suspected of representing errors in observation, but most are undoubtedly real. The cause of these breaks in gradient, or the relation the breaks may have to other channel features, however, are not readily apparent. The first supposition is that they represent bedrock controls. It is known from inspection of the channel that bedrock is not exposed in the bed of the channel at these points, but it may be that bedrock occurs beneath a thin deposit of alluvium, and therefore its presence has not been recognized. It is intended that in the cause of further study, these breaks will be investigated more fully.

Interpretation of the surfaces and alluvial deposits--The findings made to date in connection with the surfaces and alluvial deposits permit drawing only tentative conclusions. In the course of the work many questions have arisen relative to the processes of fluvial aggradation or degradation which merit further study. For example, relating the alluvium associated with each of the surfaces to its source and the events by which the surfaces were produced is believed to be significant, but as yet has not been satisfactorily interpreted. Although the deposits differ in some respects, they all contain some material alike in lithology and texture, so that determination of the source for each is difficult. It is evident however, from the lithology of the material making up the deposits that the ultimate source of an appreciable if not a major part of the material was far back in the Wind River or Owl Creek mountains. Some of the material is believed to have been derived from the bedrock occurring immediately upstream in the Maverick Springs area. Furthermore, the deposits associated with each surface contain some material derived from alluvial deposits successively older. A reliable determination of the relative amounts from each source and establishment of the principal source, however, can be made only by systematic sampling and intensive study of the deposits. Because of the need for completing the map first, this phase of the work was barely touched during 1948, but is planned as the study progresses. Some help in dating the deposits may be obtained by a search for artifacts and paleontological evidence. Work of this kind has been carried on to some extent and has met with some success in other areas.

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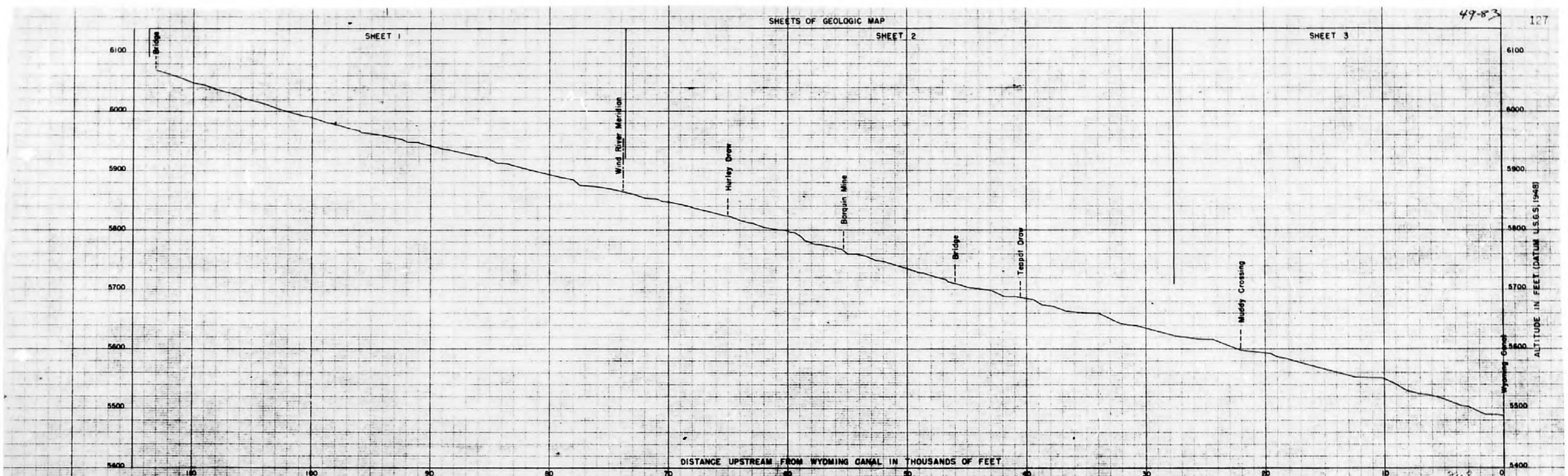


PROFILE OF FIVE MILE CREEK CHANNEL, WIND RIVER BASIN, WYOMING

FLUVIAL SEDIMENTS

Purpose and Scope of Investigations

The investigations of fluvial sediments in the Bighorn River Drainage Basin were undertaken to determine (1) the amount of sediment in transport in the Bighorn River, (2) the probable amount of space required for accumulated sediment storage in proposed main stem reservoirs, (3) the probable rate of aggradation or degradation of the river channel, (4) sources of fluvial sediments with respect to quantities and specific contributing areas, and (5) erosional characteristics of these specific contributing areas.

In September 1948 an intensive investigation of fluvial sediments intributary streams in the Wind River Basin was started. Results and conclusions reached from this investigation will be included in a later report.

Modes of Transportation

Sediment is transported by flowing water in two general ways, (1) by suspension and (2) by irregular movement on or immediately adjacent to the bed. Particles which remain in suspension for any period of time move as suspended load with a velocity which is considered to be equal to that of the filament of water adjacent thereto. Particles which are intermittently in suspension for short intervals move as saltation load by a series of short skips or jumps above the bed. Particles which roll or slide at intermittent intervals along the bed move as bed-load. The line of demarcation between saltation and bed-load cannot be readily defined and neither is readily susceptible to measurement or analysis.

In any stream channel which has variation in slope or cross-sectional area, there will be deposition or scour from reach to reach. Sediment particles may move in suspension in one reach and as bed-load in the next or vice-versa depending on the velocity changes in the vertical section and in the area adjacent to the bed. During flood periods streams scour their beds if in erodible channels on rising stages and fill their beds on falling stages depending on contributions of water and sediment from tributary areas. In steep mountain streams aggradation may occur on rising stages with some degradation on falling stages.

The diffusion of turbulence in any stream cross-section is seldom sufficient to provide a uniform concentration throughout the area except in streams transporting material less the 1/16 mm in diameter. In an average stream there is considerable variation in both the horizontal and vertical sections.

Measurement of Sediment Discharge

T he quantities of water and sediment in a stream at any given time are only indirectly related to each other and both fluctuate because of a number of factors which may produce variable quantities of each under similar conditions. These factors include (1) intensity of precipitation or rate of snow melt, (2) vegetal cover, (3) season of the year, (4) condition and type of soil, (5) topography, (6) size of stream, and irrigation tracts, (9) shape of drainage basin of main stream and tributaries above measuring station and (10) storage in reservoirs and retarding basins.

The measurement of sediment discharge of a stream is accomplished by concurrent measurement of both water and sediment. The daily water discharge of streams is usually obtained from records of stage, current meter measurements, and other general information with respect to type of control or channel and weather conditions. As the procedure for the measurement of flow is described in detail in Water Supply Paper 888 _/

_/ Corbett, Don M., Stream-Gaging Procedure: U.S. Geol. Survey Water-Supply Paper 888, 1943.

no further discussion will be included in this report.

The measurement of the sediment discharge of a steam includes the determination of the quantity of material moving in suspension and as bed-load; size and distribution of particles in transport; and studies of channel changes and sediments. At present it is not possible to measure the total sediment discharge except in small streams even though the quantities of sediment moving as bed-load may be appreciable.

Measurement of suspended sediments may be made with integrating or instantaneous samplers. The depth-integrating sampler takes a sample of the water-sediment mixture while traversing the vertical at a uniform rate of speed. The point-integrating sampler can be used as a depth-integrating sampler although the former is specifically designed to take time-integrated samples at any point in the vertical section. The instantaneous sampler is designed to trap a sample at any point in the vertical section.

The measurement of the suspended sediment discharge with depth-integrating samplers is limited to streams with depths less than 30 feet. The point-integrating and instantaneous samplers can be designed for streams of any depth.

In the depth-integration method sediment samples are obtained at points of equal water discharge, the number of sampling verticals depending on the variation of the concentration in the cross-section. The arithmetical average of the concentration obtained at the points of equal water discharge is then the average for the cross-section. The product then of the average concentration and the water discharge is the sediment discharge. When the point-integrating or instantaneous samplers are used, the average concentration in the vertical section is obtained by weighting each individual concentration by the stream velocity at the point of collection.

The suspended sediment discharge of a stream can be readily determined if sufficient depth-integrated samples can be obtained to delineate the change in concentration with time.

Sampling Equipment and Procedure

The equipment adopted by the Geological Survey for the measurement of suspended sediment discharge is that developed under the Joint Project at the Hydraulics Laboratory University of Iowa, Iowa City, Iowa. _/

_/ A study of methods used in measurement and analysis of sediment loads in streams, Joint Reports 1-9, published by Corps of Engineers, St. Paul, Minnesota.

The US D-43 and DH-48 samplers are used by local observers to obtain samples and by engineering personnel to make sediment discharge measurements. The sediment discharge measurements are made with the 50-lb. D-43 sampler and a "steam-gaging crane" except during periods of medium or low flow when the hand sampler, DH-49, is used. Under shifting channel conditions current meter measurements are made prior to the sediment discharge measurements to obtain points of equal discharge. Samples obtained by the local observer are collected from cableways or from installations attached to the side of highway bridges. During periods of rapidly changing stage, the observers are instructed to make as many observations as possible; each observation consists of two samples collected consecutively.

During winter weather when temperatures are appreciably below freezing, the local observer obtains samples with a bottle sampler vented for air release. The concentrations obtained with such equipment are corrected on the basis of comparative tests made with standard samplers at appropriate intervals during the winter period.

The US D-47 and P-46 samplers were used in a limited way during flood flows. It is anticipated that the P-46 sampler will be satisfactory for all sampling procedures during floods. It will be used more extensively in the future in order to learn more about the distribution of the particle size of the material in the vertical section. Such information is invaluable with respect to studies of bed-load movement.

Surface samples of bed material for particle size and related weight-volume ratio studies were obtained adjacent to each measuring station.

Laboratory Procedure

The sediment samples are transported by truck to the laboratory for analysis. Each sample is weighed and transferred to a "settling bench". After the sediment has settled to the bottom of the pint bottle, the supernantant liquid is drawn off and the residue washed into a Gooch cruicible or a pyrex evaporating dish, depending on the amount of sediment. The evaporating dish or cruicilbe is placed in an electric oven or over an air bath until all moisture has been removed from the sample. The samples are allowed to cool in a desicctor and then weighed. If the evaporating dish is used the result is corrected for the dissolved solids previously determined.

Particle size analyses of suspended sediments were made with the bottom withdrawal tube using both native and distilled water as settling mediums. Analyses of bed or channel sediments were made by the wet seive process or by means of the dry sieve and Ro-Tap Machine. Some analyses were run with the bottom withdrawal tube where the material contained a large percentage of silt and clay materials and the sand size did not exceed one millimeter.

Computation Procedure

The procedure for computing the suspended sediment discharge consists of (1) tabulating the results of sediment discharge measurements (2) determining the relationship between the average concentration in the cross section as determined from the sediment discharge measurement and the concentration found at the daily sampling stations, (3) adjusting the daily observation based on item two (4) plotting the daily observations on the gage-height chart, (5) computing the mean daily concentration and (6) computing the mean daily sediment discharge.

If the "concentrations" at the daily sampling station approximate the average in the cross section within 10 percent (Item 2) and the average variation is equal to zero (unity) no adjustments are made to the daily observations. Where adjustments are required they are made in a manner similar to that used in making "shift corrections" to water discharge measurements.

The sediment discharge in tons per day is obtained from the mean daily sediment concentration and the mean daily water discharge except during periods when the concentration and water discharge are changing rapidly. During these intervals each day is sub-divided in accordance with accepted practice if the error introduced by not "subdividing" would be above two percent or greater. Additional studies and comparisons are made of the sediment and water discharge, and precipitation data on a hydrographic basis for each station.

Definition of Terms

The units in which the sediment data are presented in this report and other related terms used herein are defined as follows.

Sediment is fragmental material transported by, suspended in, or deposited by, water or air, or accumulated in beds by other natural agents.

Suspended sediment is sediment that is found to be in suspension at any measuring station and has a velocity equal to that of adjacent water particles.

Bed-load sediment is sediment that is in almost continuous contact with the stream bed but moves with a velocity less than adjacent water particles.

Sediment sample is a quantity of a water-sediment mixture which is representative of the average concentration in any stream vertical or at any sampling point depending on type of sample obtained.

"Sediment concentration" is the ratio of the dry weight of the sediment in a water-sediment mixture to the total weight of the mixture. It is expressed in parts per million.

Daily suspended sediment discharge is the dry weight of the total sediment passing a measuring station. This figure is expressed in tons per day and is obtained by the following equation:

Tons per day = mean sediment concentration x water discharge in second-feet x 0.0027. The weight of one cubic foot of water is taken as 62.4 pounds. Weighted mean sediment concentration is computed by dividing the sediment discharge for a period, by the weight of the water discharge for the same period.

RECORDS OF SUSPENDED SEDIMENT DISCHARGE

Suspended Sediment

The preliminary study of fluvial sediments in the Bighorn River Drainage Basin included the measurement of the suspended sediment at four stations on the Bighorn River located at Thermopolis, Manderson, and Kane, Wyoming, and near Custer, Montana. Some additional miscellaneous information was obtained for Badwater Creek near Bonneville, Wyoming and other tributary streams.

The variation of the water and sediment discharge for each river station is illustrated by individual days in plates 46, 47, 48, 49, for the period of record. Records of the monthly values together with appropriate station descriptions are contained in Appendix I of this report. Records of the daily values are included in Appendix II.

Bed-load Sediment

No quantitive information was obtained with respect to sediment being transported as bed-load in the Bighorn River. Visual observations of small tributary streams would indicate that the amount of sediment moving as bed-load is an appreciable part of the total load under certain conditions of flow.

Size Composition of Suspended Sediments

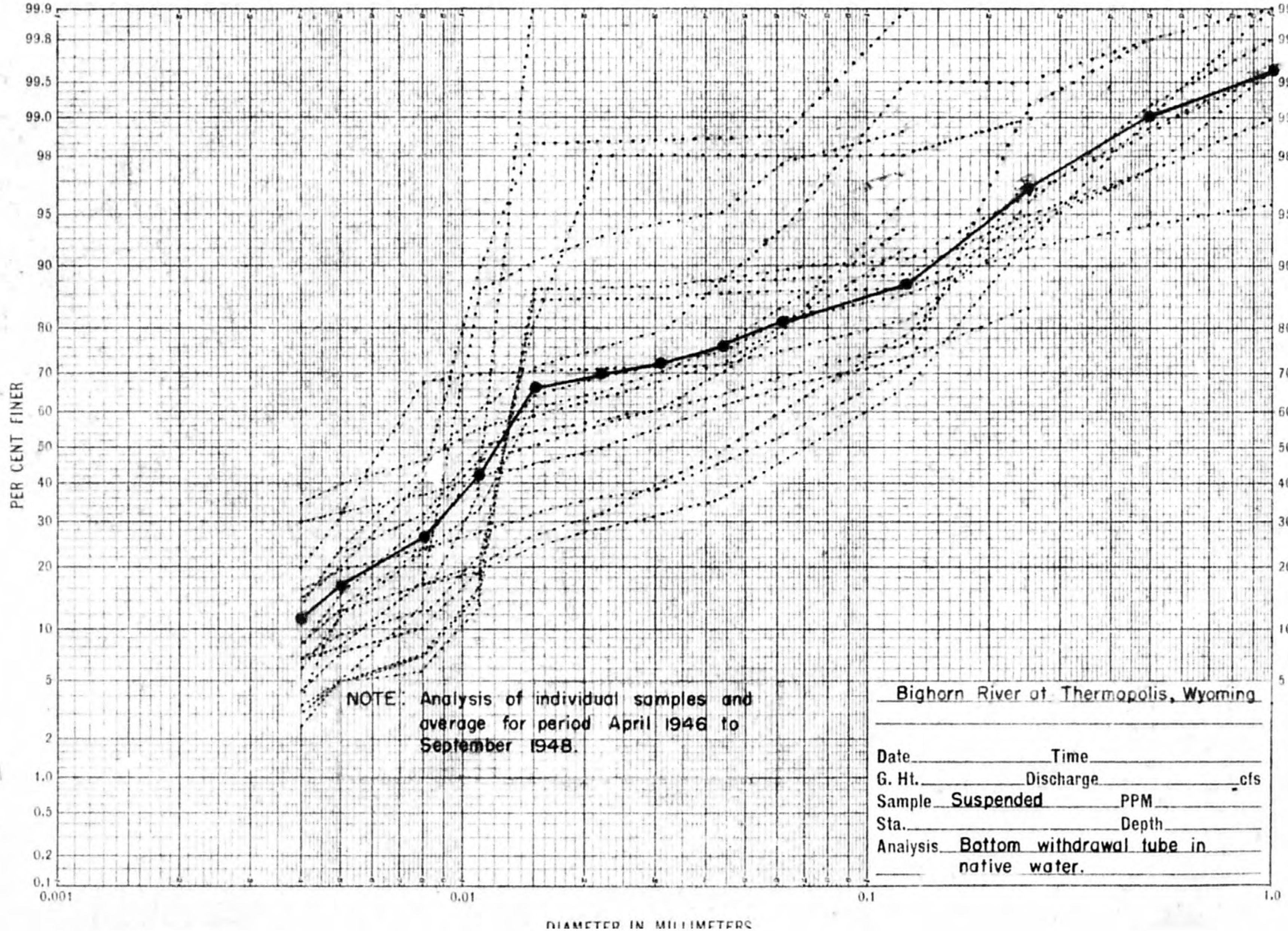
The particle size or sedimentation diameter of the suspended sediments was obtained from representative samples collected at each of the four measuring stations. Analyses were made with the bottom withdrawal tube using both native and distilled water as the settling media. Results of the analyses are shown in figures 9, 10, 11; figures 12, 13, 14; figures 15, 16, 17 and figures 18, 19, 20 for the measuring stations at Thermopolis, Manderson, Kane and "near Custer" respectively. The information obtained for the Manderson and Kane stations is much more complete than that shown for the other two stations and is believed to be representative of the suspended material in transport. The average median size found at each station is given in table 4. Results of individual analyses are given in Appendix I.

Table 4 Average median sedimentation diameter of suspended sediments, Bighorn River, Wyoming and Montana.

Station	Settling Medium	
	Native water (dia. mm)	Distilled water (dia. mm)
Thermopolis	0.012	.0037
Manderson	.012	.0046
Kane	.013	.0046
Custer	.013	.0080

Size Composition of Deposited Sediments

Samples of bed material were obtained from exposed bars and other channel deposits in the Bighorn River Drainage Basin. The size distribution and average for the samples collected at or adjacent to each measuring station are shown in figures 21, 22, 23, 24. The average median size for the samples collected at these stations is 0.15 mm and the average for the Bighorn River channel including Wind River is 0.16 mm (fig. 25).



PER CENT FINER
DIAMETER IN MILLIMETERS
0.001
0.01
0.1
1.0
99.9
99.8
99.5
99.0
98
95
90
80
70
60
50
40
30
20
10
5
2
1.0
0.5
0.2
0.1
NOTE: Analysis of individual samples and average for period April 1946 to September 1948.
Bighorn River at Thermopolis, Wyoming
Date Time
G. Ht. Discharge cfs
Sample Suspended PPM
Sta. Depth
Analysis Bottom withdrawal tube in native water.

Fig. 9

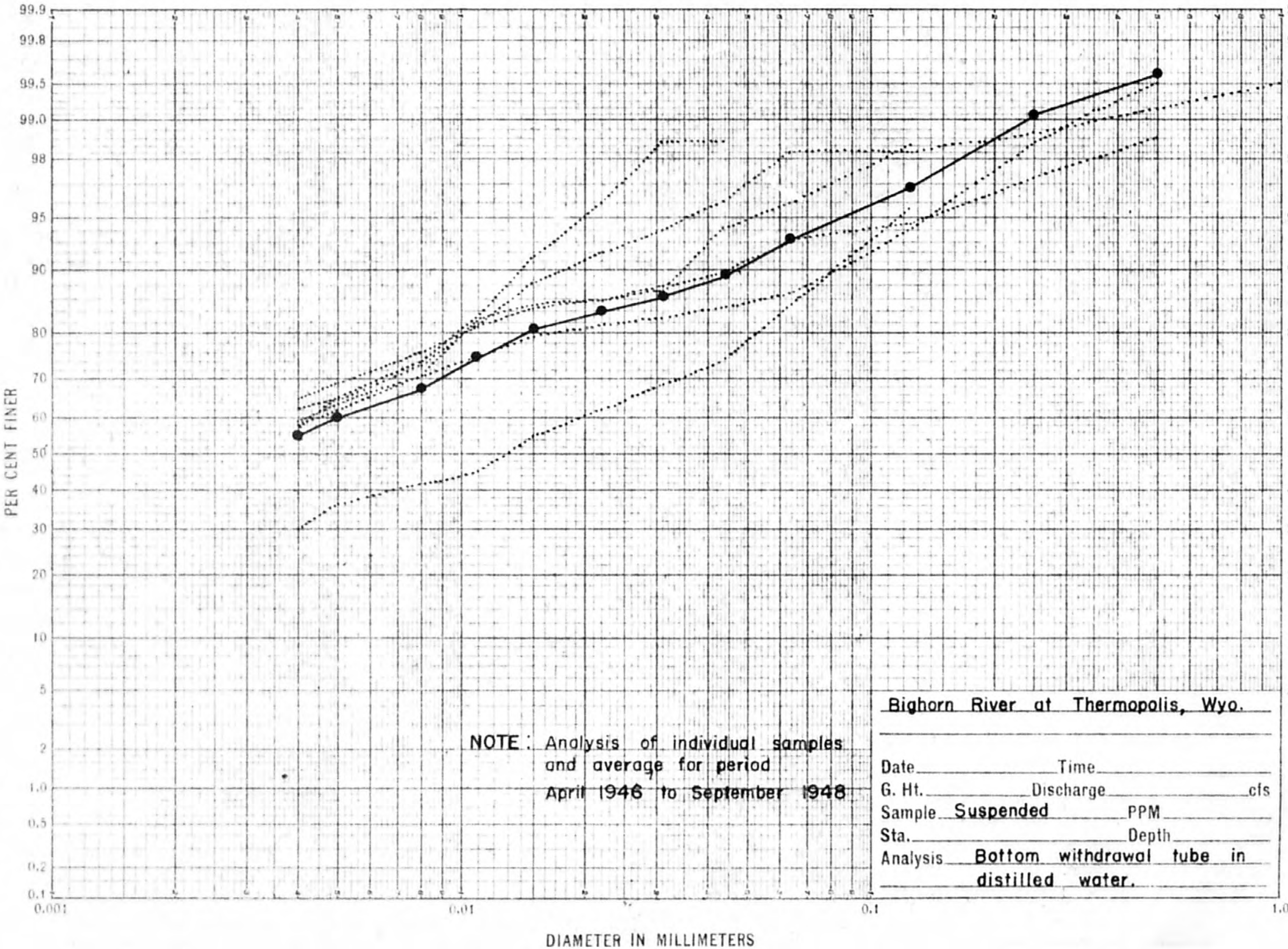
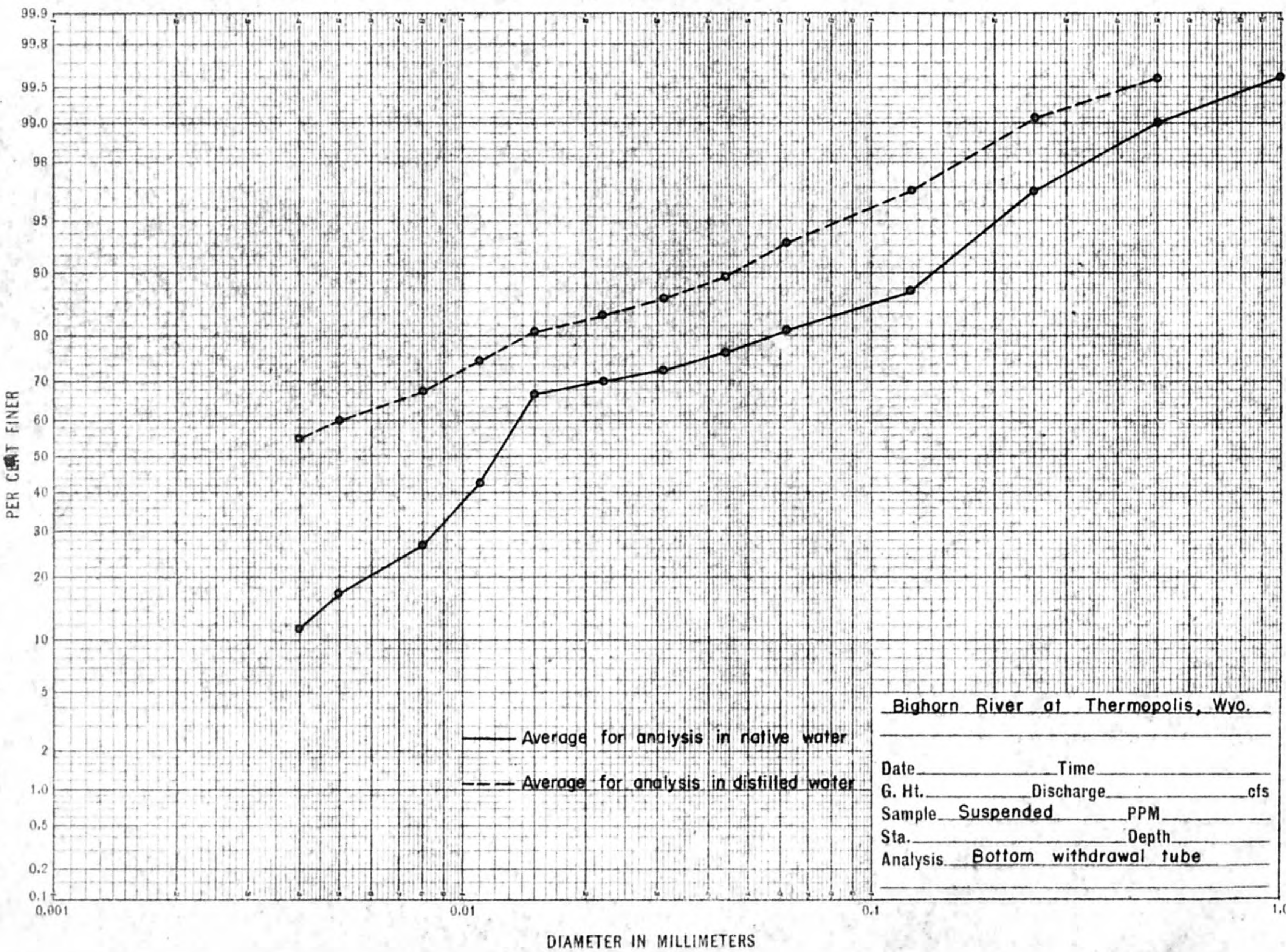

PER CENT FINER
DIAMETER IN MILLIMETERS
0.001
0.01
0.1
1.0
99.9
99.8
99.5
99.0
98
95
90
80
70
60
50
40
30
20
10
5
2
1.0
0.5
0.2
0.1
NOTE: Analysis of individual samples and average for period April 1946 to September 1948
Bighorn River at Thermopolis, Wyo.
Date
Time
G. Ht.
Discharge
cfs
Sample Suspended
PPM
Sta.
Depth
Analysis Bottom withdrawal tube in distilled water.

Fig. 10

139



PER CENT FINER
DIAMETER IN MILLIMETERS
Average for analysis in native water
Average for analysis in distilled water
Bighorn River at Thermopolis, Wyo.
Date
Time
G. Ht.
Discharge
cfs
Sample Suspended
PPM
Sta.
Depth
Analysis Bottom withdrawal tube

Fig. 11

140

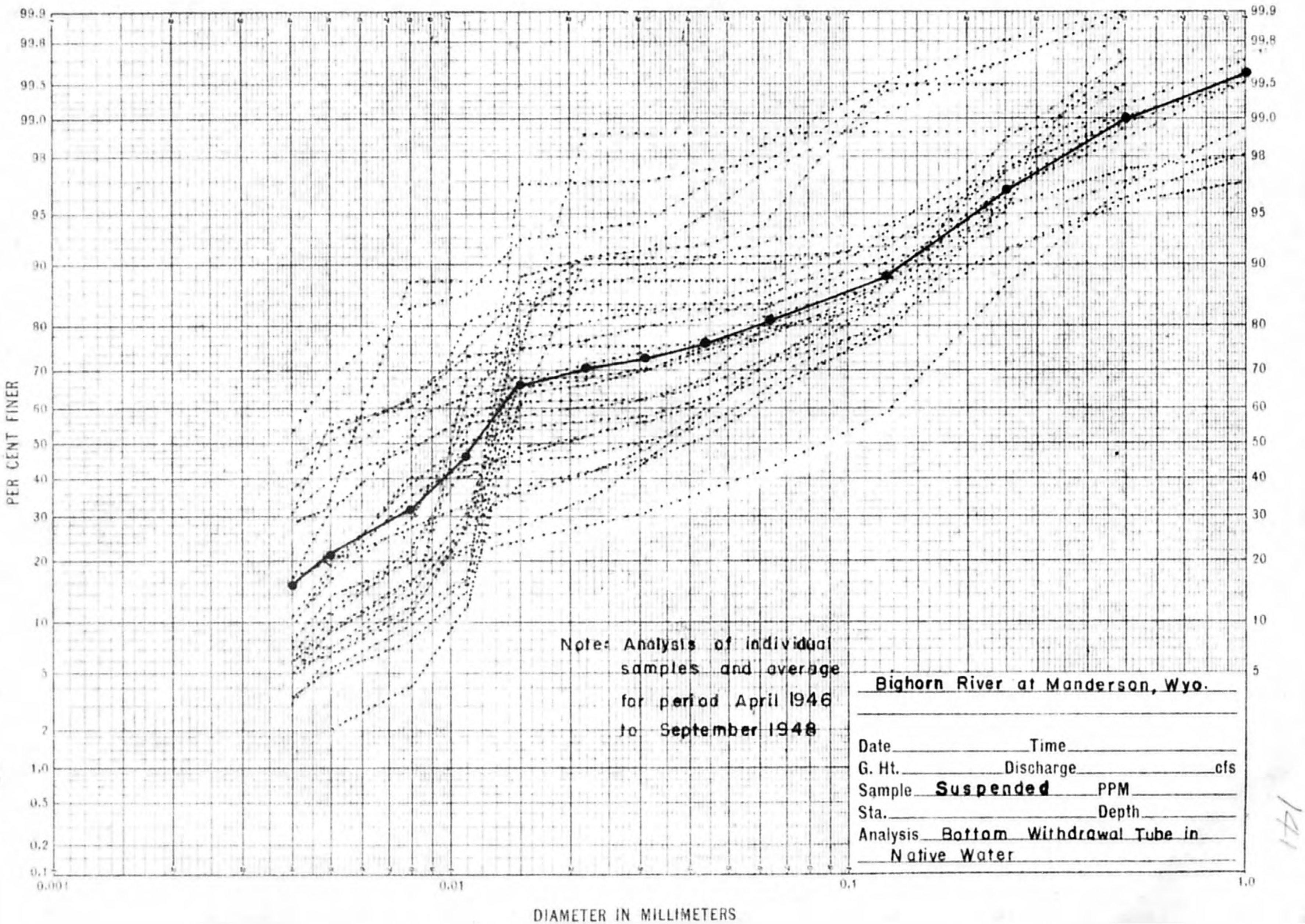

PER CENT FINER
DIAMETER IN MILLIMETERS
0.001
0.01
0.1
1.0
99.9
99.8
99.5
99.0
98
95
90
80
70
60
50
40
30
20
10
5
2
1.0
0.5
0.2
0.1
Note: Analysis of individual samples and average for period April 1946 to September 1948
Bighorn River at Manderson, Wyo.
Date
Time
G. Ht.
Discharge
cfs
Sample Suspended
PPM
Sta.
Depth
Analysis Bottom Withdrawal Tube in Native Water

Fig. 12

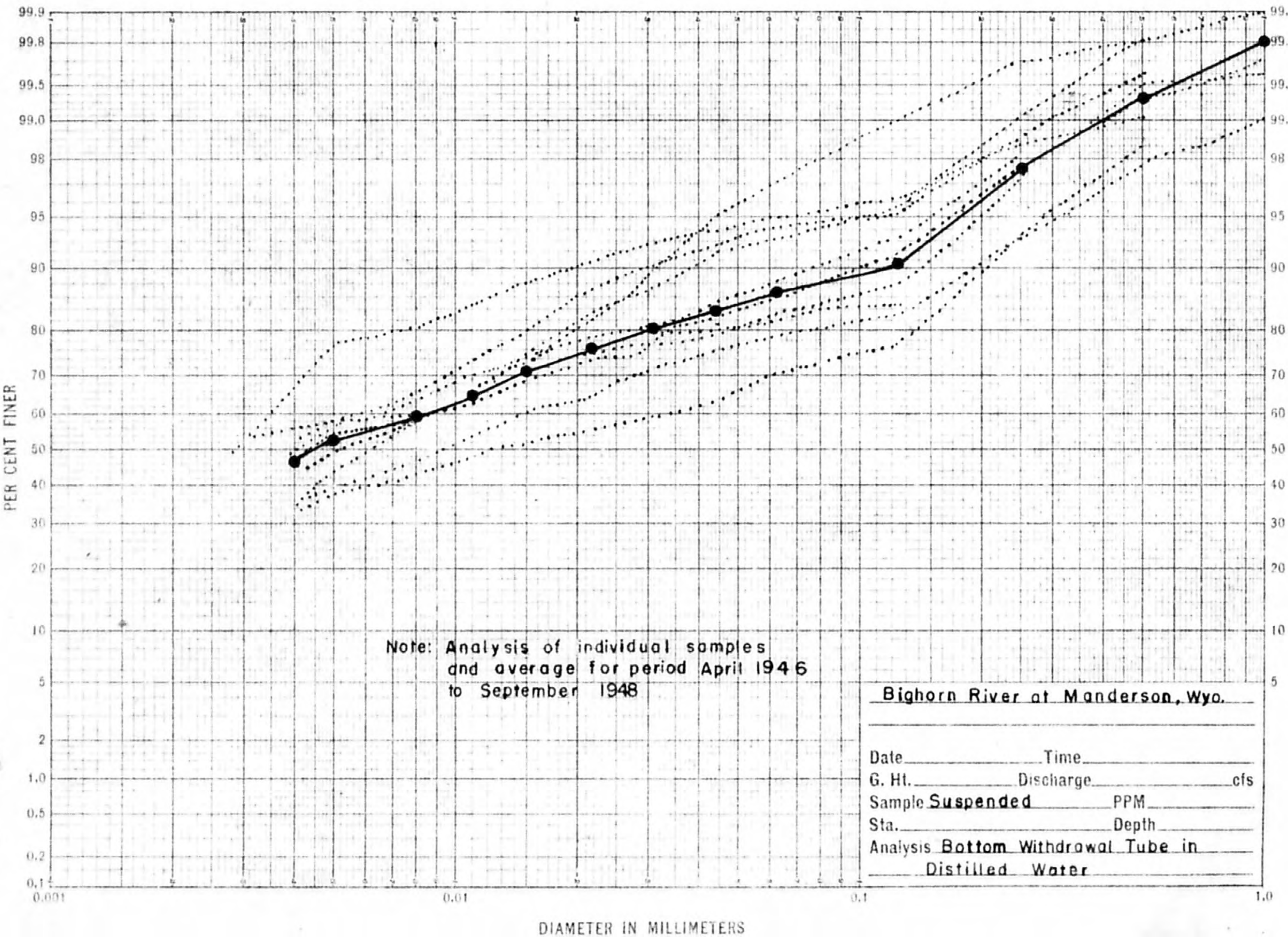
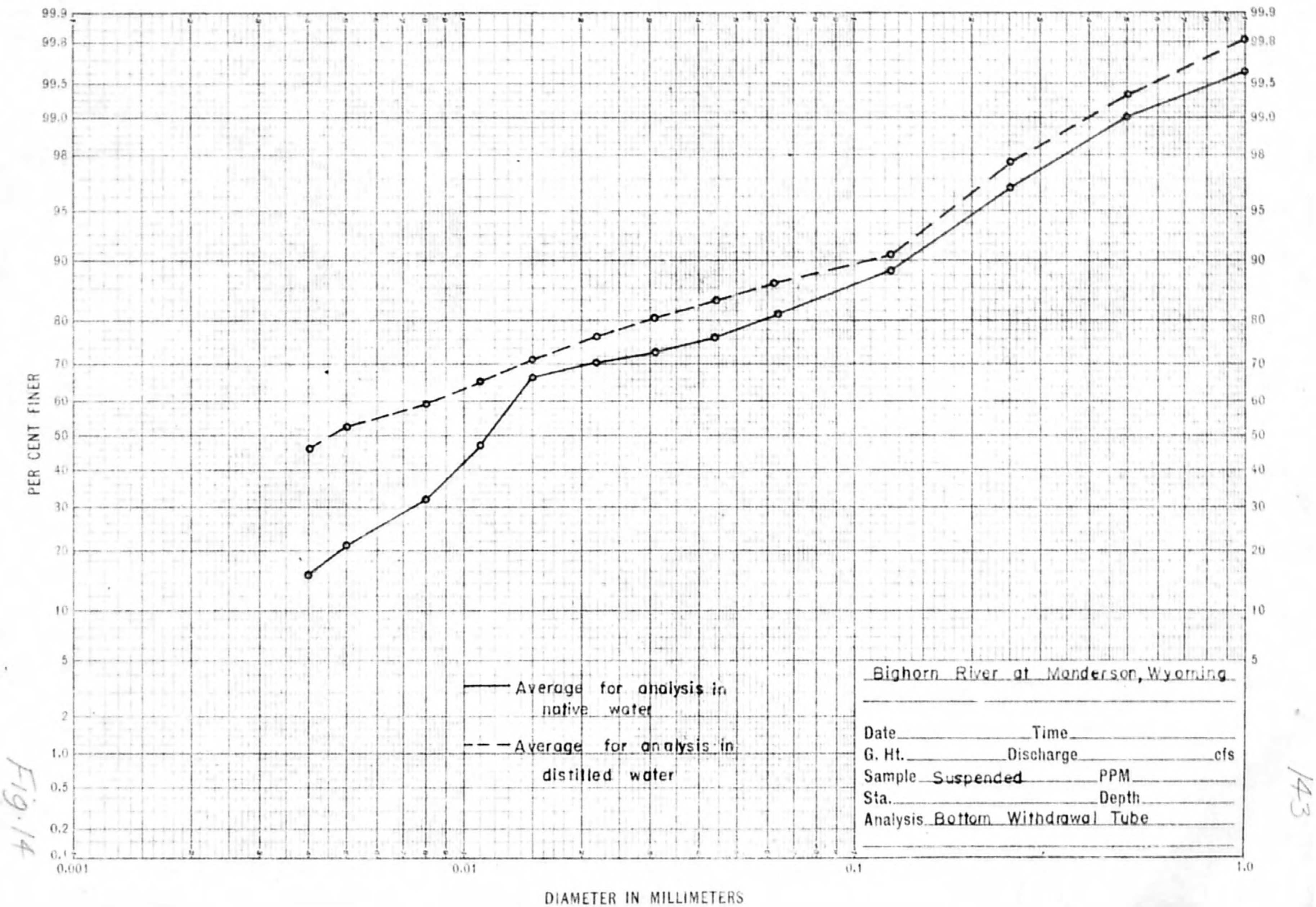
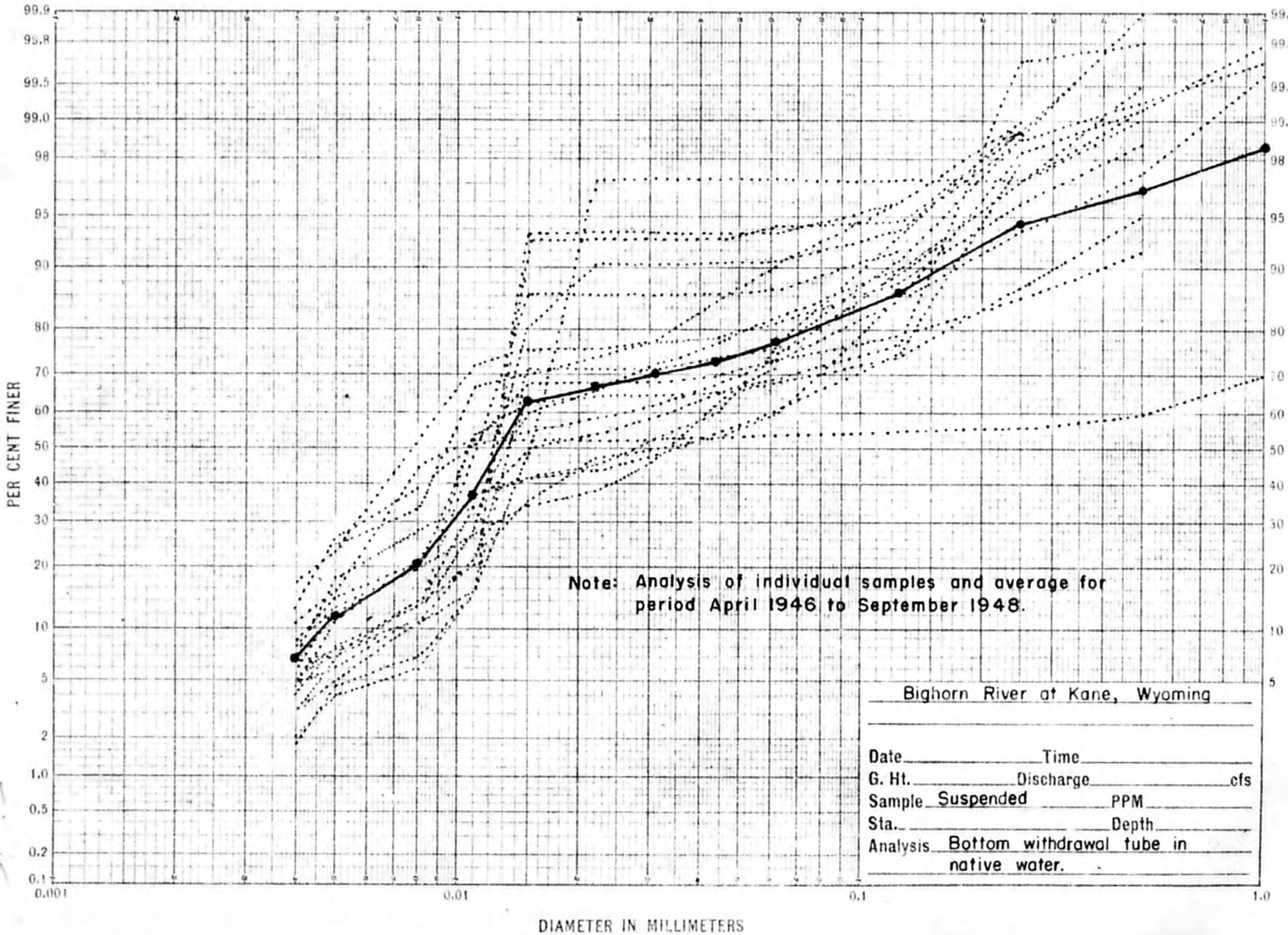

PER CENT FINER
DIAMETER IN MILLIMETERS
0.001
0.01
0.1
1.0
99.9
99.8
99.5
99.0
98
95
90
80
70
60
50
40
30
20
10
5
2
1.0
0.5
0.2
0.1
Note: Analysis of individual samples and average for period April 1946 to September 1948
Bighorn River at Manderson, Wyo.
Date Time
G. Ht. Discharge cfs
Sample Suspended PPM
Sta. Depth
Analysis Bottom Withdrawal Tube in Distilled Water

Fig. 13

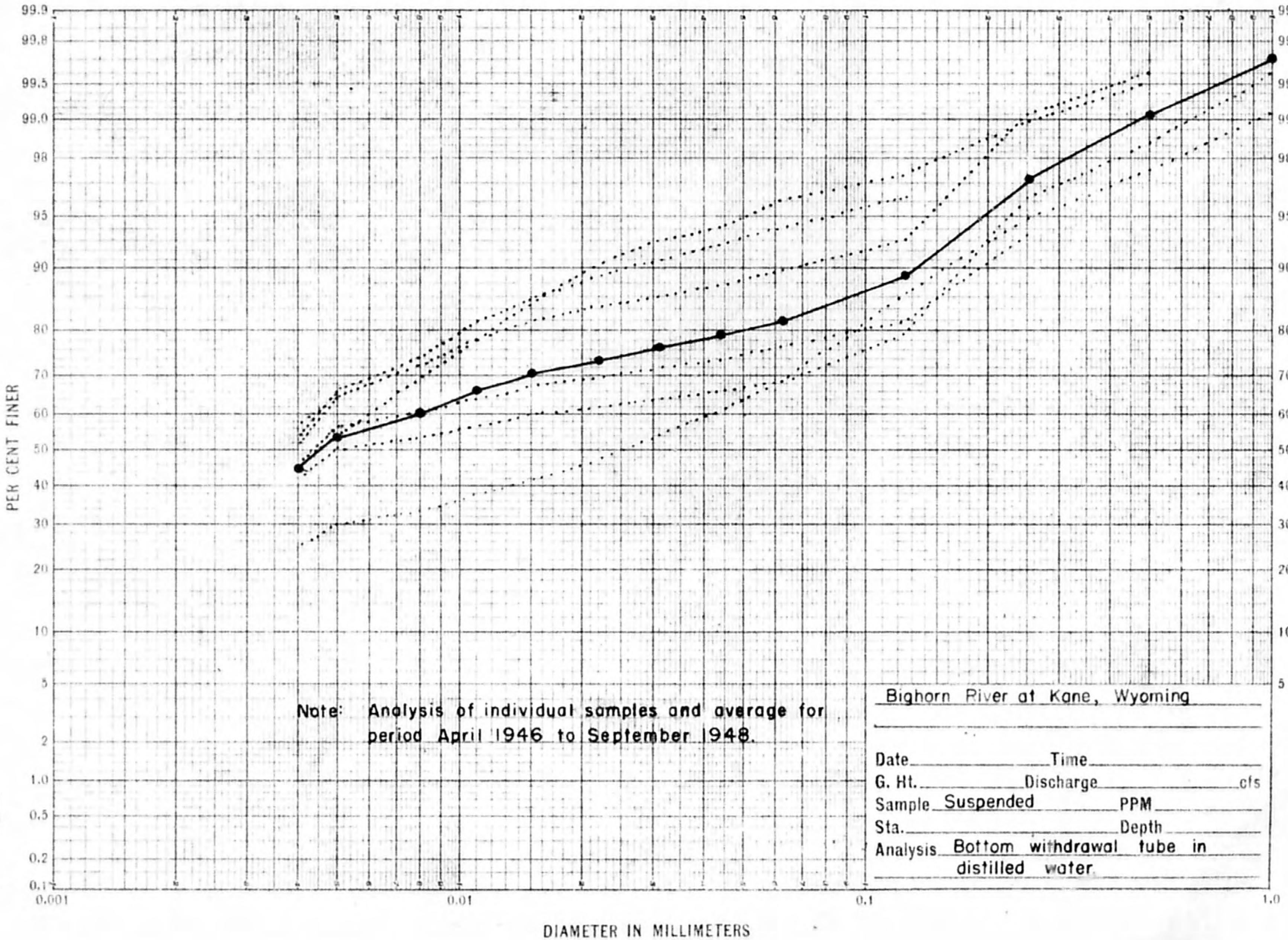

PER CENT FINER
DIAMETER IN MILLIMETERS
Average for analysis in native water
Average for analysis in distilled water
Bighorn River at Manderson, Wyoming
Date
Time
G. Ht.
Discharge
cfs
Sample Suspended
PPM
Sta.
Depth
Analysis Bottom Withdrawal Tube
Fig. 14
143



PER CENT FINER
DIAMETER IN MILLIMETERS
0.001
0.01
0.1
1.0
99.9
99.8
99.5
99.0
98
95
90
80
70
60
50
40
30
20
10
5
2
1.0
0.5
0.2
0.1
Note: Analysis of individual samples and average for period April 1946 to September 1948.
Bighorn River at Kane, Wyoming
Date Time
G. Ht. Discharge cfs
Sample Suspended PPM
Sta. Depth
Analysis Bottom withdrawal tube in native water.

Fig. 15

144



PER CENT FINER
DIAMETER IN MILLIMETERS
0.001
0.01
0.1
1.0
99.9
99.8
99.5
99.0
98
95
90
80
70
60
50
40
30
20
10
5
2
1.0
0.5
0.2
0.1
Note: Analysis of individual samples and average for period April 1946 to September 1948.
Bighorn River at Kane, Wyoming
Date Time
G. Ht. Discharge cfs
Sample Suspended PPM
Sta. Depth
Analysis Bottom withdrawal tube in distilled water

Fig. 16

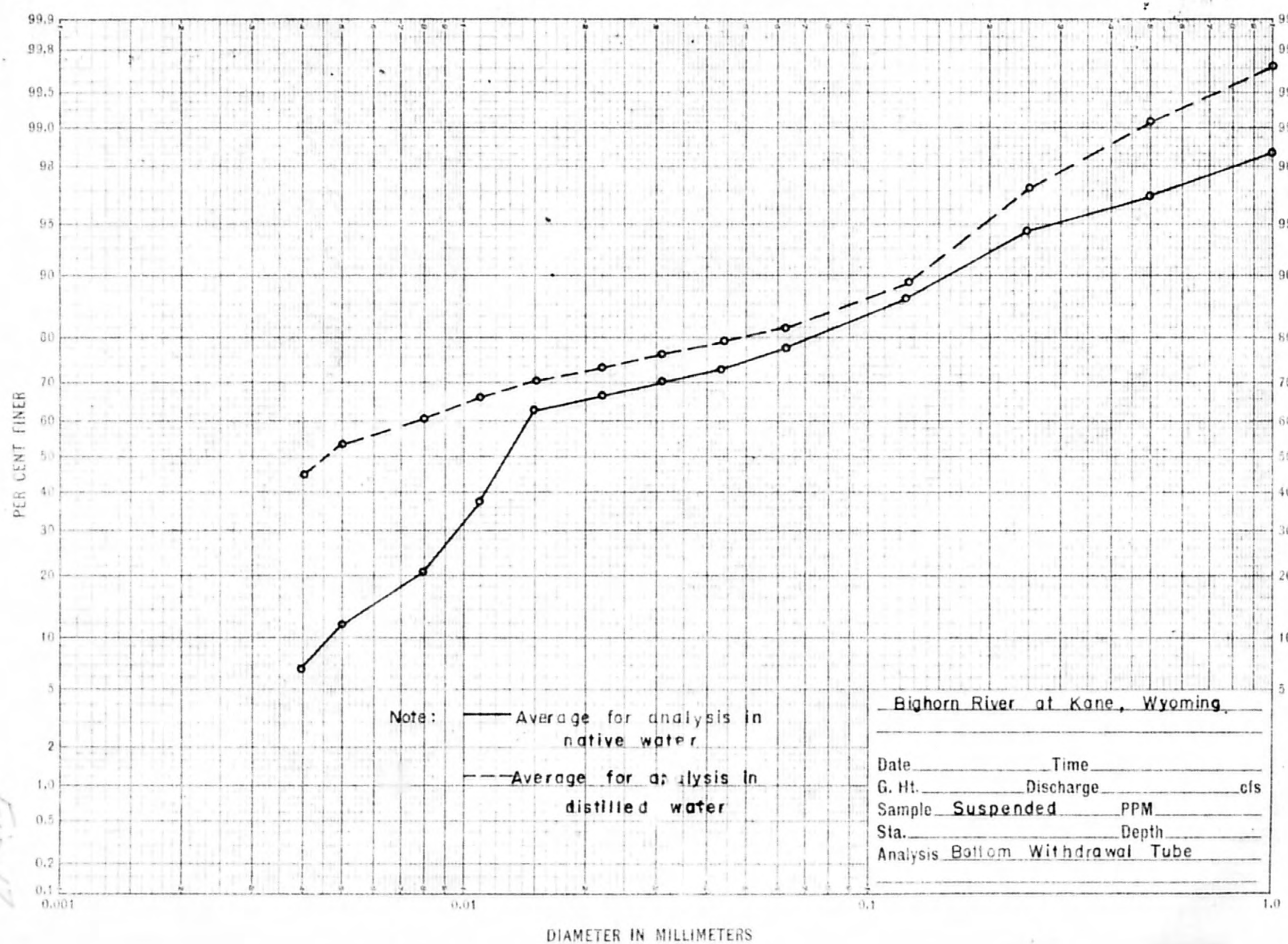

PER CENT FINER
99.9
99.8
99.5
99.0
98
95
90
80
70
60
50
40
30
20
10
5
2
1.0
0.5
0.2
0.1
0.001
0.01
0.1
1.0
DIAMETER IN MILLIMETERS
Note: Average for analysis in native water
Average for a; alysis in distilled water
Bighorn River at Kane, Wyoming.
Date
Time
G. Ht.
Discharge
cfs
Sample Suspended
PPM
Sta.
Depth
Analysis Bottom Withdrawal Tube

Fig. 17

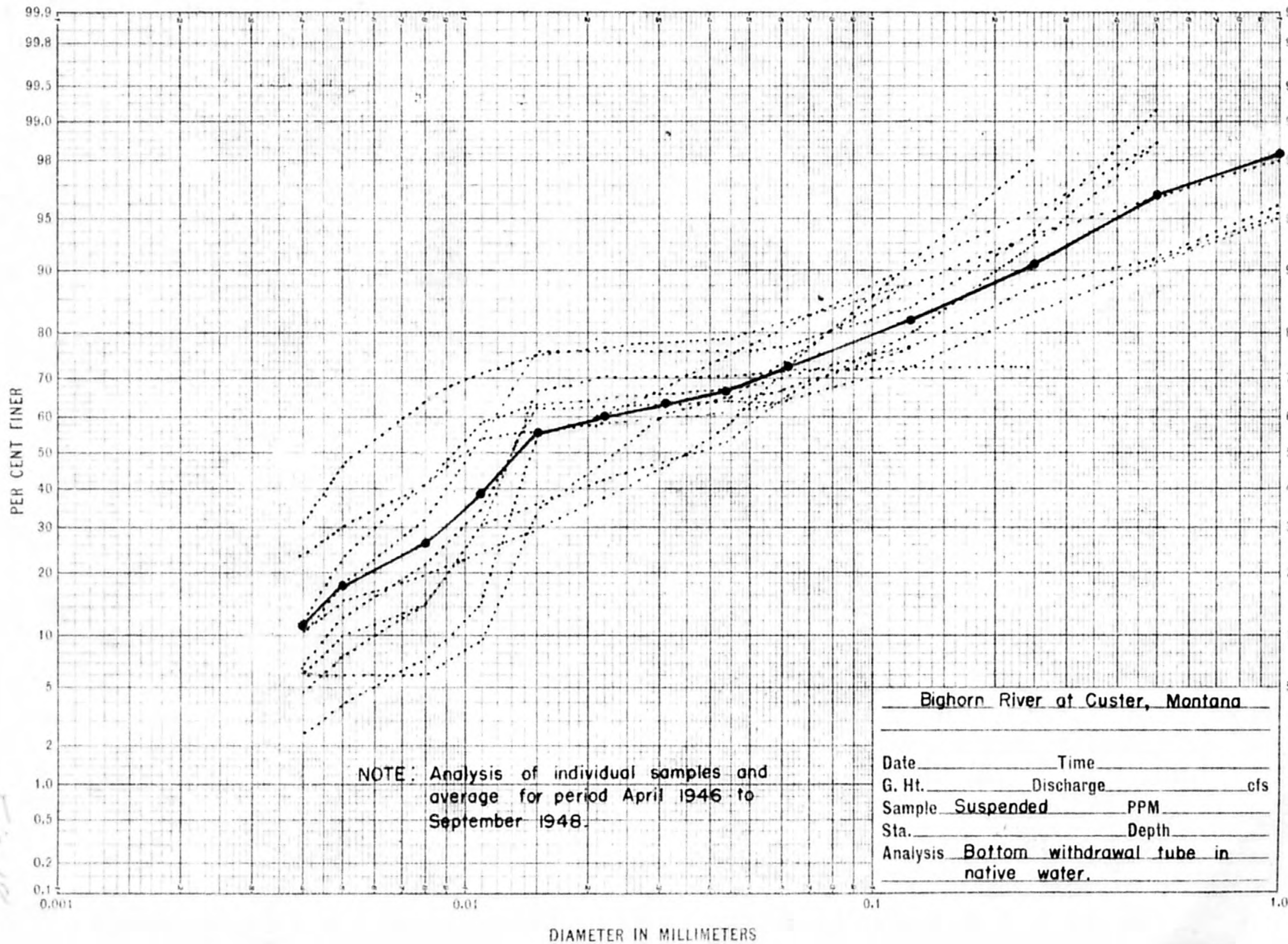

PER CENT FINER
DIAMETER IN MILLIMETERS
NOTE: Analysis of individual samples and average for period April 1946 to September 1948.
Bighorn River at Custer, Montana
Date Time
G. Ht. Discharge cfs
Sample Suspended PPM
Sta. Depth
Analysis Bottom withdrawal tube in native water.

Fig. 18

147

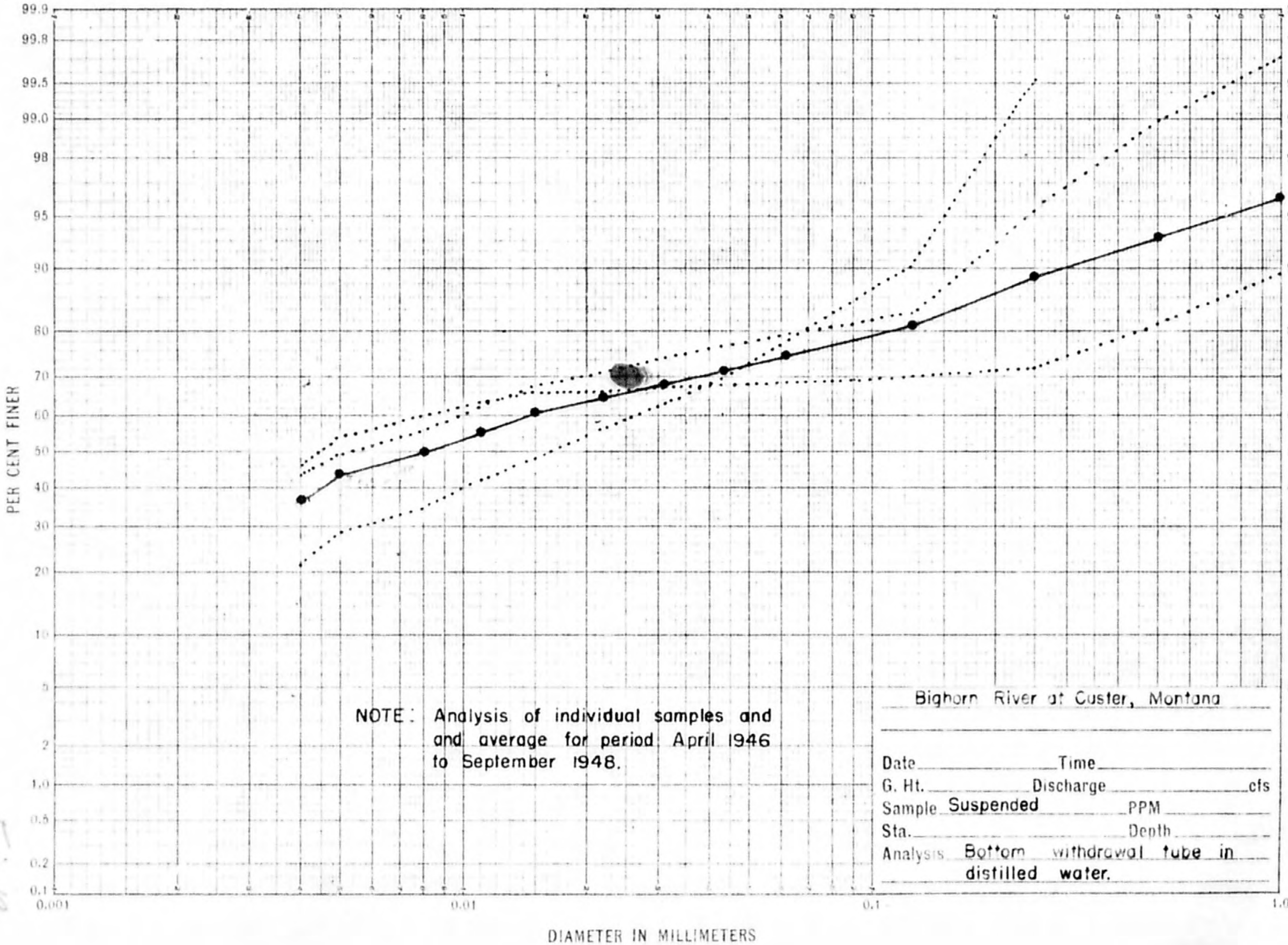
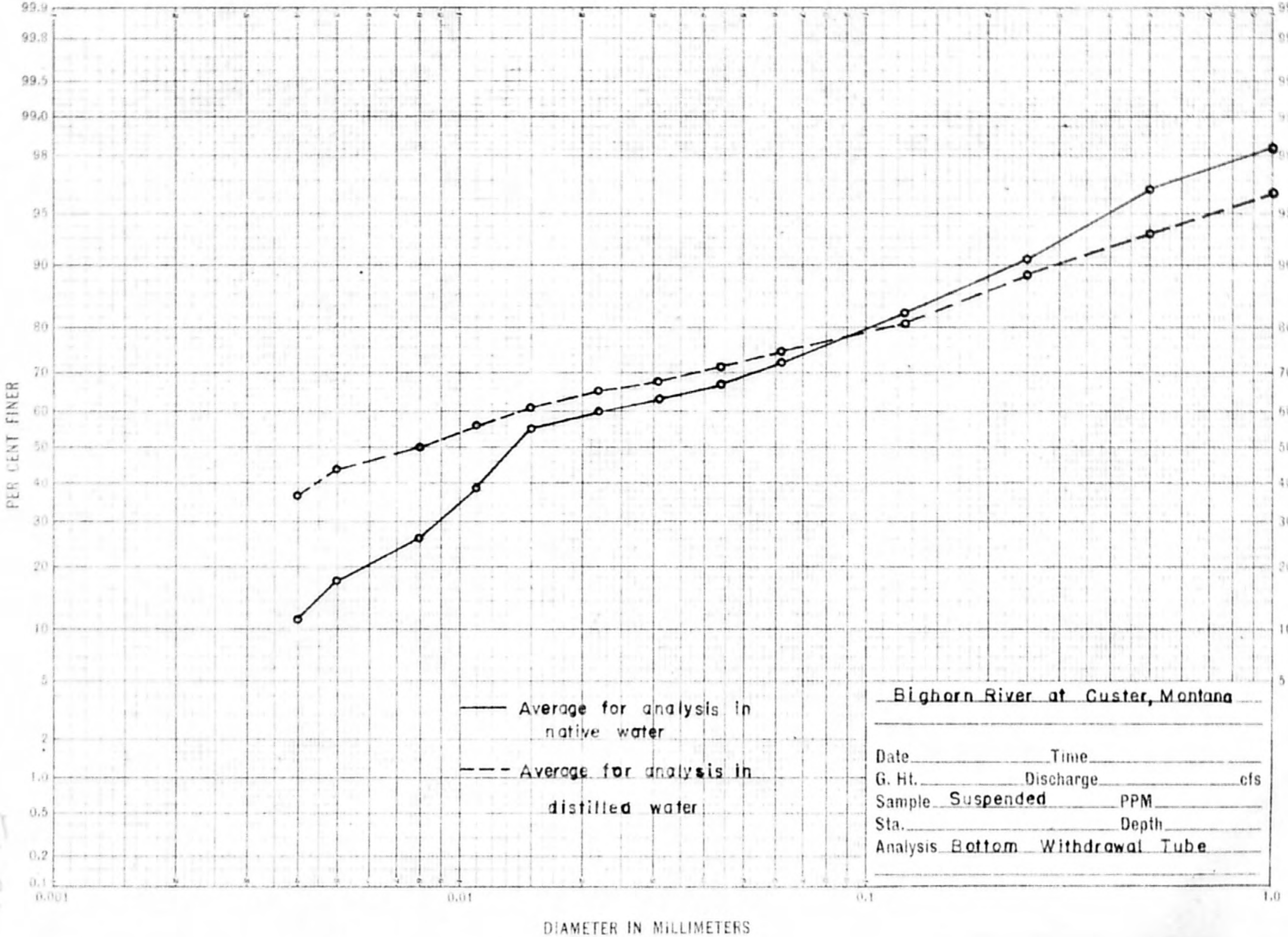

PER CENT FINER
DIAMETER IN MILLIMETERS
0.001
0.01
0.1
1.0
99.9
99.8
99.5
99.0
98
95
90
80
70
60
50
40
30
20
10
5
2
1.0
0.5
0.2
0.1
NOTE: Analysis of individual samples and and average for period April 1946 to September 1948.
Bighorn River at Custer, Montana
Date
Time
G. Ht.
Discharge
cfs
Sample Suspended
PPM
Sta.
Depth
Analysis Bottom withdrawal tube in distilled water.

Fig. 19

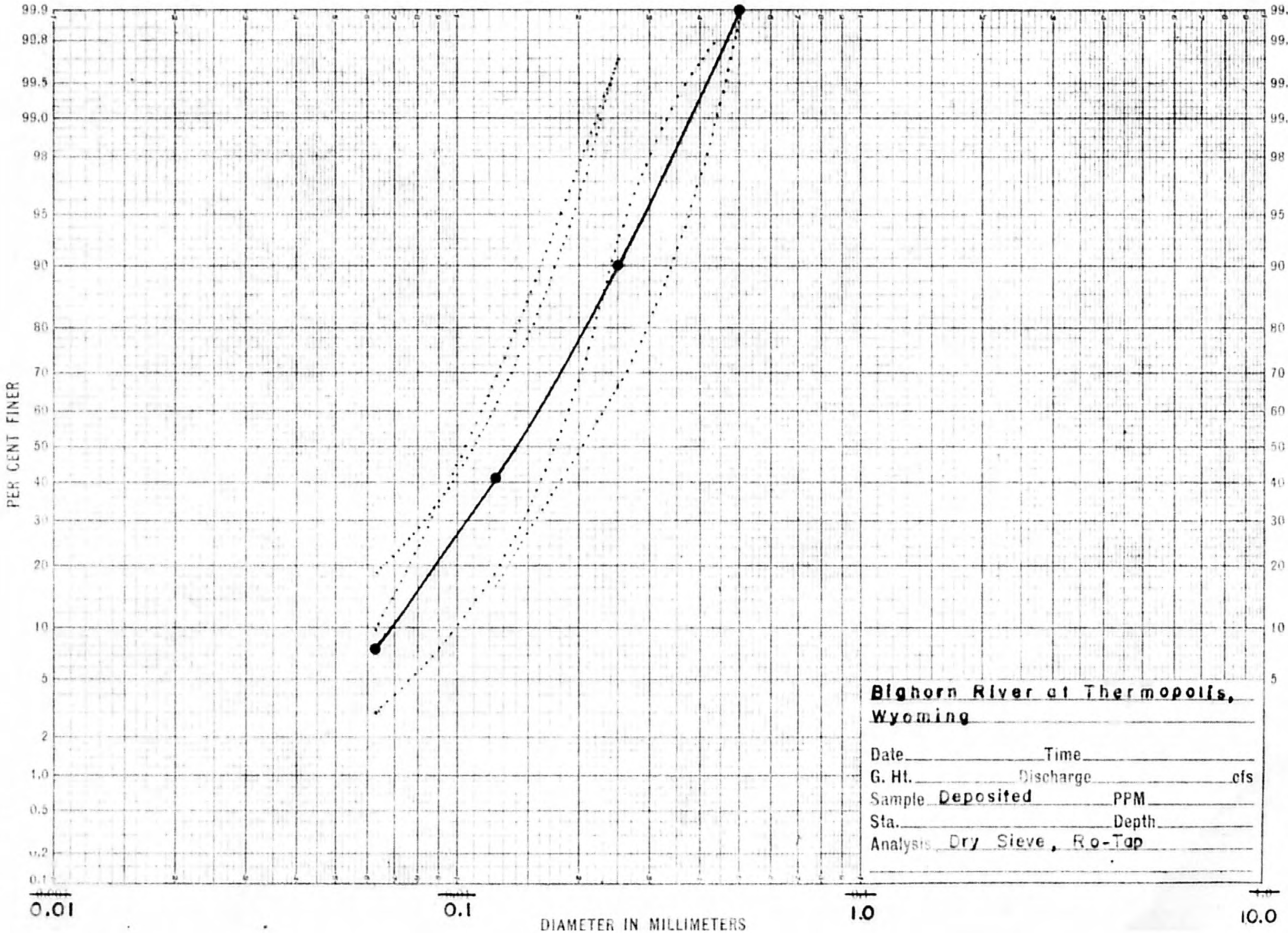
148



PER CENT FINER
DIAMETER IN MILLIMETERS
0.001
0.01
0.1
1.0
99.9
99.8
99.5
99.0
98
95
90
80
70
60
50
40
30
20
10
5
2
1.0
0.5
0.2
0.1
Average for analysis in native water
Average for analysis in distilled water
Bighorn River at Custer, Montana
Date
Time
G. Ht.
Discharge
cfs
Sample Suspended
PPM
Sta.
Depth
Analysis Bottom Withdrawal Tube

Fig. 20

149



PER CENT FINER
99.9
99.8
99.5
99.0
98
95
90
80
70
60
50
40
30
20
10
5
2
1.0
0.5
0.2
0.1
0.01
0.1
1.0
10.0
DIAMETER IN MILLIMETERS
Bighorn River at Thermopolis, Wyoming
Date
Time
G. Ht.
Discharge
cfs
Sample Deposited
PPM
Sta.
Depth
Analysis Dry Sieve, Ro-Tap

Fig. 21

150

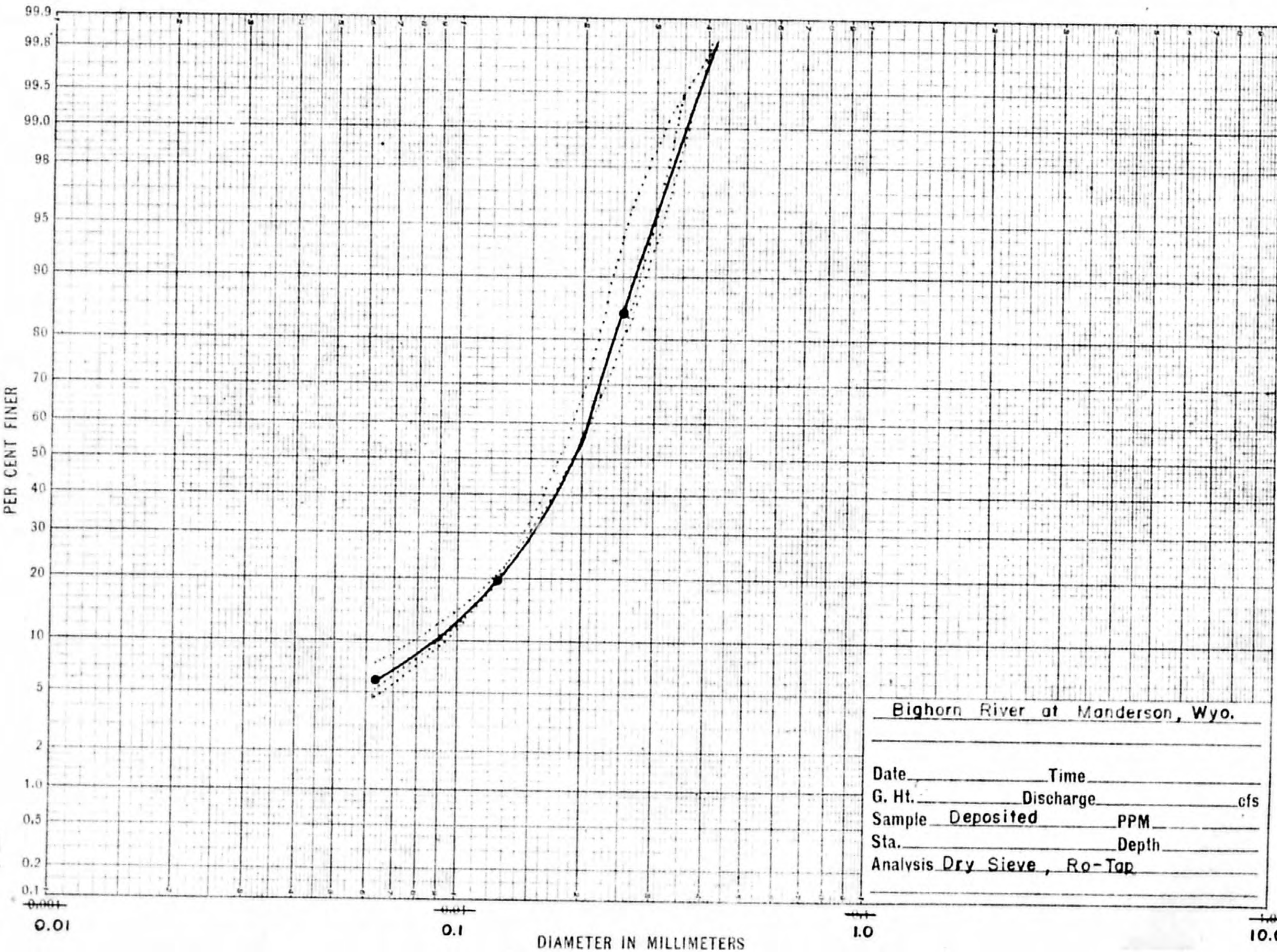
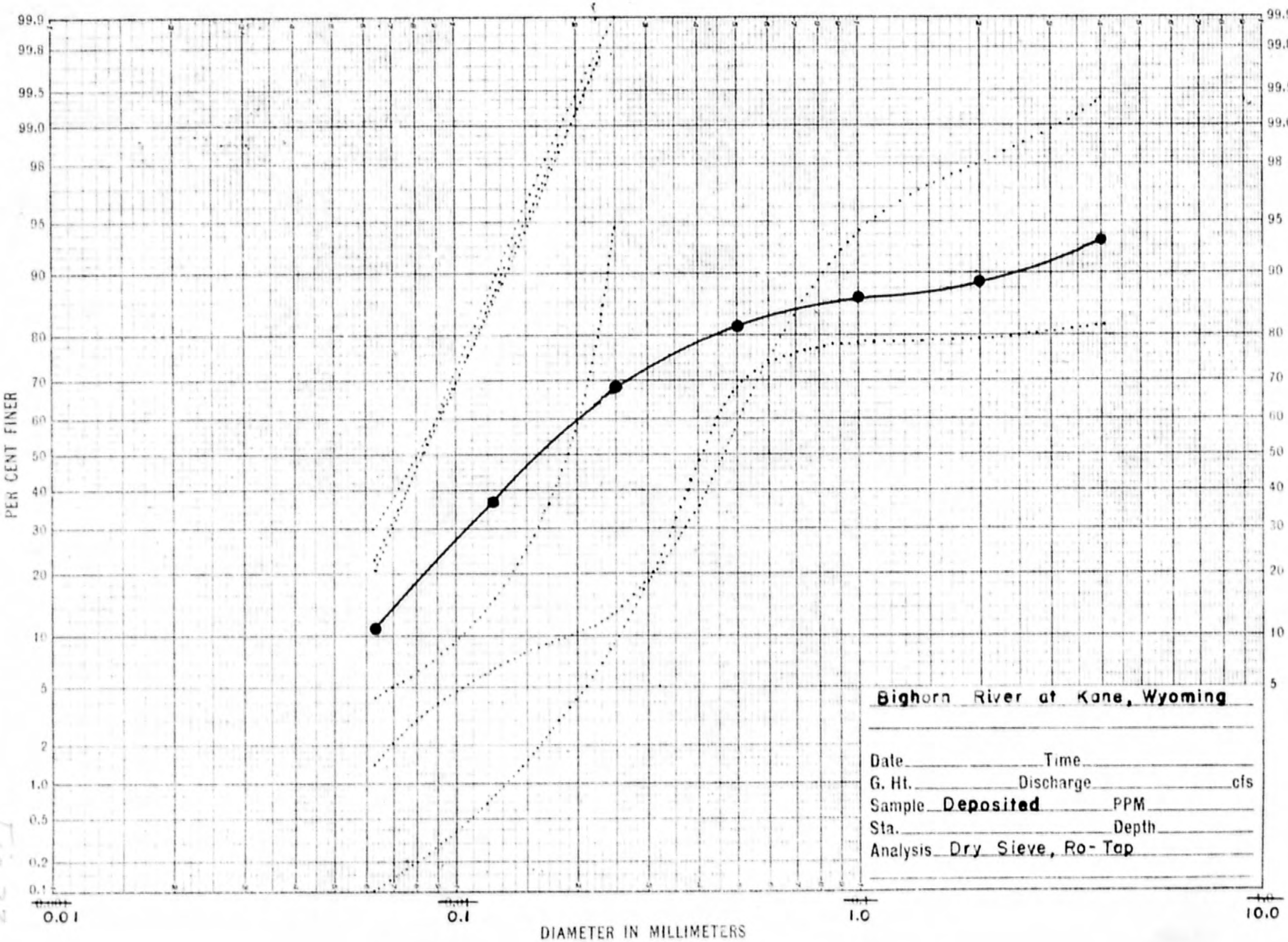

PER CENT FINER
DIAMETER IN MILLIMETERS
0.01
0.1
1.0
10.0
Bighorn River at Manderson, Wyo.
Date
Time
G. Ht.
Discharge
cfs
Sample Deposited
PPM
Sta.
Depth
Analysis Dry Sieve , Ro-Tap

Fig. 22

151



PER CENT FINER
DIAMETER IN MILLIMETERS
0.01
0.1
1.0
10.0
Bighorn River at Kane, Wyoming
Date
Time
G. Ht.
Discharge
cfs
Sample Deposited
PPM
Sta.
Depth
Analysis Dry Sieve, Ro-Tap

Fig. 23

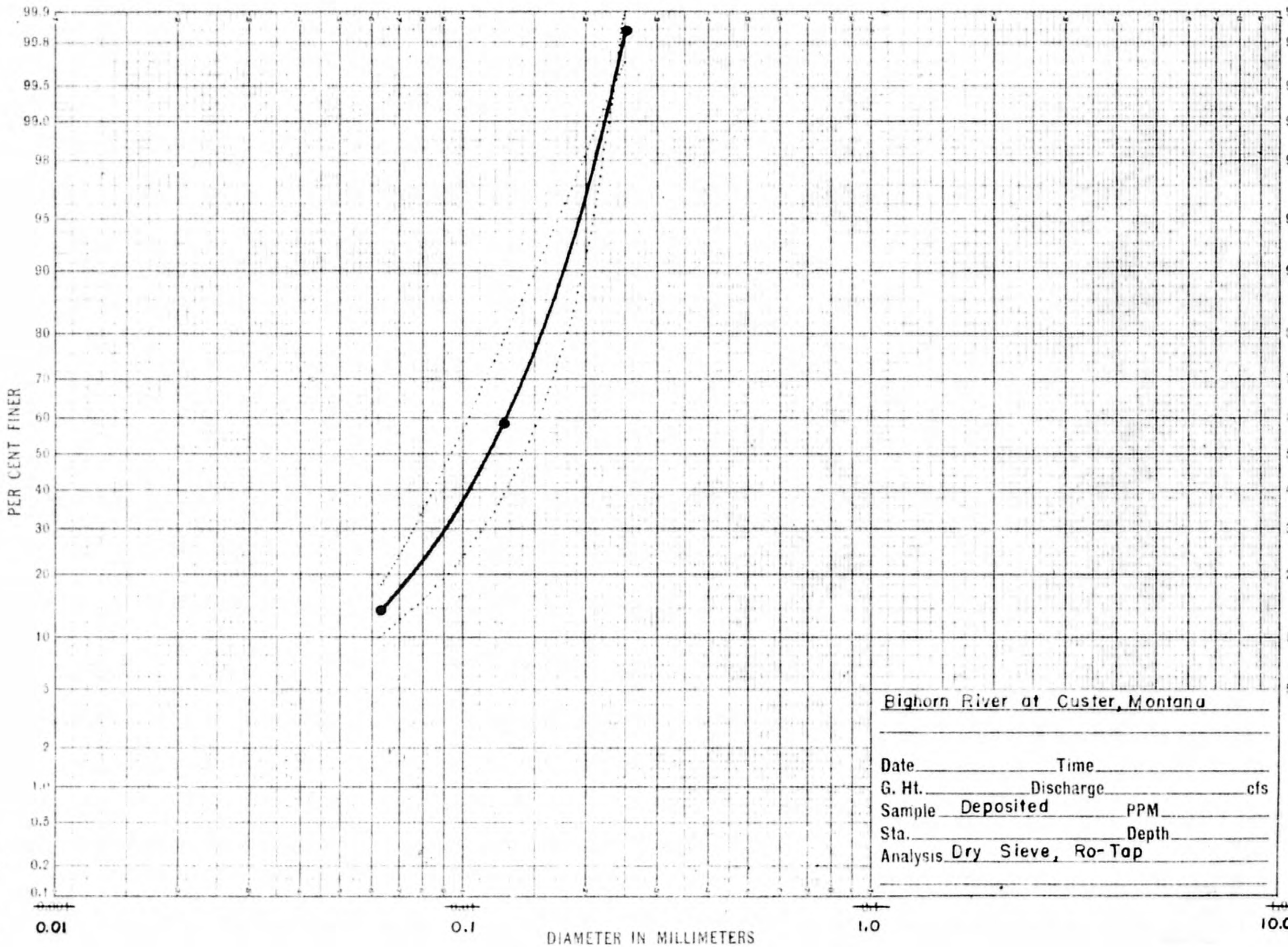

PER CENT FINER
DIAMETER IN MILLIMETERS
0.01
0.1
1.0
10.0
Bighorn River at Custer, Montana
Date
Time
G. Ht.
Discharge
cfs
Sample Deposited
PPM
Sta.
Depth
Analysis Dry Sieve, Ro-Tap

Fig. 24

153

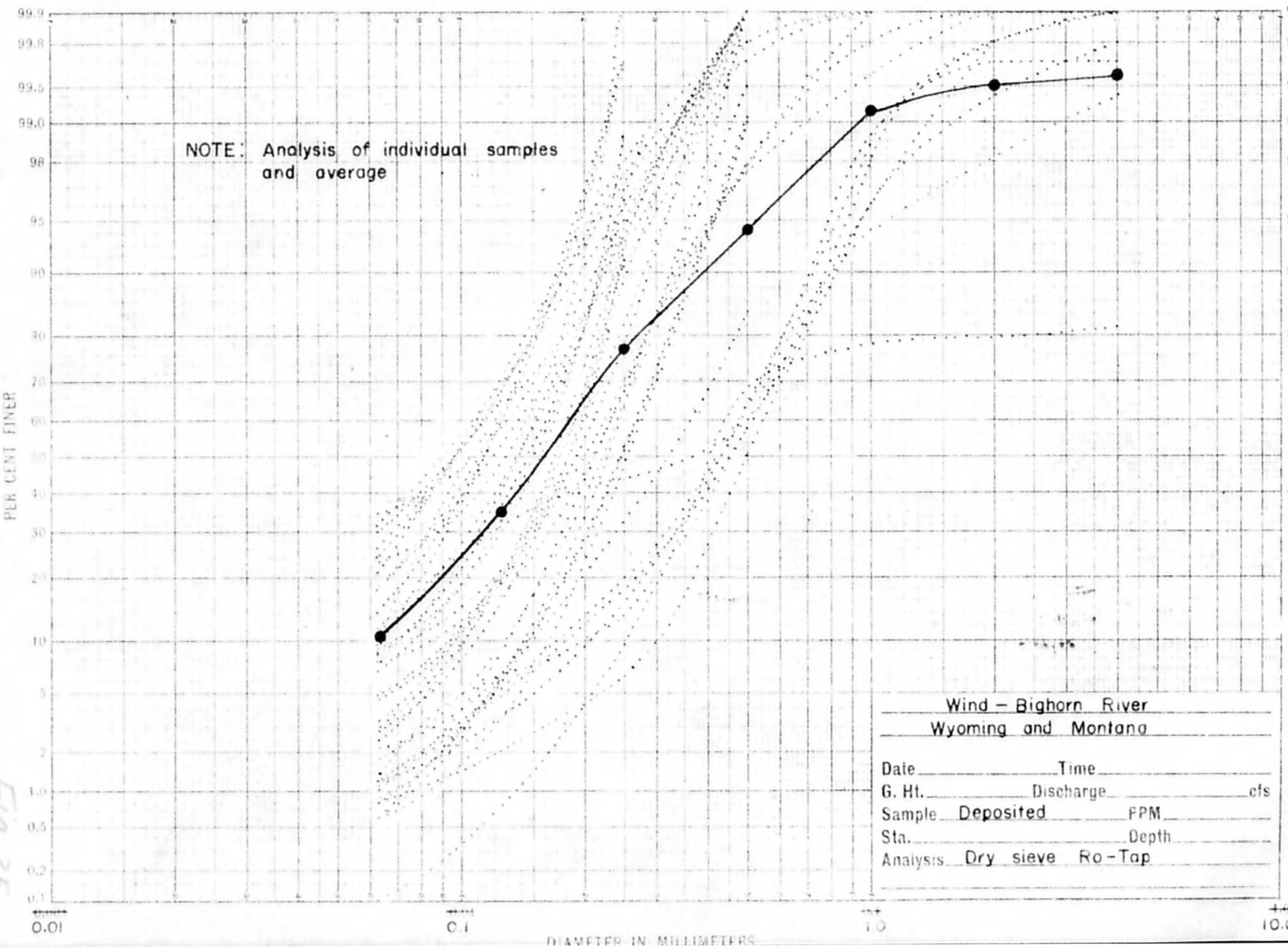

NOTE: Analysis of individual samples and average
PER CENT FINER
DIAMETER IN MILLIMETERS
0.01
0.1
1.0
10.0
99.9
99.8
99.5
99.0
98
95
90
80
70
60
50
40
30
20
10
5
2
1.0
0.5
0.2
0.1
Wind – Bighorn River
Wyoming and Montana
Date
Time
G. Ht.
Discharge
cfs
Sample Deposited
PPM
Sta.
Depth
Analysis Dry sieve Ro-Tap

Fig. 25

154

WEIGHT-VOLUME RELATIONSHIPS OF FLUVIAL SEDIMENTS

Investigations of the fluvial sediments with respect to rates of reservoir silting require studies of the probable location and density 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 density of the sediment deposits depends upon the type material in transport, particle size (actual), effect of change in concentration of the mineral constituents in solution, degree of sorting, and rate of compaction.

The rate of deposition of suspended sediments in a stream in the upper reaches of a reservoir is obviously a function of the steam velocity (turbulence) and settling diameter of the material in transport. The coarse material will be deposited first in the immediate backwater areas with the finer material eventually reaching the face of the dam through density currents or because of reservoir draw-down or both. The reservoir operation may thus result in alternate deposition of coarse and fine material in alternate lenses at the same location.

The determination of an average figure for the initial density of the sediment in transport in order to ascertain the space it will occupy in a reservoir is not only affected by reservoir operation but also by the inaccuracies introduced in measuring the total sediment discharge.

At present only the suspended sediment permits of measurement and the bed-load must be estimated. These limiting conditions therefore only make it possible to obtain an approximate figure for an average density of the material in transport.

Suspended Sediment

The density of the suspended sediment necessarily varies with the sediment discharge of the stream. To study these variations and approximate an average value, the clay, silt, and sand fractions obtained from particle size analyses were plotted in percent versus the sediment discharge in tons per day for each of the four mainstem stations (see plates 51, 52, 53, 54, 55. The apparent variation of the settling diameter when using native and distilled water is found to be about 32 percent for the clay and silt fractions and little or no variation for the sand fraction. As the settling diameter in distilled water more nearly represents the actual diameter of the water stable aggregates, it would necessarily be used with respect to density values.

If the assumption is made that the average curves shown in plates 51 to 54 are representative of the size fraction of the suspended sediments the density or weight-volume can be computed by (1) determining the percent distribution of clay, silt, and sand for the period of record and (2) using appropriate density values for the three size fractions. From data given in Report 9_/ and pages 157 to 160

_/ Idem.

Density and Median Particle Size of Reservoir Sediments

Source	Sample No.	Density Lbs./cu.ft.	Median particle size Millimeters
Lake Claremore, Rogers County, Oklahoma Collected by Soil Conservation Service	FC 11-3-39 CM-1	43	.0017
	FC 11-3-39 CM-2	45	.0018
	FC 11-3-39 CM-3	40	.0019
	FC 11-3-39 CM-4	44	.0026
	FC 11-3-39 CM-5	51	.0054
	FC 11-3-39 CM-6	55	.0046
	FC 11-3-39 CM-7	54	.0066
	FC 11-3-39 CM-8	63	.0116
	FC 11-3-39 CM-9	51	.0038
	FC 11-3-39 CM-10	65	.0290
High Point Reservoir, High Point, N. Carolina Collected by Soil Conservation Service	FC 10-5-38 HPR-6	59	.0215
	FC 10-5-38 HPR-9	62	.0338
	FC 10-5-38 HPR-10	68	.0016
	FC 10-5-38 HPR-13	41	.0032
	FC 10-5-38 HPR-14	60	.0105
	FC 10-5-38 HPR-16	44	.0130
	FC 10-5-38 HPR-18	64	.0012
	FC 10-5-38 HPR-21	45	.0163
	FC 10-5-38 HPR-22	37	.0055
	FC 10-5-38 HPR-23	40	.0008
Wills Point Reservoir, Wills Point, Texas Collected by Soil Conservation Service	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, Missouri Collected by Soil Conservation Service	FC 7-25-39 GR-1	53	.0096
	FC 7-25-39 GR-2	56	.0125
	FC 7-25-39 GR-3	117	.3330

Density and Median Particle Size of Reservoir Sediments

Source	Sample No.	Density Lbs./cu.ft.	Median particle size Millimeters
Kirk Lake, Allen County, Kansas Collected by Soil Conservation Service	FC 9-15-39 KR-1	42	.0024
	FC 9-15-39 KR-2	55	.0054
Lancaster Reservoir, Lancaster, South Carolina Collected by Soil Conservation Service	FC 10-5-38 LA-1	54	.0020
	FC 10-5-38 LA-2	70	.0064
	FC 10-5-38 LA-3	70	.0166
	FC 10-5-38 LA-4	79	.0248
	FC 10-5-38 LA-5	68	.0117
	FC 10-5-38 LA-6	39	.0118
	FC 10-5-38 LA-7	62	.0163
	FC 10-5-38 LA-8		.0070
Mountain Lake, Wayne County, Missouri Collected by Soil Conservation Service	FC 8-1-39 MO-1	57	.0076
	FC 8-1-39 MO-2	41	.0244
	FC 8-1-39 MO-3	66	.0137
Moran Reservoir, Allen County, Kansas Collected by Soil Conservation Service	FC 9-11-39 MN-1	50	.0025
	FC 9-11-39 MN-2	38	.0020
	FC 9-11-39 MN-3	52	.0046
	FC 9-11-39 MN-4	62	.0177
	FC 9-11-39 MN-5	49	.0061
	FC 9-11-39 MN-6	43	.0023
Neosha County State Lake, Kansas Collected by Soil Conservation Service	FC 8-18-39 NE-1	37	.0015
	FC 8-18-39 NE-2	30	.0021
	FC 8-18-39 NE-3	36	.0055
	FC 8-18-39 NE-4	38	.0044
	FC 8-18-39 NE-5	45	.0130

Density and Median Particle Size of Reservoir Sediments

Source	Sample No.	Density Lbs./cu.ft.	Median particle size Millimeters
Shepherd Mountain Lake, Iron County, Missouri Collected by Soil Conservation Service	FC 8-1-39 SH-1	43	.0109
	FC 8-1-39 SH-3	85	.4900
Lake Lee, Monroe, North Carolina Collected by Soil Conservation Service	FC 38 LE-1	62	.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, Wisconsin Collected by Soil Conservation Service	FC 9-15-39 MA-1	40	.0024
	FC 9-15-39 MA-2	52	.0022
	FC 9-15-39 MA-3	56	.0046
	FC 9-15-39 MA-4	55	.0052
	FC 9-15-39 MA-5	60	.0076
	FC 9-15-39 MA-6	70	.0070
	FC 9-15-39 MA-7	63	.0077
	FC 9-15-39 MA-8	60	.0099
	FC 9-15-39 MA-9	66	.0126
	FC 9-15-39 MA-10	80	.0274
	FC 9-15-39 MA-11	77	.0136
	FC 9-15-39 MA-12	69	.0175
	FC 9-15-39 MA-13	85	.0290
	FC 9-15-39 MA-14	87	.0220

Density and Median Particle Size of Reservoir Sediments

Source	Sample No.	Density Lbs./cu.ft.	Median particle size Millimeters
Arrowrock Reservoir, Idaho Collected by U.S. Bureau of Reclamation	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
	9	85.2	1.30
	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
	17	85.9	2.72
	18	52.1	.0114
Guernsey Reservoir, North Platte River, Wyoming Collected by U.S. Bureau of Reclamation	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
	12	84.2	1.34

the following density values were assigned to the three fractions; sand 93 lbs., silt 65 lbs., and clay 40 lbs.

The method of computing the average percent sand, silt, and clay is shown on pages 162-165. Using these values and the records of suspended sediment discharge, as shown, the average weight per cubic foot was found to be 55 pounds. (see page 166)

An additional study was made of the density of the suspended sediments by plotting the median particle size of the samples analyzed versus the sediment discharge in tons per days shown in plate 56. The method used to determine the general relationship between analyses run in native and distilled water is shown in plate 57. Using this method and the density values shown for the median particle size in figure 26 the average density for the suspended sediment at the Manderson station for 1947 was found to be 60 lbs. per cubic foot (see pages 157 to 160 for data on reservoir sediments). On the basis of available data an average weight of 60 lbs. per cubic foot will be used for suspended sediments for the period of record.

Deposited Sediments

Samples of the deposited sediments in the Bighorn River channel were obtained from bars at 15 locations including these adjacent to each of the measuring stations. The density and percent of material greater than .0625 mm are tabulated on pages 169 to 173 and shown graphically in figure 27. The dry weight per unit volume of the 62 samples collected ranged from 77 to 105 lbs. per cubic foot and averaged 90 lbs.

DISTRIBUTION OF SAND, SILT, AND CLAY WITH SUSPENDED SEDIMENT DISCHARGE

Bighorn River, Thermopolis, Wyoming

Suspended sediment discharge						1946					1947					1948				
From	To	Average	Sand	Silt	Clay	Days	Sediment	Sand	Silt	Clay	Days	Sediment	Sand	Silt	Clay	Days	Sediment	Sand	Silt	Clay
Tons per day			Percent				Tons					Tons					Tons			
64	100	82	0	52	48						6	492	0	256	236	1	96	0	50	46
100	136	118	0	56	44						2	236	0	132	104	1	118	0	66	52
136	185	160	0	60	40						8	1,280	0	768	512	5	800	0	480	320
185	251	218	0	63	37						5	1,090	0	687	403	9	1,962	0	1,236	726
251	342	296	0	66	34						8	2,368	0	1,563	805	13	3,848	0	2,540	1,308
342	464	403	1	68	31						8	3,224	32	2,193	999	11	4,433	44	3,015	1,374
464	630	547	2	70	28						13	7,111	142	4,978	1,991	6	3,282	65	2,298	919
630	857	743	3	72	25						30	22,290	669	16,049	5,572	5	3,715	111	2,675	929
857	1,170	1,013	4	73	23	1	1,013	41	739	233	22	22,286	891	16,269	5,126	15	15,195	608	11,092	3,495
1,170	1,570	1,370	6	74	20	2	2,740	164	2,028	548	17	23,290	1,397	17,235	4,658	15	20,550	1,233	15,207	4,110
1,570	2,150	1,860	7	75	18	6	11,160	781	8,370	2,009	14	26,040	1,823	19,530	4,687	34	63,240	4,427	47,430	11,383
2,150	2,930	2,540	8	76	16	5	12,700	1,016	9,652	2,032	23	58,420	4,674	44,399	9,347	35	88,900	7,112	67,564	14,224
2,930	3,980	3,455	9	78	13	17	58,735	5,286	45,813	7,636	30	103,650	9,328	80,847	13,475	43	148,565	13,371	115,881	19,313
3,980	5,410	4,695	10	78	12	33	154,935	15,494	120,849	18,592	26	122,070	12,207	95,215	14,648	40	187,800	18,780	146,484	22,536
5,410	9,360	7,385	13	78	9	27	199,395	25,921	155,528	17,946	16	118,160	15,361	92,165	10,634	31	228,935	29,762	178,569	20,604
9,360	10,000	9,680	15	77	8	16	154,880	23,232	119,258	12,390	9	87,120	13,068	67,082	6,970	17	167,620	25,143	129,067	13,410
10,000	13,600	11,800	16	77	7	19	224,200	35,872	172,634	15,694	5	59,000	9,440	45,430	4,130	17	200,600	32,096	154,462	14,042
13,600	18,500	16,050	18	76	6	21	337,050	60,669	256,158	20,223	18	288,900	52,002	219,564	17,334	14	224,700	40,446	170,772	13,482
18,500	25,100	21,800	20	74	6	18	392,400	78,480	290,376	23,544	33	719,400	143,880	532,356	43,164	9	196,200	39,240	145,188	11,772
25,100	34,200	29,650	23	70	7	14	415,100	95,473	290,570	29,057	16	474,400	109,112	332,080	33,208	5	148,250	34,097	103,775	10,378
34,200	46,400	40,300	25	67	8	11	443,300	110,825	297,011	35,464	19	765,700	191,425	513,019	61,256	5	201,500	50,375	135,005	16,120
46,400	63,000	54,700	28	60	12	4	218,800	61,264	131,280	26,256	11	601,700	168,476	361,020	72,204	15	820,500	229,740	492,300	98,460
63,000	85,700	74,350	30	50	20	3	223,050	66,915	111,525	44,610	14	1,040,900	312,270	520,450	208,180	10	743,500	223,050	371,750	148,700
85,700	117,000	113,500	33	43	24	1	113,500	37,455	48,805	27,240	8	908,000	299,640	390,440	217,980	5	313,925	103,595	134,988	75,342
117,000	157,000	137,000	33	42	25	1	137,000	45,210	57,540	34,250	4	548,000	180,840	230,160	137,000	1	137,000	45,210	57,540	34,250
157,000	215,000	186,000	34	41	25	2	372,000	126,480	152,520	93,000						2	372,000	126,480	152,520	93,000
215,000	293,000	254,000	35	40	25											1	254,000	88,900	101,600	63,500
293,000	398,000	345,500																		
					Total			790,578	2,270,656	410,724			1,526,677	3,603,887	874,563			1,113,885	2,743,554	693,795
					Total Tons				3,471,958					6,005,127					4,551,234	
					Percent			22.8%	65.4%	11.8%			25.4%	60.0%	14.6%			24.5%	60.3%	15.2%

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DISTRIBUTION OF SAND, SILT, AND CLAY WITH SUSPENDED SEDIMENT DISCHARGE

Bighorn River, Manderson, Wyoming

Suspended sediment discharge						1946					1947					1948				
From	To	Average	Sand	Silt	Clay	Days	Sediment	Sand	Silt	Clay	Days	Sediment	Sand	Silt	Clay	Days	Sediment	Sand	Silt	Clay
Tons per day			Percent				Tons					Tons					Tons			
64	100	82	4	48	48						3	246	10	118	118	3	246	10	118	118
100	136	118	4	52	44											2	236	9	123	104
136	185	160	6	53	41						1	160	10	85	66					
185	251	218	7	55	38	1	218	15	120	83	1	218	15	120	83	12	2,616	180	1,439	994
251	342	296	9	56	35	3	888	80	497	311						7	2,072	186	1,160	725
342	464	403	10	58	32	7	2,821	282	1,636	903						8	3,224	322	1,870	1,032
464	630	547	11	60	29	4	2,188	240	1,313	635	1	547	60	328	159	8	4,376	481	2,626	1,269
630	857	743	11	62	27	2	1,486	163	921	401	1	743	82	461	201	7	5,201	572	3,225	1,404
857	1,170	1,013	13	63	24	2	2,026	263	1,276	486	37	37,481	4,872	23,613	8,995	17	17,221	2,239	10,849	4,133
1,170	1,570	1,370	13	64	23	1	1,370	178	877	315	7	9,590	1,247	6,138	2,206	10	13,700	1,781	8,768	3,151
1,570	2,150	1,860	15	66	19	4	7,440	1,116	4,910	1,414	10	18,600	2,790	12,276	3,534	25	46,500	6,975	30,690	8,835
2,150	2,930	2,540	16	67	17	6	15,240	2,438	10,211	2,591	15	38,100	6,096	25,527	6,477	16	40,640	6,502	27,229	6,908
2,930	3,980	3,455	16	69	15	14	48,370	7,739	33,375	7,256	54	186,570	29,851	128,733	27,986	24	82,920	13,267	57,215	12,438
3,980	5,410	4,695	17	70	13	15	70,425	11,972	49,298	9,155	18	84,510	14,367	59,157	10,986	35	164,325	27,935	115,028	21,362
5,410	9,360	7,385	18	72	10	24	177,240	31,903	127,613	17,724	29	214,165	38,550	154,199	21,416	17	125,545	22,598	90,392	12,554
9,360	10,000	9,680	19	72	9	22	212,960	40,462	153,331	19,166	26	251,680	47,819	181,209	22,651	22	212,960	40,462	153,331	19,166
10,000	13,600	11,800	19	73	8	18	212,400	40,356	155,052	16,992	13	153,400	29,146	111,982	12,272	31	365,800	69,502	267,034	29,264
13,600	18,500	16,050	20	74	6	12	192,600	38,520	142,524	11,556	23	369,150	73,830	273,171	22,149	20	321,000	64,200	237,540	19,260
18,500	25,100	21,800	19	76	5	15	327,000	62,130	248,520	16,350	20	436,000	82,840	331,360	21,800	25	545,000	103,550	414,200	27,250
25,100	34,200	29,650	19	76	5	8	237,200	45,068	180,272	11,860	22	652,300	123,937	495,748	32,615	13	385,450	73,235	292,942	19,272
34,200	46,400	40,300	20	76	4	9	362,700	72,540	275,652	14,508	18	725,400	145,080	551,304	29,016	13	523,900	104,780	398,164	20,956
46,400	63,000	54,700	20	75	5	6	328,200	65,640	246,150	16,410	22	1,203,400	240,680	902,550	60,170	6	328,200	65,640	246,150	16,410
63,000	85,700	74,350	20	75	5	4	297,400	59,480	223,050	14,870	11	817,850	163,570	613,388	40,893	12	892,200	178,440	669,150	44,610
85,700	117,000	113,500	23	71	6	6	681,000	156,630	483,510	40,860	11	1,248,500	287,155	886,435	74,910	14	878,990	202,168	624,083	52,739
117,000	157,000	137,000	25	69	6	2	274,000	68,500	189,060	16,440	12	1,644,000	411,000	1,134,360	98,640	5	685,000	171,250	472,650	41,100
157,000	215,000	186,000	28	66	6						4	744,000	208,320	491,040	44,640	5	930,000	260,400	613,800	55,800
215,000	293,000	254,000	29	64	7	3	762,000	220,980	487,680	53,340	3	762,000	220,980	487,680	53,340	4	1,016,000	294,640	650,240	71,120
293,000	398,000	345,500	30	62	8						3	1,036,500	310,950	642,630	82,920	3	1,036,500	310,950	642,630	82,920
398,000	541,000	469,500	30	61	9	1	469,500	140,850	286,395	42,255						1	469,500	140,850	286,395	42,255
541,000	736,000	638,500	30	60	10	1	638,500	191,550	383,100	63,850						1	638,500	191,550	383,100	63,850
					Total			1,259,095	3,686,343	379,731			2,443,257	7,513,612	678,243			2,354,674	6,702,141	680,999
					Total Tons				5,325,169					10,635,112					9,737,814	
					Percent			23.6%	69.2%	7.13%			23.0%	70.6%	6.4%			24.2%	68.8%	7.0%

DISTRIBUTION OF SAND, SILT, AND CLAY WITH SUSPENDED SEDIMENT DISCHARGE

Bighorn River, Kane, Wyoming

Suspended sediment discharge						1946					1947					1948				
From	To	Average	Sand	Silt	Clay	Days	Sediment	Sand	Silt	Clay	Days	Sediment	Sand	Silt	Clay	Days	Sediment	Sand	Silt	Clay
Tons per day			Percent				Tons					Tons					Tons			
64	100	82																		
100	136	118																		
136	185	160	11	41	48											5	800	88	328	384
185	251	218	12	44	44											5	1,090	130	480	480
251	342	296	15	46	39											6	1,776	266	817	693
342	464	403	17	48	35						1	403	68	193	141	9	3,627	617	1,740	1,269
464	630	547	18	52	30						1	547	98	284	164	11	6,017	1,083	3,129	1,805
630	857	743	20	54	26						3	2,229	446	1,204	580	8	5,944	1,189	3,210	1,545
857	1,170	1,013	22	56	22	5	5,065	1,114	2,836	1,114	33	33,429	7,354	18,720	7,354	12	12,156	2,674	6,807	2,674
1,170	1,570	1,370	22	60	18	7	9,590	2,110	5,754	1,726	10	13,700	3,014	8,220	2,466	22	30,140	6,631	18,084	5,425
1,570	2,150	1,860	22	62	16	3	5,580	1,228	3,460	893	7	13,020	2,864	8,072	2,083	9	16,740	3,683	10,379	2,678
2,150	2,930	2,540	22	64	14	1	2,540	559	1,626	356	54	137,160	30,175	87,782	19,202	9	22,860	5,029	14,630	3,200
2,930	3,980	3,455	23	65	12	6	20,730	4,768	13,474	2,488	19	65,645	15,098	42,669	7,877	20	69,100	15,893	44,915	8,292
3,980	5,410	4,695	23	67	10	5	23,475	5,399	15,728	2,348	41	192,495	44,274	128,971	19,250	23	107,985	24,837	72,350	10,798
5,410	9,360	7,385	23	68	9	17	125,545	28,875	85,370	11,299	21	155,085	35,670	105,458	13,958	23	169,855	39,067	115,501	15,287
9,360	10,000	9,680	23	69	8	18	174,240	40,075	120,226	13,939	11	106,480	24,490	73,471	8,518	33	319,440	73,471	220,414	25,555
10,000	13,600	11,800	23	70	7	16	188,800	43,424	132,160	13,216	12	141,600	32,568	99,120	9,912	36	424,800	97,704	297,360	29,736
13,600	18,500	16,050	23	71	6	23	369,150	84,904	262,096	22,149	17	272,850	62,756	193,724	16,371	18	288,900	66,447	205,119	17,334
18,500	25,100	21,800	23	71	6	13	283,400	65,182	201,214	17,004	18	392,400	90,252	278,604	23,544	18	392,400	90,252	278,604	23,544
25,100	34,200	29,650	23	72	5	21	622,650	143,209	448,308	31,132	16	474,400	109,112	341,568	23,720	20	593,000	136,390	426,960	29,650
34,200	46,400	40,300	23	72	5	13	523,900	120,497	377,208	26,195	12	483,600	111,228	348,192	24,180	10	403,000	92,690	290,160	20,150
46,400	63,000	54,700	23	72	5	13	711,100	163,553	511,992	35,555	18	984,600	226,458	708,912	49,230	16	875,200	201,296	630,144	43,760
63,000	85,700	74,350	24	72	4	9	669,150	160,596	481,788	26,766	18	1,338,300	321,192	963,576	53,532	9	669,150	160,596	481,788	26,766
85,700	117,000	113,500	24	72	4	8	908,000	217,920	653,760	36,320	15	1,702,500	408,600	1,225,800	68,100	14	1,589,000	381,360	1,144,080	63,560
117,000	157,000	137,000	24	72	4	8	1,096,000	263,040	789,120	43,840	8	1,096,000	263,040	789,120	43,840	11	1,507,000	361,680	1,085,040	60,280
157,000	215,000	186,000	24	72	4	5	930,000	223,200	669,600	37,200	8	1,488,000	357,120	1,071,360	59,520	10	1,860,000	446,400	1,339,200	74,400
215,000	293,000	254,000	23	72	5	3	762,000	175,260	548,640	38,100	11	2,794,000	642,620	2,011,680	139,700	4	1,016,000	233,680	731,520	50,800
293,000	398,000	345,500	22	72	6	3	1,036,500	228,030	746,280	62,190	8	2,764,000	608,080	1,990,080	165,840	3	1,035,000	227,700	745,200	62,100
398,000	541,000	469,500	20	72	8						3	1,408,500	281,700	1,014,120	112,680	2	939,000	187,800	676,080	75,120
541,000	736,000	638,500	18	72	10	1	638,500	114,930	459,720	63,850										
736,000	1,000,000	868,000	15	72	13	1	868,000	130,200	624,960	112,840										
Total								2,218,073	7,155,320	600,520			3,678,277	11,510,900	871,717			2,858,653	8,844,039	657,285
Total Tons									9,973,913					16,060,894					12,359,977	
Percent								22.3%	71.7%	6.0%			22.9%	71.7%	5.4%			23.1%	71.6%	5.3%

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DISTRIBUTION OF SAND, SILT, AND CLAY WITH SUSPENDED SEDIMENT DISCHARGE

Bighorn River, Custer, Montana

Suspended sediment discharge						1946					1947					1948				
From	To	Average	Sand	Silt	Clay	Days	Sediment	Sand	Silt	Clay	Days	Sediment	Sand	Silt	Clay	Days	Sediment	Sand	Silt	Clay
Tons per day			Percent				Tons					Tons					Tons			
64	100	82																		
100	136	118	18	14	68															
136	185	160																		
185	251	218	19	20	61															
251	342	296	20	23	57											14	4,144	829	953	2,362
342	464	403	20	27	53											8	3,224	645	870	1,709
464	630	547	20	30	50			Incomplete					Incomplete			14	7,658	1,532	2,297	3,829
630	857	743	22	33	45											6	4,458	981	1,471	2,006
857	1,170	1,013	23	35	42											6	6,078	1,398	2,127	2,553
1,170	1,570	1,370	23	39	38											17	23,290	5,357	9,083	8,850
1,570	2,150	1,860	23	42	35											17	31,620	7,273	13,280	11,067
2,150	2,930	2,540	24	45	31											17	43,180	10,363	19,431	13,386
2,930	3,980	3,455	25	48	27											28	96,740	24,185	46,435	26,120
3,980	5,410	4,695	27	50	23											34	159,630	43,100	79,815	36,715
5,410	9,360	7,385	27	55	18											26	192,010	51,843	105,606	34,562
9,360	10,000	9,680	28	58	14											17	164,560	46,077	95,445	23,038
10,000	13,600	11,800	28	59	13											20	236,000	66,080	139,240	30,680
13,600	18,500	16,050	28	62	10											30	481,500	134,820	298,530	48,150
18,500	25,100	21,800	28	64	8											21	457,800	128,184	292,992	36,624
25,100	34,200	29,650	28	66	6											9	226,850	63,518	149,721	13,611
34,200	46,400	40,300	28	66	6											8	322,400	90,272	212,784	19,344
46,400	63,000	54,700	28	67	5											6	328,200	91,896	219,894	16,410
63,000	85,700	74,350	27	68	5											12	892,200	240,894	606,696	44,610
85,700	117,000	113,500	26	69	5											15	1,702,500	442,650	1,174,725	85,125
117,000	157,000	137,000	24	70	6											10	1,370,000	328,800	959,000	82,200
157,000	215,000	186,000	23	71	6											19	3,534,000	812,820	2,509,140	212,040
215,000	293,000	254,000	22	71	7											6	1,524,000	335,280	1,082,040	106,680
293,000	398,000	345,500	20	72	8											2	691,000	138,200	497,520	55,280
398,000	541,000	469,500	19	72	9											4	1,878,000	356,820	1,352,160	169,020
541,000	736,000	638,500																		
736,000	1,000,000	868,000																		

	Sand	Silt	Clay
Total	3,423,817	9,871,255	1,085,971
Total tons		14,381,043	
Percent	23.8%	68.6%	7.6%

US D-43 sediment sampling installation
Bighorn River at Thermopolis, Wyoming

US D-43 sediment sampling installation and water-stage recorder shelter. Bighorn River at Kane, Wyoming.

DENSITY AND PERCENT SAND, SILT, AND CLAY OF SUSPENDED SEDIMENT

BIGHORN RIVER, WYOMING AND MONTANA

Station	Based on analysis of samples in native water				Based on analysis of samples in distilled water			
	Sand	Silt	Clay	Density	Sand	Silt	Clay	Density
	Percent by weight			Lbs./cu.ft.	Percent by weight			Lbs./cu.ft.
				1946				
				April - September				
Thermopolis	22.8	65.4	11.8	65	22.8	33.4	43.8	54
Manderson	23.6	69.2	7.2	67	23.6	37.2	39.2	56
Kane	22.3	71.7	6.0	67	22.3	39.7	38.0	56
				1947				
Thermopolis	25.4	60.0	14.6	64	25.4	28.0	46.6	54
Manderson	23.0	70.6	6.4	68	23.0	38.6	38.4	55
Kane	22.9	71.7	5.4	67	22.9	39.7	37.4	56
				1948				
Thermopolis	24.5	60.3	15.2	64	24.5	28.3	47.2	53
Manderson	24.2	68.8	7.0	67	24.2	36.8	39.0	55
Kane	23.1	71.6	5.3	68	23.1	39.6	37.3	56
Custer	23.8	68.6	7.6	67	23.8	36.6	39.6	55

Density values computed using 93 lbs. per cu. ft. for sand; 65 lbs. per cu. ft. for silt; and 40 lbs. per cu. ft. for clay.

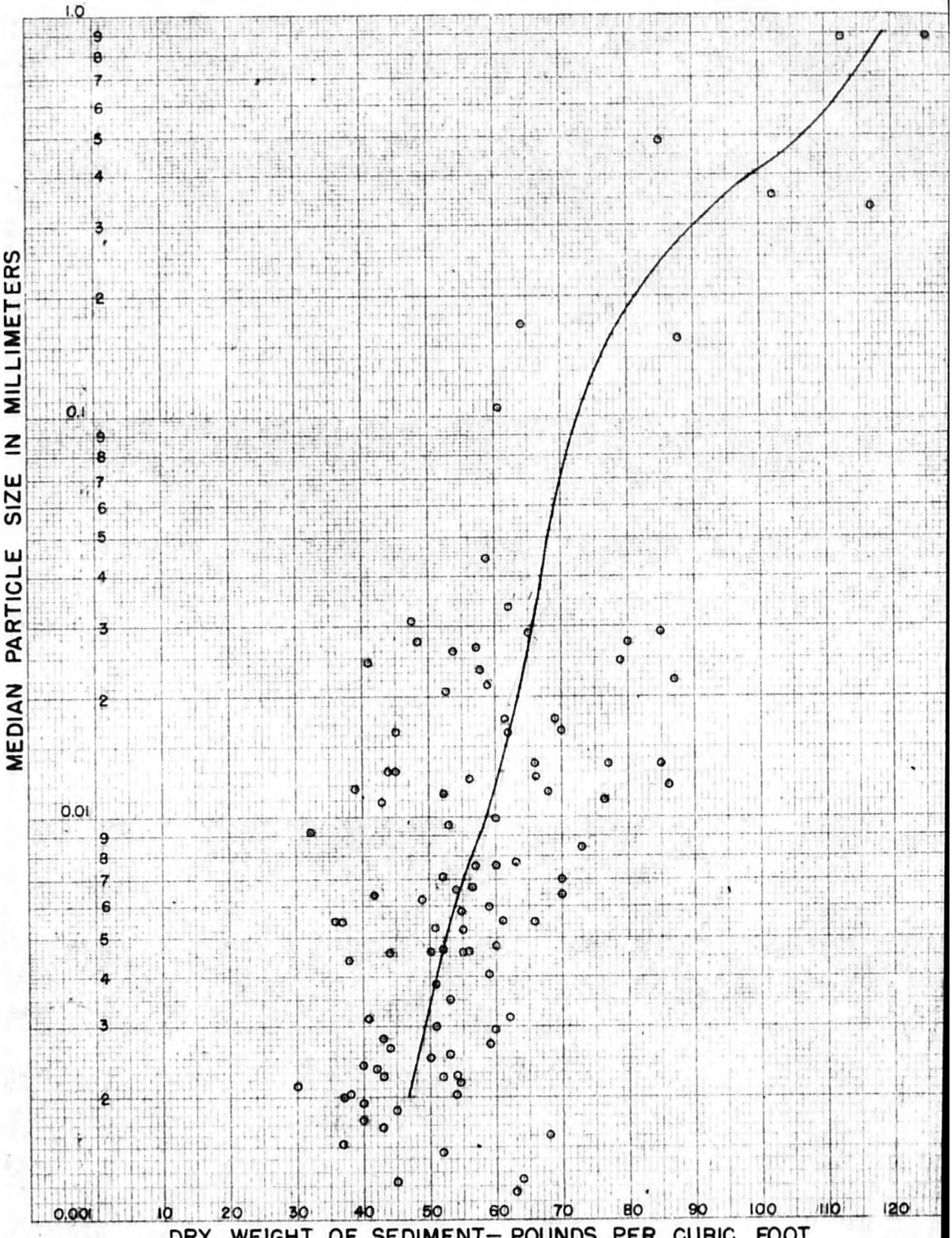

Fig. – Relation of unit weight of sediments deposited in reservoirs to median particle size

DISTRIBUTION OF MEDIAN PARTICLE SIZE WITH SUSPENDED SEDIMENT DISCHARGE
BIGHORN RIVER, MANDERSON, WYOMING, 1947

Suspended sediment discharge: Average Tons per day	Days	Total tons	Median particle size (Distilled water) millimeters	Density Lbs.cu.ft.	Cu.ft./2000
82	3	246	0.0010	47	5.2
118					
160	1	160	.0013	47	3.4
218	1	218	.0014	47	4.6
296					
403					
547	1	547	.0019	47	11.6
743	1	743	.0021	48	15.5
1,013	37	37,481	.0022	48	781.0
1,370	7	9,590	.0024	48	199.7
1,860	10	18,600	.0026	49	380
2,540	15	38,100	.0028	49	775
3,455	54	186,570	.0030	49	3,808
4,695	18	84,510	.0032	50	1,690
7,385	29	214,165	.0034	50	4,283
9,680	26	251,680	..0035	50	5,034
11,800	13	153,400	.0038	51	3,007
16,050	23	369,150	.0050	53	6,965
21,800	20	436,000	.0070	56	7,785
29,650	22	652,300	.0120	61	10,693
40,300	18	725,400	.0140	62	11,700
54,700	22	1,203,400	.0150	62	19,410
74,350	11	817,850	.0160	62	13,191
113,500	11	1,248,500	.0170	62	20,137
137,000	12	1,644,000	.0170	62	26,516
186,000	4	744,000	.0170	62	12,000
254,000	3	762,000	.0170	62	12,290
345,500	3	1,036,500	.0170	62	16,718
Totals		10,635,110			177,404

$$\text{Average density} = \frac{10,635,110}{177,404} = 59.9 \text{ lbs./cu.ft.}$$

DENSITY AND SIZE ANALYSIS OF DEPOSITED SEDIMENT
Bighorn River Drainage Basin

Location	Sample No.	Density (lbs./cu.ft.)	Percent finer than given size in millimeters						
			4	2	1	0.5	.25	.125	.0625
Wind River	56	84.7	100.0	100.0	100.0	99.0	51.3	6.5	2.1
Stream Bed	57	84.2	100.0	100.0	100.0	99.0	49.6	3.5	0.6
NW ¼ sec.2, T.1 S., R.4 E.	58	85.3	100.0	100.0	100.0	99.5	69.0	8.8	1.1
near Riverton, Wyo.	59	83.4	100.0	100.0	100.0	99.0	52.3	4.6	0.9
	60	83.7	100.0	100.0	100.0	99.1	52.4	5.6	0.6
Bighorn River near Shoshoni, Wyo.	240	92.6	100.0	100.0	100.0	84.5	27.6	6.1	0.6
Bighorn River	31	91.8	99.9	99.8	98.0	58.0	15.8	5.1	1.2
Stream Bed	32	91.6	98.8	98.4	96.0	51.0	6.3	2.0	0.8
NW¼ sec.16, T.3 N., R.6 E.	33	89.3	99.9	99.8	98.6	63.9	20.1	5.6	1.2
near Shoshoni, Wyo.	34	87.1	100.0	99.8	96.1	59.7	43.9	31.4	11.6
	35	90.8	99.7	99.7	98.7	63.4	15.2	3.7	1.2
Bighorn River	21	88.6	99.9	99.9	99.5	97.7	64.5	9.5	1.8
Stream Bed	22	89.6	99.9	99.9	99.8	97.7	62.8	6.2	0.8
NE¼ sec.32, T.4 N., R.6 E.	23	88.9	100.0	100.0	99.9	97.9	70.3	21.8	8.7
near Shoshoni, Wyo.	24	90.3	100.0	100.0	100.0	99.9	89.2	21.2	3.3
	25	90.2	100.0	100.0	100.0	99.8	82.0	20.3	4.9

Location	Sample No.	Density (lbs./cu.ft.)	Percent finer than given size in millimeters						
			4	2	1	0.5	.25	.125	.0.625
Bighorn River	6	93.0	100.0	100.0	99.9	99.8	95.9	69.0	31.9
Stream Bed	7	91.5	100.0	100.0	99.9	99.7	97.1	67.2	26.1
NW¼ sec. 9, T.4. N., R.6 E.	8	90.1	100.0	100.0	100.0	99.8	98.0	71.0	21.0
near Shoshoni, Wyo.	9	91.5	100.0	100.0	100.0	99.9	94.9	58.1	34.8
	10	88.3	100.0	100.0	100.0	99.7	97.5	67.9	24.2
Bighorn River	11	87.9	100.0	100.0	100.0	99.9	92.2	53.3	17.7
Stream Bed	12	86.8	100.0	100.0	100.0	99.9	94.4	42.1	10.8
NW¼ sec.28, T.5 N., R.6 E.	13	88.0	100.0	100.0	100.0	99.9	90.8	62.2	9.5
near Shoshoni, Wyo.	14	87.1	100.0	100.0	100.0	99.9	92.7	19.4	2.4
	15	86.5	100.0	100.0	100.0	99.9	93.8	39.4	7.8
Bighorn River near	230	82.2	100.0	100.0	100.0	100.0	98.7	29.8	9.2
Boysen, Wyo.	231	87.5	100.0	100.0	100.0	100.0	100.0	65.1	30.0
	232	80.8	100.0	100.0	100.0	100.0	99.7	59.5	14.0
	233	83.0	100.0	100.0	100.0	100.0	96.8	32.7	6.7
	234	83.9	100.0	100.0	100.0	100.0	92.0	15.8	2.8
	235	77.0	100.0	100.0	100.0	100.0	100.0	48.4	23.3
	237	93.7	100.0	100.0	100.0	100.0	96.3	36.0	8.8
Bighorn River at	190	89.3	100.0	100.0	100.0	99.9	67.3	16.1	
Thermopolis, Wyo.	191	91.0	100.0	100.0	100.0	100.0	99.7	61.2	18.4
	192	85.8	100.0	100.0	100.0	100.0	99.7	69.7	9.8
	193	85.6	100.0	100.0	100.0	100.0	93.2	19.0	3.0

Location	Sample No.	Density (lbs./cu.ft.)	Percent finer than given size in millimeters						
			4	2	1	0.5	.25	.125	.0625
Bighorn River at Worland, Wyo.	180	80.6	100.0	100.0	100.0	100.0	100.0	84.8	24.4
	181	85.3	100.0	100.0	100.0	100.0	100.0	100.0	28.9
	182	92.1	100.0	100.0	100.0	100.0	100.0	39.8	10.4
Bighorn River at Henderson, Wyo.	170	102.6	100.0	100.0	100.0	100.0	80.9	20.2	7.8
	171	94.2	100.0	100.0	100.0	100.0	94.9	19.7	4.9
	172	97.5	100.0	100.0	100.0	100.0	79.0	18.8	5.2
Bighorn River near Greybull, Wyo.	160	87.5	100.0	100.0	100.0	100.0	100.0	32.5	6.9
Bighorn River at Kane, Wyo.	150	82.2	100.0	100.0	100.0	100.0	100.0	85.4	29.7
	151	104.9	81.9	79.8	78.1	68.4	9.4	0.8	0.1
	152	83.7	100.0	100.0	100.0	100.0	100.0	87.5	22.9
	153	99.3	99.4	98.0	94.3	59.0	13.0	6.6	1.4
	154	94.4	100.0	100.0	100.0	100.0	94.4	27.9	7.7
	155	78.6	100.0	100.0	100.0	100.0	94.4	15.1	4.4
Bighorn River near Custer, Mont.	250	96.8	100.0	100.0	100.0	100.0	100.0	38.5	10.0
	251	88.2	100.0	100.0	100.0	100.0	99.7	78.4	18.0
Beaver Creek Stream Bed SE¼ sec.16, T.1 S., R.4 E. near Riverton, Wyo.	46	94.4	100.0	99.5	97.1	89.7	59.0	13.4	3.1
	47	94.9	100.0	99.7	97.6	91.2	72.3	35.1	17.7
	48	91.3	100.0	99.8	98.8	91.1	61.5	15.7	4.3
	49	88.1	100.0	99.9	99.0	92.0	62.3	16.3	5.7
	50	92.4	100.0	99.9	99.1	91.3	60.3	12.4	3.1

Location	Sample No.	Density (lbs./cu.ft.)	Percent finer than given size in millimeters						
			4	2	1	0.5	.25	.125	.0625
Popo Agie River	51	81.7	100.0	100.0	99.9	99.5	94.6	23.9	5.5
Stream Bed	52	87.6	100.0	100.0	99.9	99.6	95.1	38.8	15.9
NW¼ sec.11, T.1 S., R.4 E.	53	89.2	100.0	100.0	99.9	99.4	92.9	38.0	15.1
near Riverton, Wyo.	54	80.8	100.0	100.0	99.7	99.2	94.2	33.4	11.4
	55	88.3	100.0	100.0	100.0	99.7	96.7	36.1	12.4
Lower Five Mile Creek	16	99.6	100.0	100.0	100.0	99.4	94.2	75.8	18.8
10 ft. below surface	17	104.6	100.0	100.0	100.0	98.5	91.1	60.1	24.5
Gaging Station site	18	104.9	100.0	100.0	100.0	99.5	94.3	59.8	18.7
SW¼ sec.19, T.3 N., R.6 E.	19	97.8	100.0	100.0	100.0	97.6	90.1	54.0	19.8
near Shoshoni, Wyo.	20	99.5	100.0	100.0	100.0	99.2	94.0	57.2	16.1
Five Mile Creek	36		100.0	100.0	99.2	95.9	86.8	59.4	25.2
Stream Bed	37	92.1	100.0	100.0	99.7	97.7	89.9	65.7	34.0
SE¼ sec.18, T.3 N., R.6 E.	38	94.3	100.0	100.0	99.9	98.5	94.4	50.3	18.3
near Shoshoni, Wyo.	39	100.3	100.0	98.5	95.6	89.4	71.5	36.0	13.0
	40	95.0	100.0	100.0	99.9	99.3	87.9	51.1	17.5
Five Mile Creek near	210	116.3	79.9	69.3	60.0	51.8	36.4	15.1	5.0
Shoshoni, Wyo.	211	95.6	99.5	98.2	95.0	90.9	82.2	35.8	10.1
	212	110.2	89.4	79.1	63.5	47.0	22.2	4.7	0.4
	213	94.8	100.0	100.0	100.0	100.0	100.0	34.3	8.2
Badwater Creek near	220	99.3	100.0	99.1	97.5	92.7	56.6	12.8	3.6
Shoshoni, Wyo.	221	97.1	100.0	100.0	99.9	97.8	43.7	7.3	1.6
	222	105.7	91.0	87.9	82.1	67.6	25.5	4.0	0.5

Location	Sample No.	Density (lbs./cu.ft.)	Percent finer than given size in millimeters						
			4	2	1	0.5	.25	.125	.0625
Badwater Creek	41	89.5	99.8	98.9	96.8	87.3	45.3	9.4	3.2
Stream Bed	42	90.3	99.4	98.4	95.1	88.7	54.5	13.6	4.7
SW¼ sec.7, T.38 N., R.94 W.	43	92.2	100.0	99.7	98.8	93.4	53.7	13.5	4.5
near Shoshoni, Wyo.	44	89.8	100.0	99.1	97.6	88.8	50.1	12.8	4.4
	45	93.0	99.8	99.1	97.1	87.1	45.7	11.3	6.3
Muddy Creek near	200	94.7	100.0	100.0	100.0	100.0	66.7	20.9	5.6
Shoshoni, Wyo.	201	102.1	98.3	97.0	95.0	84.7	34.8	8.6	1.6
	202	92.5	100.0	100.0	100.0	100.0	79.6	19.7	3.4
	203	97.2	100.0	100.0	98.7	92.1	36.4	11.9	3.4
Muddy Creek	26	90.9	100.0	100.0	100.0	98.4	83.0	36.3	15.2
Stream Bed	27		100.0	100.0	100.0	99.1	78.3	26.5	9.5
SE¼ sec.30, T.4 N., R.6 E.	28	88.9	100.0	100.0	100.0	99.5	93.4	48.6	22.3
near Shoshoni, Wyo.	29	89.1	100.0	100.0	100.0	98.6	81.2	45.4	23.8
	30		100.0	100.0	100.0	96.4	63.1	26.7	15.2
Cottonwood Creek	1	94.3	100.0	99.6	96.9	87.9	52.2	12.7	4.1
Stream Bed	2	93.1	99.4	98.5	96.6	91.5	54.2	8.9	2.1
NE¼ sec.12, T.4 N., R.5 E.	3	96.4	98.8	97.4	94.3	82.2	39.4	4.3	1.0
near Shoshoni, Wyo.	4	95.2	99.0	98.4	97.0	88.0	45.2	8.8	2.1
	5	92.2	100.0	99.9	99.6	98.5	59.8	8.9	2.5

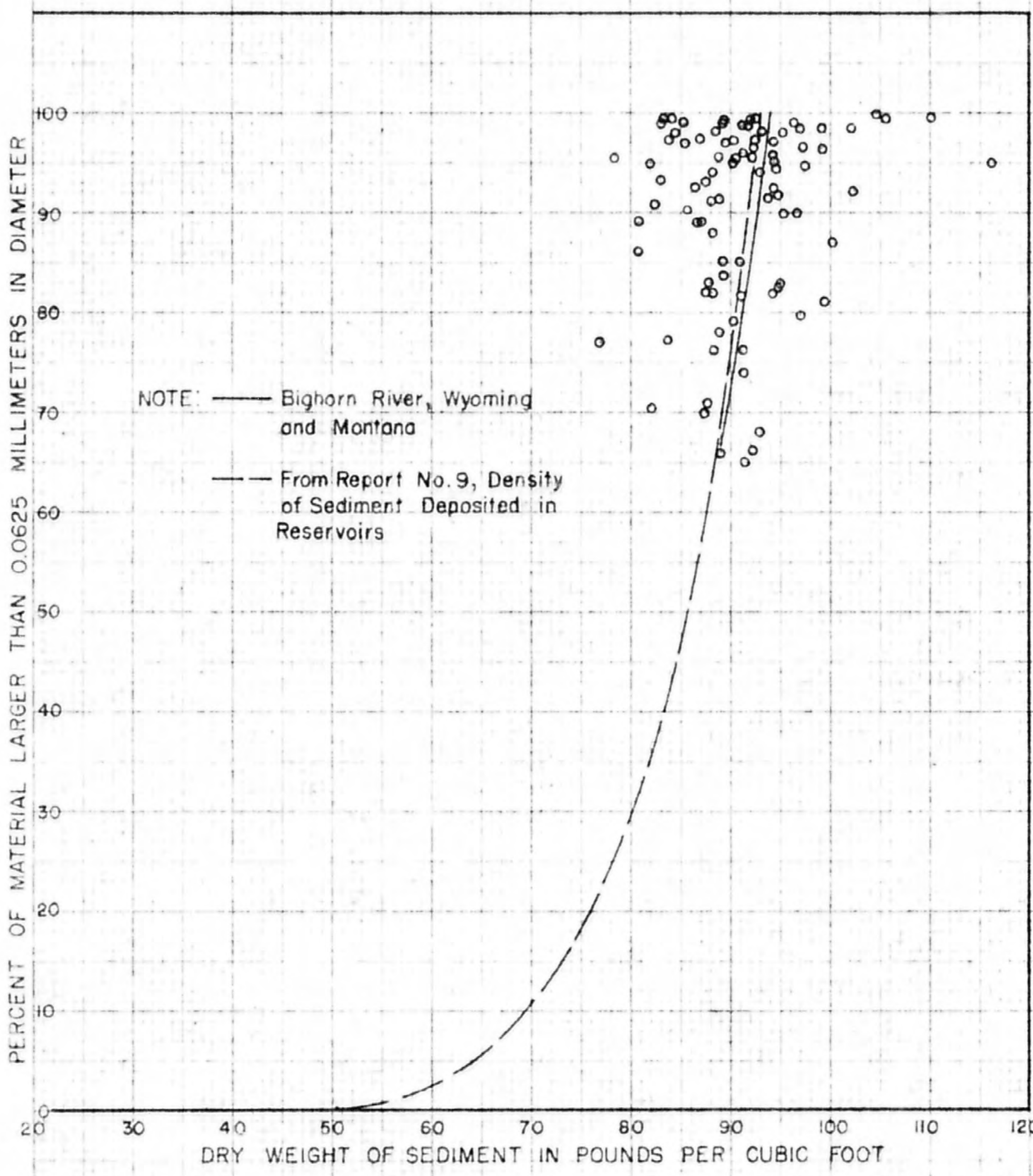

Fig. — Relation unit weight of deposited sediments to percent of sand

Bed-load Sediments

As it is not possible to obtain samples of sediment moving as bed-load no information is available concerning the particle size or density of the material in transport. Results of size analyses of samples of deposited sediments indicate that the major part of the material moving as bed-load would be classed as coarse silt or fine sand. The density of the total sediment load would then only be increased in proportion to the change in the silt or sand fraction, which would be a negligible amount.

MAJOR SOURCES OF SEDIMENT IN THE BIGHORN RIVER

It is axiomatic that the quantity of sediments which a stream will transport will increase with the water discharge provided the supply of sediment is always in excess of the stream's capacity to transport. The sediment which the Bighorn River is transporting is derived mainly from its tributaries. The river is flowing close to grade and contributes sediments only by slow downcutting and lateral corrasion. The tributaries, on the other hand, are actively downcutting and in many instances are eroding headward. Most of them pass through areas of loose, easily eroded Tertiary sediments and floodplain alluvium. The latter material was probably deposited during a wet period of considerable length during and following the Pleistocene glaciation in the region. Twenhofel _/

_/ Twenhofel, W. H., Principles of sedimentation, McGraw-Hill Book Co., New York, p. 17, 18, 1939.

describes this sequence in events as follows:

"The postulate was made that glaciers covered higher parts of the upland. If conditions should arise to eliminate these, there would be extension of vegetation to areas released from ice. The disappearance of ice would result in decreasing the quantity of sediments contributed to streams. These would not be loaded to capacity and thus would reach the foot of the upland in a condition to acquire a load from the loose deposits previously made when glaciers were present. The materials would then be transported downstream to other sites of deposition ---the floodplains and deltas. This sequence of events has taken place in the mountains of Montana and Wyoming and is splendidly shown on the east side of the Bighorn Mountains. During the Pleistocene the mountains had far more extensive glaciers than at present. These supplied the streams originating in them with vast quantities of silt, sand, gravels, and boulders. These streams reached the foot of the mountains with loads they were unable to carry over the lowlands because of decrease of velocity. There was thus built a great thickness of deposits flanking the mountains. The glaciers have largely disappeared; areas formerly covered by them have now become covered by vegetation. No longer is large load provided in the uplands; streams reach the lowlands as clear water with unused capacity and competence, and as they flow over the former deposits

> the unutilized energy is applied to remove these. The once extensive deposits are now represented by remnants between which the streams flow essentially as clear water. If the mountains should again become covered with glaciers and the conditions of the Pleistocene were restored, deposition would again begin over the areas about the foot of the mountains and the new deposits would hold disconformable relationships with the old."

Many of the tributary streams are cutting through alluvium which appears to have been deposited under conditions described by Twenhofel.

Bighorn River at Thermopolis, Wyoming

The natural flow in the Bighorn River at Thermopolis, Wyoming has been regulated to a degree since the first irrigation diversion in 1906 and to greater extent after the completion of the Riverton Irrigation Project by the Bureau of Reclamation in 1923. The records of suspended sediment discharge obtained for the Bighorn River at Thermopolis reflect the present rate of erosion in the drainage area above the station.

Field investigations of the drainage area above Thermopolis indicate that the major part of the measured sediment load is contributed to the Bighorn River by Badwater and Fivemile Creeks. The rate of erosion in the Badwater Creek drainage is probably slightly higher than the geologic or normal rate owing to agricultural activities. In the Fivemile Creek drainage the accelerated erosion, since the flood in 1923, is largely due to irrigation practices and resultant drainage from irrigated lands together with runoff from cloudburst storms. The present channel is a typical example of valley trenching with severe stream bank erosion in areas not protected by bed rock formations. In the unprotected areas the channel has a maximum width of approximately 1200 feet. The

Five Mile Creek about one mile above confluence with Bighorn River, near Riverton, Wyoming.

Five Mile Creek at bridge crossing just above confluence with Bighorn River near Shoshoni, Wyoming.

Bank erosion, Five Mile Creek near Riverton, Wyoming.

View along the Bighorn River showing massive sandstone outcrop of the Wind River formation.

View at the head of Red Canyon southwest of Lander, Wyoming shows late Tertiary conglomerate overlying Triassic Chugwater formation.

View upstream Muddy Creek at bridge.

View downstream Muddy Creek at bridge just above confluence with Bighorn River near Shoshoni, Wyoming. Note channel has filled in almost to bottom of bridge stringers.

View downstream Bighorn River at Thermopolis, Wyoming.
Measuring bridge in background.

View downstream Bighorn River at Kane, Wyoming.
Measuring bridge in background.

drains or wasteways entering Fivemile Creek follow the same pattern as the parent stream except where restricted by bed-rock or artificial control structures.

Miscellaneous data obtained for tributaries entering the Bighorn River above the Thermopolis measuring station are given in Table 5.

The cumulative water runoff and suspended sediment discharge by months and by years for the period of record is shown in Plate 58. The cumultative water runoff for the Bighorn River for the period of record is shown in Plate 59 and the flow deficiency curves in Plate 60. This information is pertinent to studies of the probable space required for sediment storage in the reservoir which will be formed when Boysen Dam is completed.

Bighorn River at Manderson, Wyoming

The natural flow in the Bighorn River at the Manderson station is depleted by irrigation of lands in the Riverton area and similarly for lands between Thermopolis and Manderson. The records of suspended sediment discharge for this station do not include all the material passing Thermopolis owing to canal diversions between the two measuring stations. No records of sediment entering these canals were obtained.

Field investigations of the tributaries entering the Bighorn River above Manderson but below Thermopolis indicate appreciable quantities of sediment in transport during runoff from snowmelt or rain. Miscellaneous sediment discharge measurements on the tributary streams indicate that Fifteen Mile Creek probably contributes the largest load. Data for other tributaries are given in Table 5.

The sediment contributions by the tributary streams will necessarily affect the rate of channel degradation or aggradation after storage is effected in the reservoir to be created by Boysen Dam.

The cumulative water runoff and suspended sediment discharge by months and by years for the period of record is shown in Plate 65.

Bighorn River at Kane, Wyoming

Tributary inflow in the Manderson-Kane reach exceeds any canal diversions for irrigation of adjacent lands. Return flow from irrigated areas to the Greybull River, the largest of the tributaries, is heavily laden with sediments. Other tributaries such as Nowood and Dry Creeks, contribute large quantities of sediments during periods of storm runoff.

The rate of accumulation of water and sediment for the period of investigation is illustrated in figure 66.

Except for minor canal diversions it may be said that practically the entire suspended sediment load passing the Manderson station passes the Kane station. The sediment discharge measured at the latter station does not include the material transported by the Shoshone River as it enters below the measuring station.

Bighorn River near Custer, Montana

The water and suspended sediment discharge measured at this station reflect the quantities entering the Yellowstone River. The quantities measured include contribution from the Shoshone River which enters the Bighorn River above the Yellowtail damsite, the Little Bighorn River which enters near Hardin, Montana below the damsite, and other minor tributaries.

The runoff per acre foot of suspended sediment at the four measuring stations for the period of record is illustrated graphically in figure 28. Similarly the relation for the intervening areas between Manderson and Kane; and between Kane and Custer is shown in figure 29. The average values for the period of record are given in Table 6.

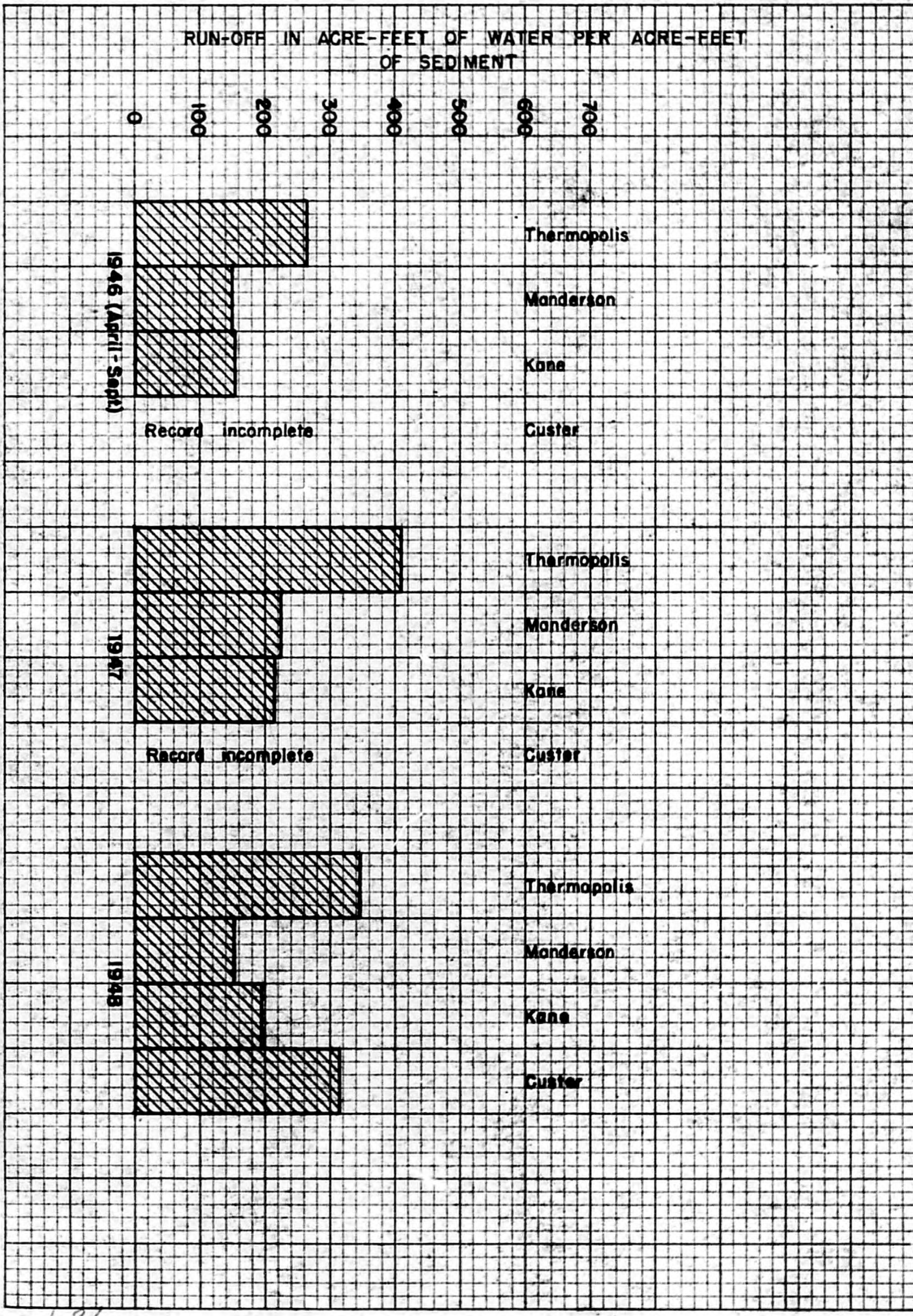

Fig. 28 - Relation of water run-off per acre-foot of suspended sediment, Bighorn River, Wyoming & Montana

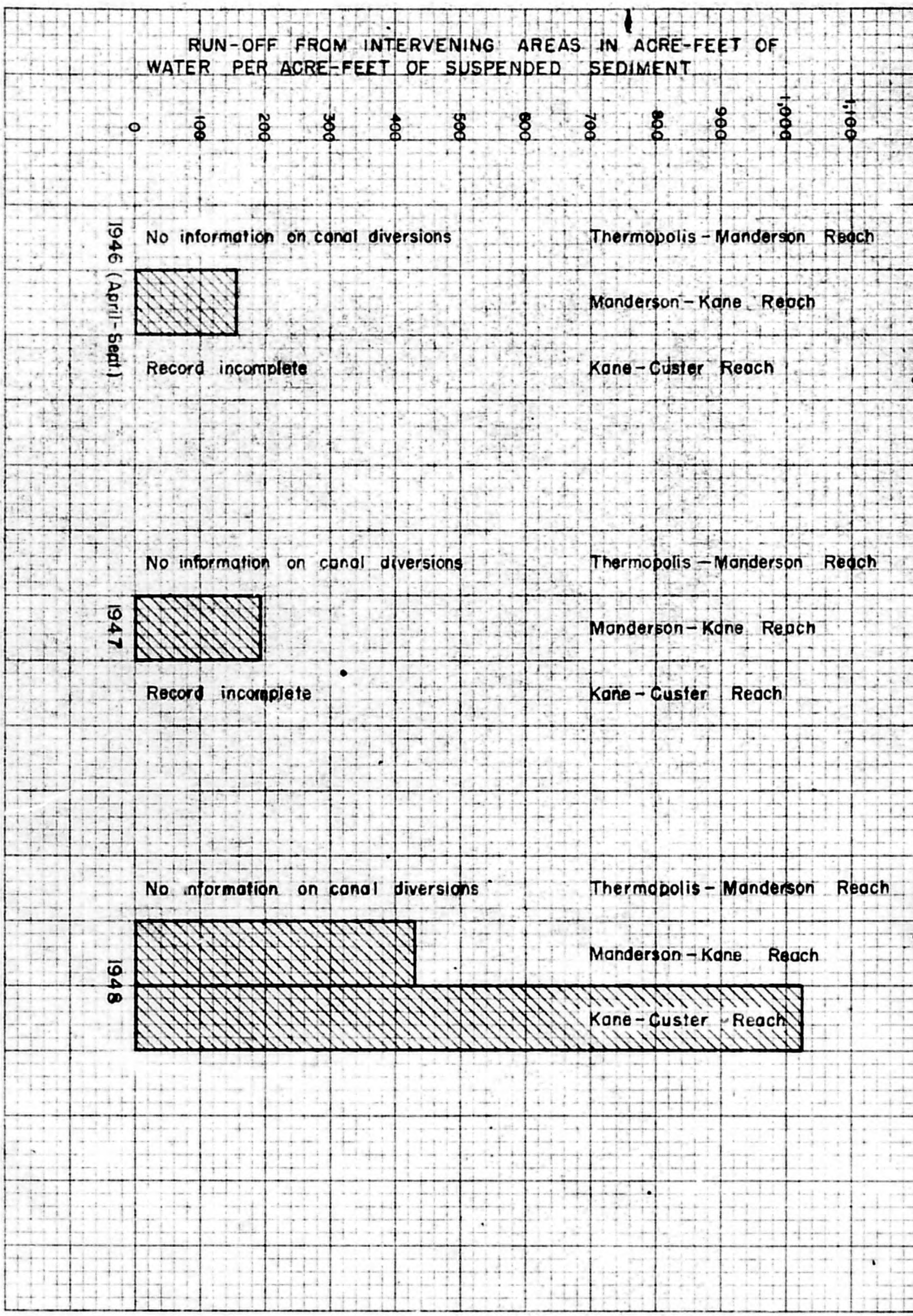

Fig. 29—Relation of water run-off per acre-foot of suspended sediment, Bighorn River, Wyoming & Montana

WATER RUNOFF AND SUSPENDED SEDIMENT DISCHARGE

BIGHORN RIVER, WYOMING AND MONTANA

Station	Water year	Suspended sediment discharge in tons	Sediment discharge in acre feet		Water runoff in acre feet	
			Yearly	Cumulative	Yearly	Cumulative
Thermopolis, Wyo.	1946 (April-Sept.)	3,461,720	2,648	2,648	702,350	702,350
	1947	5,731,837	4,384	7,032	1,783,440	2,485,790
	1948	4,467,263	3,417	10,449	1,185,250	3,671,040
Manderson Wyo.	1946 (April-Sept.)	5,097,783	3,899	3,899	588,250	588,250
	1947	10,317,852	7,893	11,792	1,759,540	2,347,790
	1948	10,096,615	7,724	19,516	1,189,990	3,537,780
Kane, Wyo.	1946 (April-Sept.)	9,738,366	7,449	7,449	1,151,720	1,151,720
	1947	15,567,641	11,909	19,358	2,551,420	3,703,140
	1948	12,023,444	9,197	28,555	1,822,600	5,525,740
Custer, Wyo.	1948	14,033,157	10,735		3,398,954	

$$\text{Volume in acre feet} = \frac{\text{Tons x 2000 lbs.}}{\text{60 lbs./cu ft. x 43,560 sq. ft/acre}}$$

RELATION OF WATER RUNOFF PER ACRE FOOT OF SUSPENDED SEDIMENT

BIGHORN RIVER, WYOMING AND MONTANA

Measuring Station	Drainage area	Acre feet of runoff per acre foot of suspended sediment			
	Square miles	April-Sept. 1946	October 1946 September 1947	October 1947 September 1948	Period of record
Thermopolis, Wyo.	8,080	265	407	347	351
Intervening area	3,820	- -	- -	- -	- -
Manderson, Wyo.	11,900	151	223	154	181
Intervening area	4,000	159	198	429	220
Kane, Wyoming	15,900	155	214	198	194
Intervening area	7,100	- -	- -	1,025	1,025
Custer, Montana	23,000	- -	- -	317	317

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Summary

In the Bighorn River Drainage Basin, some 550 square miles, or 2.4 percent of the drainage area, (23,000 square miles) is under irrigation, (1940 census). In these areas the rate of erosion in drains and natural stream channels is considerably above normal owing to return flow and cloudburst storms. In the non-irrigated areas, which comprise 97.6 percent of the drainage area, the rate of erosion is probably slightly above the geologic norm as a result of cultural activities.

For the period of record, (April 1946 to September 1948), the water discharge averaged 351 acre feet per acre foot of suspended sediment discharge at the Thermopolis measuring station. At the Kane measuring station the water discharge averaged 194 acre feet per acre foot of suspended sediment discharge. This large variation is brought about in part by canal diversions between the measuring stations and in part by sediment contributions by tributary streams.

The sediment discharge at the Kane station for the period of record is 2.8 times that measured at the Thermopolis station. The data thus reveals that in the Bighorn River Drainage Basin the respective geographic areas contribute sediment with respect to quantities in the following order: Bighorn Basin, Wind River Basin, and Bighorn Valley.

QUALITY OF THE WATER

Purpose and Scope of Investigation

Investigation of the quality of water in the Bighorn River drainage basin has two objectives. As a contribution to the general hydrologic inventory of the basin the study reveals saline conditions in the main stream and tributaries, and establishes quantities of dissolved constituents present, correlated insofar as possible with geologic, climatic, hydrologic, and cultural influences. Of equal importance, facts on the chemical character of the waters in the basin are made available which, upon interpretation, assist materially in such studies as proposed projects for the improvement by drainage of existing irrigated lands; plans for further irrigation development; selection of sites for municipal, domestic and industrial water supplies; and evaluation of those conditions affecting living aquatic organisms which are of primary interest to the aquatic biologist.

Discussion of quality of water in the basin covers work completed to September 30, 1948 inclusive, and is based on daily or intermittent sampling of river waters at eight gaging stations within the basin. Seven of these stations - Dubois and Riverton on the Wind River; Thermopolis, Manderson, and Kane on the Bighorn River; and Buffalo Bill reservoir and Byron on the Shoshone River - are in Wyoming. The remaining station, Bighorn River near Custer, is located in Montana. Figure 30 shows a map of the area under study and the location of sampling points for the chemical analysis of river waters. In table 7 below is listed each individual sampling site, with drainage area, period of record and frequency of sampling.

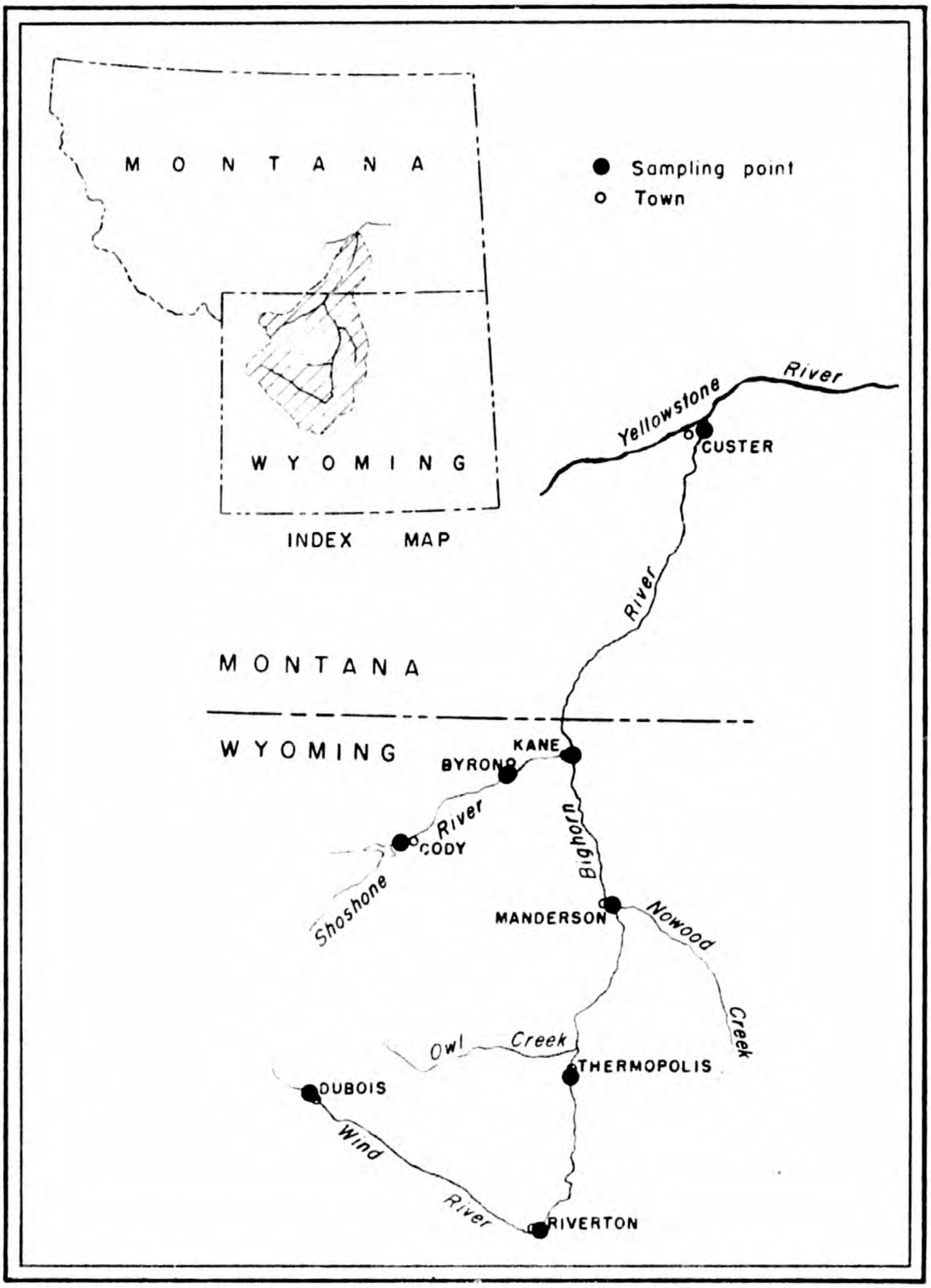

Figure Map of Bighorn River Drainage Basin, Wyoming and Montana showing sampling points for chemical analysis of river waters.

Table 7 Sampling points for the chemical analysis of Bighorn River Drainage Basin Waters, Wyoming and Montana

River	Station	Location	Drainage Area (Square miles)	Period of Record	Sampling frequency
Wind	Dubois	on HWY 287, seven miles NW of Dubois, Wyo.	233	Apr. 1, 1947 to Sept. 30, 1948	Daily
Do	Riverton	at State HWY bridge, 3/4 mile SE of Riverton, Wyo.	2,320	Mar. 31,1947 to Sept. 30, 1948	Do
Bighorn	Thermopolis	at HWY bridge in Thermopolis, Wyo.	8,080	Apr. 1, 1947 to Sept. 30, 1948	Do
Do	Manderson	3/8 mile W of Manderson, Wyo. and 2 1/2 miles upstream from Nowood Creek	11,900	Mar. 26,1947 to Aug. 17, 1948	Inter-mittently
Do	Kane	1/2 mile east of Kane, Wyo.	15,900	Mar. 26,1947 to Aug. 17, 1948	Do
Do	Custer	4 1/2 miles upstream from mouth and 4 miles SE of Custer, Mont.	23,000	Nov. 16,1945 to Aug. 30, 1948	Do
Shoshone	Below Buffalo Bill Reservoir	3 1/2 miles W of Cody, Wyo.	1,520	Apr. 1, 1947 to Sept. 30, 1948	Daily
Do	Byron	at Byron, Wyo.	2,300	Mar. 24,1947 to Sept. 30, 1948	Do

Miscellaneous single samples were collected during the course of the study from smaller tributary waters including Owl Creek, Nowood Creek and Paintrock Creek, and results of analyses for these samples are included in this report.

The quality of ground waters in the drainage basin is discussed in separate reports released as progress studies for administrative use. Ground water projects for which reports have been prepared or are now in process, include the Riverton area, Owl Creek, Paintrock Creek, and Heart Mountain - Shoshone Extension units, all in Wyoming.

Composition of River Waters

The composition of a river water varies considerably with time and place. Changes in concentration occur between periods of high flows and low flows and both composition and concentration are influenced by tributary waters. Clarke[1] points out that a river water is the average of all

[1] Clarke, F. W., The data of geochemistry, 5th ed: U. S. Geol. Survey Bull. 770, p. 69, 1924.

its tributaries plus the influence of rain and ground water. Rivers may be considered as the resultant products of the relatively weak solutions of the immediate run-off and the stronger ground-water solutions from the zone of discharge which have been in longer contact with rocks and soils and have leached them more thoroughly. In general a river water at or near its source reflects in some measure the composition of the rocks from which it rises. Water from limestone is rich in calcium, that from dolomite contains significant amounts of magnesium, and that from granite is characterized by relatively higher silica and alkalies. In small streams these resemblances are apparent; in large rivers, however, the commingling of the tributaries tends to produce an average composition which may be called that of a normal water. Furthermore the great continental rivers resemble one another much more nearly than do their component branches.[1]

[1] Clarke, F. W., idem., p. 94.

Rain water in its descent to the earth in the hydrologic cycle contains small quantities of gaseous and solid impurities depending upon the locality and its influence on the purity of the atmosphere. Above large manufacturing areas, the air is often laden with dust of all kinds, soot, silica, sulfates and carbonates, oxides of sulfur and nitrogen, hydrogen sulfide, ammonia, organic materials and other agents. These are absorbed in the falling rain or snow. Near the seacoast rain carries a quantity of sea salt absorbed from the spray that at times may reach 45 parts per million.[1] Even

[1] Collins, W. D., and Williams, K. T., Chloride and sulfate in rain water: Ind. and Eng. Chemistry, vol. 25, p. 944-945, 1933.

in places where there is no factory pollution of the air, and well inland, the rain water shows appreciable amounts of dissolved materials. A study by Riffenburg [1] of some 200 articles on the composition of rain water gives

[1] Riffenburg, H. B., Chemical character of ground waters of the Northern Great Plains: U. S. Geol. Survey Water Supply Paper 560-B, p. 34, 1925.

the following average amounts of impurities in rain water, in parts per million: Chloride (Cl), 3.0; nitrogen as (NO_3), 0.2; nitrogen as (NH_3), 0.4; sulfate (SO_4), 5.0.

Although relatively small amounts of solids are brought to the earth in rain water, atmospheric moisture is an effective agent in the disintegration of rocks. The carbon dioxide in rain water plus that added through organic processes after the rain reaches the earth is an active agent in the solution of rock particles. Distilled water will dissolve only 20 parts per million of calcium carbonate and 28 parts of magnesium carbonate, but water charged with carbon dioxide will dissolve large amounts of these solids. It is to the solvent power of carbonated waters that the rivers and lakes owe their dissolved solids.

Carbonates in river waters are largely the result of decomposition of feldspars and the solution of limestones. Waters traversing beds of gypsum or gypsiferous shales often contain considerable sulfate, and in arid regions sulfate is derived from residual soluble salts on irrigated lands. Only a very small part of the chloride contained in river waters can be traced to the decomposition of igneous rocks. Nearly all of it is primarily of organic origin, or secondarily derived from marine rocks and sediments. Nitrates are of minor significance in the study of river waters. They may be formed, together with ammonia, by electrical discharges in the atmosphere, and then brought to the surface of the earth in rain. Pollution by sewage may be the cause of abnormally high nitrates in river waters. Calcium and magnesium usually predominate in waters draining areas of carbonate rocks, while sodium is usually present in considerable amounts in waters draining arid lands. Potassium is present in small quantities, as a rule, in river waters.

After examination of a large number of analyses of river and lake waters of North America, excluding those of closed basins, Clarke [1] came to the

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[1] Clarke, F. W., The composition of the river and lake waters of the United States: U. S. Geol. Survey Prof. Paper 135, p. 5, 1924.

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conclusion that the average composition of the waters can be shown by the analysis indicated below with results shown as percentages of the total anhydrous inorganic solids.

Average composition of North American waters

	(Percent)
CO_3	33.40
SO_4	15.31
Cl	7.44
NO_3	1.15
Ca	19.36
Mg	4.87
Na	7.46
K	1.77
$(Fe,Al)_2O_3$	.64
SiO_2	8.60
	100.00

It will be noted from the above analysis that carbonate is the principal constituent in the average fresh water. This is not surprising when one considers that water containing carbonic acid in solution is the primary agent of rock decomposition. In the analysis above, percentage values of the anhydrous residue are given. Thus, bicarbonate (HCO_3) as well as carbonate (CO_3) present in solution are reported as carbonate since bicarbonates of calcium and magnesium can exist only in solution and not in the anhydrous residue.

The composition of the Wind, Bighorn, and Shoshone river waters expressed in percent of anhydrous residue is shown in table with the analysis of average composition of North American waters included for comparison. Iron and aluminum oxides, $(Fe,Al)_2O_3$, reported in Clarke's analysis, are omitted in table inasmuch as the mixed oxides are not

reported for the Bighorn drainage basin waters. The percentage of iron in the Bighorn waters is very low and omission of this value in the table has no significant effect on the percentage computation.

Table 8 is of interest in two respects. It shows the relation of the composition of the Bighorn drainage waters to the average composition for all North American river and lake waters; furthermore, it shows how rapidly and markedly the composition of a river water may be modified from headwaters to mouth. Analyses 2 to 7 inclusive give the composition of the Wind-Bighorn River waters downstream from a point near the headwaters above all major diversions to a point approximately five miles above the mouth below extensively irrigated lands. Analysis 2 represents a typical mountain water relatively high in carbonates, rich in silica and low in concentration of solids. Its composition approximates that of an average fresh water. Analysis 7, at the end of the series, shows a water rich in sulfate, low in silica, and four times more concentrated in dissolved solids. This change is caused by the leaching of salts from the soil by river water diverted for irrigation and the subsequent return of some of these waters to the stream. The Bighorn River water at the mouth near Custer, Montana represented by analysis 7 is somewhat less concentrated than the water at Kane, Wyoming upstream (analysis 6). This is the result of the diluting effect of the Shoshone River water entering the Bighorn River below Kane. (see map figure 30). Analysis 8 and 9 show similar changes of carbonate, sulfate, silica, and dissolved solids in Shoshone River water from a point just below Buffalo Bill reservoir to a point downstream approximately 20 miles above the confluence of the Shoshone and Bighorn Rivers. From the reservoir site downstream the composition of the water is altered by return irrigation flows.

Statement of Analysis

When different salts are dissolved in water, they impart distinctive properties to the solution. A simple solution of sodium carbonate is soft and alkaline, while one of sodium chloride is neither alkaline nor acid, being neutral or saline. On the other hand a solution of calcium chloride is hard and saline. If these separate salt solutions are mixed, the resulting solution retains definite properties acquired from those of its constituents. However, in the mixed solution it is no longer possible to state how much of each salt is present; reactions have taken place, and different combinations have resulted, and there is no possible way in which these combinations can be actually determined. This difficulty is overcome by expressing the results of analysis in ionic form, assigning weights directly to the chemically active parts of the dissolved solids instead of using those parts to hypothecate various combinations of salts. Thus, results for base analyses in this report are given as parts per million of the individual radicles and ions found upon laboratory determination.

The statement of the amounts of the radicles however, indicates only the chemical composition of a water and not its character, for as Palmer[1] has pointed out the physical weight of a radicle is no criterion of its chemical value in a balanced system of acids and bases such as exists in a natural water. A form of statement more convenient for study and comparison of chemical values is obtained by use of reacting values. This method of reporting results of analysis shows numerically the relative proportions of the ions by chemical weight in terms of reaction capacity. The reaction

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[1] Palmer, Chase, The geochemical interpretation of water analyses: U. S. Geol. Survey Bull. 479, p. 7, 1911.

capacities of the individual ions or radicles present in water are the quotients obtained by dividing the weight of each ion or radicle by its corresponding equivalent combining weight. Identical values are obtained by multiplying the weight of each constituent by its reaction coefficient, which Stabler[1] has defined as the chemical reacting power of a unit

[1] Stabler, Herman, The mineral analysis of water for industrial purposes and its interpretation by the engineer: Eng. News, vol. 60, p. 355, 1908; also chapter on the industrial application of water analyses in U. S. Geol. Survey Water-Supply Paper 274, pp. 165-181, 1911.

weight of a radicle or ion. The reaction coefficient of a radicle is the ratio of the reaction capacity of one part of that radicle to the reaction capacity of eight parts of oxygen. The following table shows the reaction coefficients of the positive and negative radicles most commonly determined in surface waters:

Reaction coefficients of radicles commonly found in waters

Positive radicles		Negative radicles	
Sodium (Na) - - - - - -	0.04348	Carbonate (CO_3) - - - - -	0.03333
Potassium (K) - - - - -	.02558	Bicarbonate (HCO_3) - - -	.01638
Calcium (Ca) - - - - -	.04990	Sulfate (SO_4) - - - - - -	.02082
Magnesium (Mg) - - - -	.08224	Chloride (Cl) - - - - - -	.02820
Hydrogen (H) - - - - -	.99206	Nitrate (NO_3) - - - - - -	.01613
		Fluoride (F) - - - - - -	.05263

The coefficients of silica, iron, and aluminum have been omitted from this table, as it is generally assumed that these substances are present as oxides in the colloidal state and therefore take no part in the chemical system of acids and bases.

In the tables of base analyses for this report, values for the weight of the radicles are expressed in parts per million (milligrams per kilogram), while reacting values, which have greater chemical significance, are shown as equivalents per million (milligram equivalents per kilogram).

Interpretation of Results

As a convenient basis for comparative study and an indication of the geological history of the waters in the basin the method proposed by Palmer[1]

[1] Palmer, Chase, op. cit., pp. 11-14.

for the interpretation of water analyses is particularly noteworthy. Palmer states:

"Nearly all terrestrial waters have two general properties, salinity and alkalinity, on whose relative proportions their fundamental characters depend. Salinity is caused by salts that are not hydrolyzed; alkalinity is attributed to free alkaline bases produced by the hydrolytic action of water on solutions of bicarbonates and on solutions of salts of other weak acids."

In Palmer's classification alkalies or strong bases (sodium and potassium) are designated primary constituents, while the alkaline earths (calcium and magnesium) form the secondary group. As indicated above salinity is the property in which the strong acid radicles, chloride, sulfate, nitrate, and fluoride participate, for these radicles yield saline salts. Alkalinity, on the other hand, is caused by the presence of weak acid radicles (carbonate and bicarbonate) whose salts hydrolyze in solution to yield alkaline waters. Combining these terms, the strong acids together with the alkalies, or primary bases give the property of primary salinity; the strong acids in connection with the alkaline earths form secondary salinity. Similarly, the weak acids with the alkalies give the property of primary alkalinity and with the alkaline earths, secondary alkalinity.

The above properties are deduced by first balancing the chemically strong bases with the chemically strong acids, and then balancing the excess of chemically strong bases or acids with chemically weak acids or bases. The resulting properties show the proportion of the chemical system that is relatively inert and unavailable and that which is relatively free and available, thus indicating the nature of chemical action of the water under many conditions. Most of these properties are familiar; thus secondary salinity is also known as permanent hardness, secondary alkalinity is practically equivalent to temporary hardness, and primary alkalinity has been called permanent negative hardness.

Since natural waters vary greatly in concentration the direct reacting values are not entirely satisfactory for purposes of comparison. Eliminating the factor of concentration by expressing the reacting values in percent permits wider application of these values. Also from the percentage reacting values the properties of the salinity and alkalinity of the solution are obtained in percentage proportions.

Palmer's method of interpretation based directly on the properties of the water is further discussed by Rogers -/ and has been applied by

-/ Rogers, G. S., The interpretation of water analyses by the geologist: Econ. Geology, vol. 12, pp. 56-88, 1917.

geologists, engineers, and chemists in water studies. -/

-/ See Rogers, G. S., The Sunset-Midway oil field, California, Part II, Geochemical relations of the oil, gas, and water: U. S. Geol. Survey Prof. Paper 117, pp. 52-92, 1919. Crawford, J. G., Oil field waters of Wyoming and their relation to geological formations: Bull. American Assoc. Petrol. Geologists, vol. 24, pp. 1214-1329, July 1940. Also Hill, R. A., Salts in irrigation water: Trans. American Soc. Civil Engrs., No. 107, pp. 1478-1518, 1942.

Geochemistry of Bighorn River Drainage Waters

As previously indicated the Wind-Bighorn river water is continuously undergoing change in composition from its headwaters in the Wind River Range thru the Wind River Canyon, across flood-plain terraces of low relief to the Bighorn Canyon and finally to its mouth where it joins the Yellowstone River. In terms of percentage reacting values, considerable difference exists in the ionic pattern of Bighorn River water from its source (Wind River) to its mouth near Custer. This is seen in figure 31 where proportions of individual basic and acidic constituents for these waters are plotted as trilinear graphs. At Dubois the water is richer in calcium and bicarbonate than the water near Custer which contains about equal percentage values of calcium and sodium, with sulfate composing more than one-half of the acids. Magnesium varies little in the river water near Custer, and the percentage reacting values for chloride and nitrate for both stations are quite low.

The Wind and Bighorn Rivers considered as a single continuous stream exceed 350 miles in length and drain areas of widely divergent geology and topography. Cultural influences, such as diversions of water for irrigation, and climate, which is largely semi-arid, are other important factors which modify the properties of the river water from source to mouth. Furthermore, the effects of tributary waters cannot be ignored. If the results of mineral analyses of the river water are shown as properties deduced from the percentage reacting values, as previously described, some correlation with the character of the geological formations in the basin is possible. At Dubois, above any major diversion, the river drains a basin containing sedimentary rocks as well as scattered outcrops of granite, and the water here is preponderantly secondary alkaline with some primary alkalinity exhibited. Downstream at Riverton the basin includes in addition to the

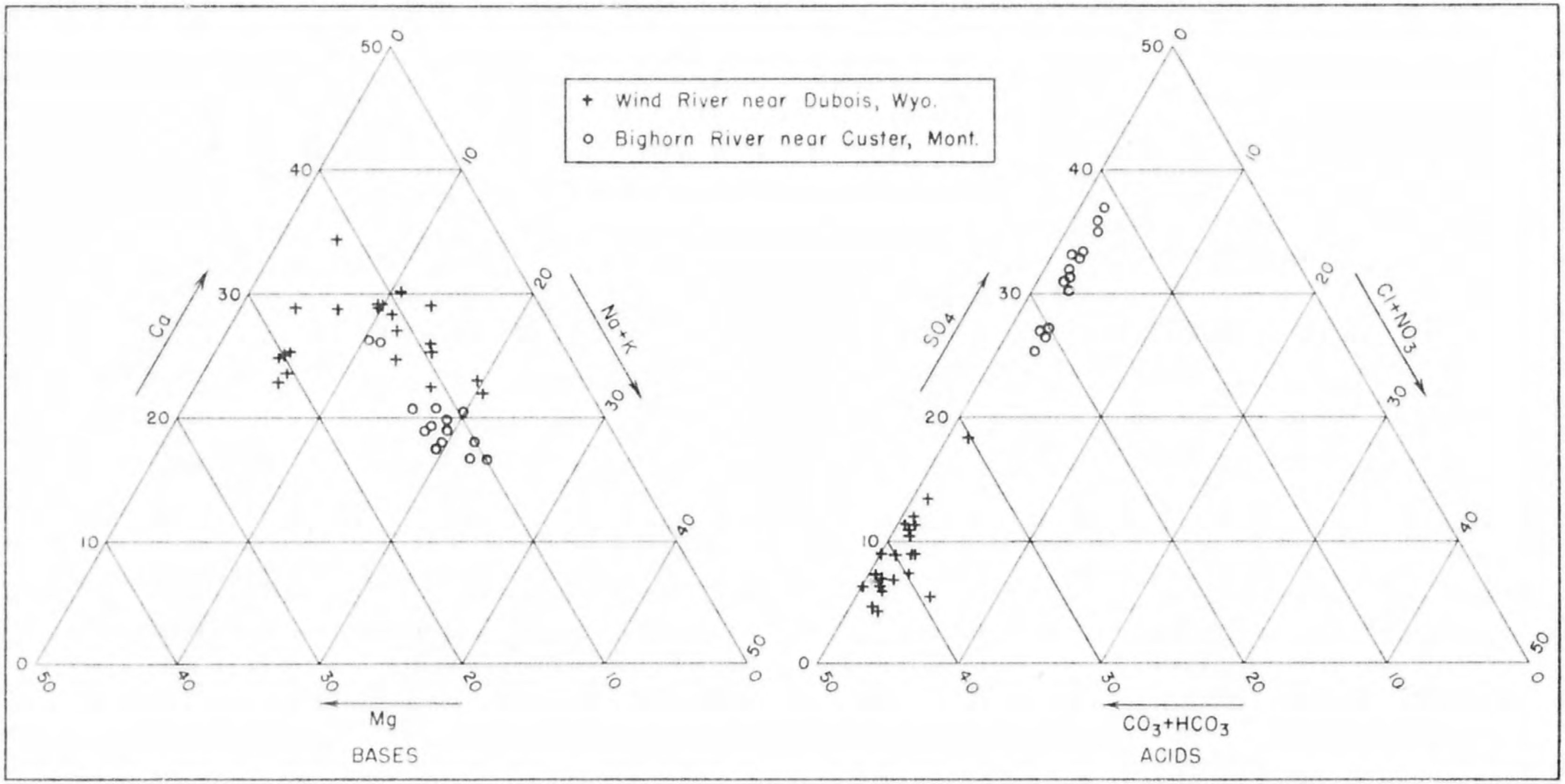

Figure 3/ Diagram showing proportions of acids and bases in waters from Wind River near Dubois, Wyoming and Bighorn River near Custer, Montana. The proportions of basic constituents and acid constituents are plotted in percentage reacting values and aggregate 50% respectively.

above, siltstones and gypsum and the water at this station shows less secondary alkalinity, no primary alkalinity and increase in secondary salinity. Return flows to the river from irrigated tracts above Riverton modify the character of the water appreciably at this station. Continuing downstream from Riverton to Thermopolis, to Manderson, to Kane and to Custer a progressive decline northward in the proportion of secondary alkalinity is observed. In addition to the general rock types noted upstream from Riverton, some metamorphic rocks are found in the lower basin; also the contribution of return flows here is considerable. The variation in secondary alkalinity is seen in figure 32 where values are plotted corresponding to sampling stations shown as miles downstream from Dubois.

The geochemical classification of a surface water not diverted for irrigation, and draining an area in which a single rock type dominates, is relatively simple. For example, a water in which primary alkalinity is prominent is commonly derived from and associated with igneous rocks; a water in which secondary salinity is prominent is generally derived from and will contribute to the formation of marine sediments. However, large rivers, or even small streams from which diversion for irrigation is made with subsequent return to the stream of waters that have leached the soil of salts, are more difficult to classify. Such rivers and streams may carry contributions of mineral particles from all kinds of rocks--effusive, intrusive, metamorphic, and sedimentary--their waters are mixed in type, and analyses of them do not afford bases for very definite conclusions.

For waters of major interest in the Bighorn River drainage basin two classes have been differentiated with respect to reaction in accordance with the classification previously outlined. _/ Waters in which strong acids

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_/ See p. 12. 97

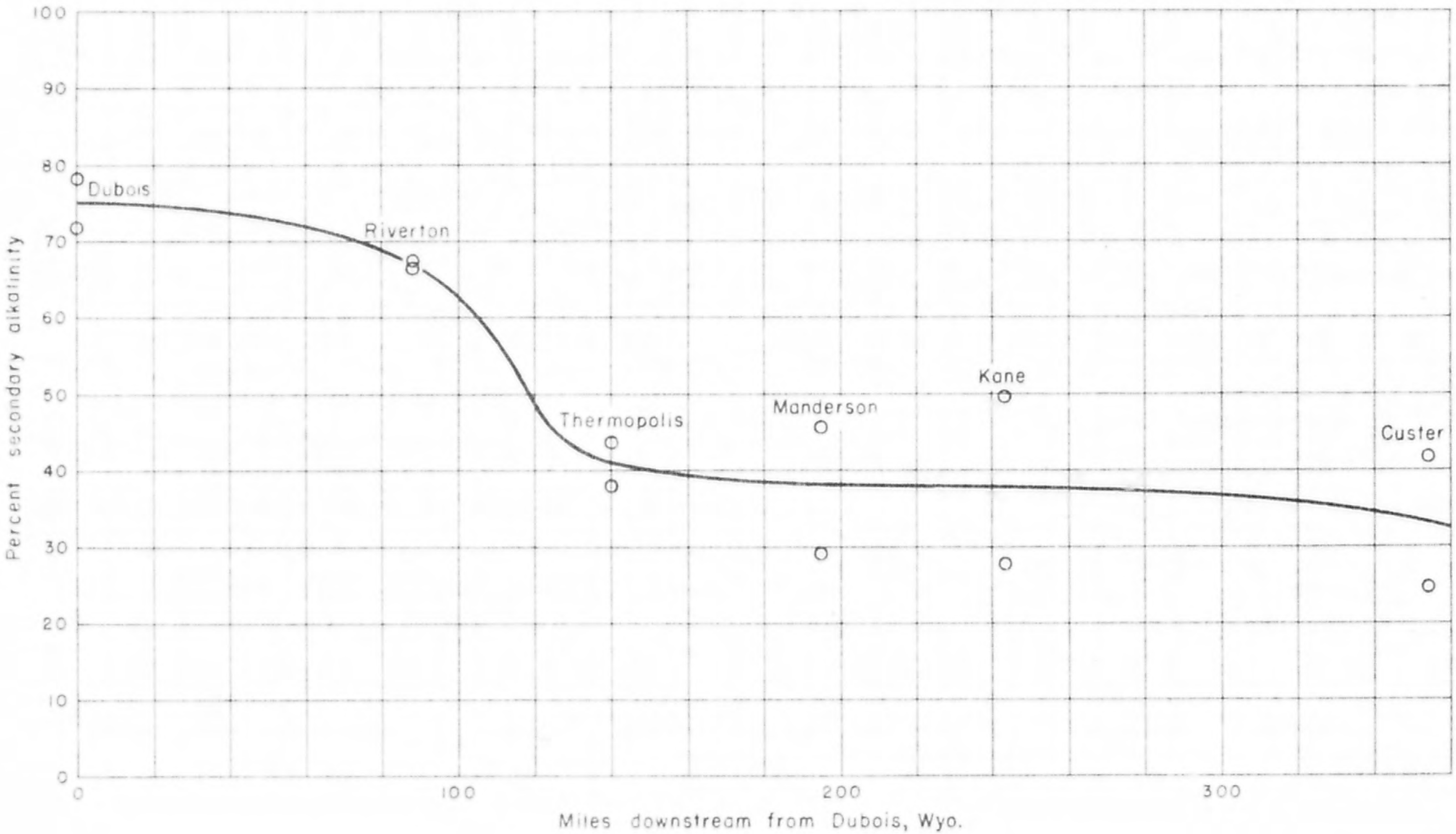


Figure 32 Variation of secondary alkalinity property in Wind River and Bighorn River waters with distance from Dubois, Wyoming.

exceed alkalies in reacting weight are called secondary saline waters and belong in Class III; those in which alkalies exceed the strong acids are called primary alkaline waters, and belong in Class I. If one were characterized by neither primary alkalinity nor secondary salinity, it would be placed in Class II.

Table 9 shows the geochemical classification of the Bighorn basin waters and the general rock types in the areas drained. Results of chemical analyses in both parts and equivalents per million are given in Appendix II.

Wind River near Dubois, Wyoming

The river at Dubois drains an area of mixed sedimentary and igneous rocks and contains a relatively high proportion of bicarbonate, calcium, and silica, and appreciable sulfate. The weighted average for a twelve-month's period of sampling shows a Class I water, having the property of primary alkalinity. Variations of dissolved solids content of the water with variations in river discharge is indicated in a general way in plate 67 where specific conductance as micromhos is plotted against flow. Conductance measurements are an index to the content of dissolved solids, and a rough approximation of the latter value can be obtained by multiplying the conductance by an average factor of 0.7.

Wind River near Riverton, Wyoming

At Riverton the water no longer exhibits primary alkalinity but is a Class III water. Bicarbonate, calcium, and silica are present in less amounts, while sodium and particularly sulfate have increased in concentration. Return flows to the river above the sampling station explain in part the increase in secondary salinity. Conductance-discharge relationships are shown in plate 68 .

Table [illegible] Geochemical classification of surface waters, Bighorn River drainage basin, Wyoming and Montana

River	Station	Primary Salinity	Secondary Salinity	Primary Alkalinity	Secondary Alkalinity	Class	General rock types in area drained
Wind	Dubois (1947)	24.0	4.4	0.0	71.6	III	Sandstones, conglomerates, tuffs, shales,
	(1948)	17.8	.0	4.2	78.0	I	some limestones and dolomites; scattered
							outcrops of granite
do	Riverton (1947)	13.4	19.4	.0	67.2	III	Above character plus siltstones and
	(1948)	24.4	9.4	.0	66.2	III	gypsum. Also acidic volcanics
Bighorn	Thermopolis (1947)	31.6	24.8	.0	43.6	III	As above with addition of some metamorphic
	(1948)	36.2	26.0	.0	37.8		rocks
do	Manderson						
	(High conc)	45.6	25.4	.0	29.0	III	do
	(Low conc)	25.6	29.0	.0	45.4	III	
do	Kane (High conc)	38.2	34.4	.0	27.4	III	do
	(Low conc)	25.0	25.6	.0	49.4	III	
do	Custer (High conc)	39.4	35.8	.0	24.8	III	do
	(Low conc)	47.6	10.6	.0	41.8	III	
Shoshone	Below Buffalo Bill						
	reservoir (1947)	37.8	.0	.6	61.6	I	Acidic volcanics, siltstones, shales, sand-
	(1948)	35.8	.0	4.0	60.2	I	stones, gypsum, limestones, and dolomites
do	Byron (1947)	40.6	4.8	.0	52.6	III	As above plus conglomerates and tuffs
	(1948)	39.6	13.8	.0	46.6	III	

Note 1. Values for 1947 computed on basis of six months daily sampling; 1948 results based on 12 months daily sampling.

Note 2. Manderson, Kane, and Custer stations sampled intermittently; values shown are maximum and minimum dissolved solids for total period sampled.

Bighorn River at Thermopolis, Wyoming

The average concentration of dissolved solids of the water at Thermopolis is about three times that at Dubois. Concentrations of sodium and sulfate are approximately twice that at Riverton, and decrease in bicarbonate, calcium, and silica is noteworthy. The water is secondary saline and Class III. The relationship between conductance and discharge is shown in plate 69 .

Bighorn River at Manderson, Wyoming

The composition of the river water at Manderson differs little from that at Thermopolis. The former shows somewhat less bicarbonate and higher sulfate and both are Class III waters.

Bighorn River at Kane, Wyoming and Custer, Montana

Samples collected at both Kane and Custer stations upon analysis gave approximately the same results. The water at Custer averages lower concentration of dissolved solids than that at Kane due to the diluting action of the Shoshone River entering the Bighorn below Kane and above Custer. Both Kane and Custer waters are secondary saline.

Shoshone River below Buffalo Bill Reservoir, Wyoming

This stream drains an area containing acidic volcanics as well as sedimentary rocks. The water exhibits primary alkalinity, is Class I, and has the lowest average concentration (115 parts per million) of dissolved solids for major streams sampled in the basin. Plate 70 shows the conductance-discharge pattern.

Shoshone River at Byron, Wyoming

Here the river water has been modified in properties and composition by irrigation practices upstream. The water is Class III being secondary saline, and its average concentration is over three times that just below the reservoir. Conductivity-discharge changes are shown in plate .

Discharge and Salt Burden

Daily samples were collected for analysis at the Dubois, Riverton, and Thermopolis stations on the main stem from April 1 to September 30, 1947--six months of the 1947 water year--and from October 1, 1947 to September 30, 1948, the complete period for the 1948 water year. A similar sampling pattern was followed for the two stations on the Shoshone River - below the reservoir west of Cody, and at Byron. Other stations for which analytical results have been reported were sampled once a month or less.

For those stations sampled on a daily basis, weighted mean concentrations of total dissolved solids, computed as tons per acre foot, are given together with discharge in table 10 below.

Table 10 Discharge and salt burden for stations in the Bighorn River basin, 1947 and 1948

Station	Period [a]	Water discharge (acre feet)	Dissolved solids	
			Tons per acre foot	Tons
Wind River - Dubois	1947	119,430	0.14	16,720
do	1948	129,400	.20	25,880
Wind River - Riverton	1947	752,760	.20	150,552
do	1948	713,700	.22	157,014
Bighorn River - Thermopolis	1947	1,476,250	.41	605,262
do	1948	1,185,000	.59	699,150
Shoshone River below reservoir	1947	756,620	.14	105,927
do	1948	913,700	.16	146,192
Shoshone River - Byron	1947	564,570	.36	203,245
do	1948	797,500	.52	414,700

[a] 1947 results based on six month period only.

From table 10 it is seen that in 1948 Wind River discharged 129,400 acre feet of water at Dubois, the upper station. This was increased to 713,700 acre feet at Riverton, and to 1,185,000 acre feet at Thermopolis. In respect to the salt burden the data shows that the river carried 25,880 tons of dissolved solids at Dubois, 157,014 tons at Riverton, and 699,150 tons at Thermopolis. The Shoshone River in 1948 discharged 913,700 acre feet of water below Buffalo Bill reservoir west of Cody, and 797,500 acre feet at Byron. Salt loads in tons for the Shoshone River during 1948 were 146,192 below the reservoir and 414,700 at Byron.

In table // below, net volumes of water and quantities of salts contributed from the portion of the drainage basin between each two successive gaging stations have been computed for 1948.

Table // Discharge and salt burdens for sampling stations and intervening areas, Bighorn River basin, 1948

Station	Water discharge (acre feet)	Dissolved solids	
		Tons per acre foot	Tons
Wind - Bighorn River			
At Dubois	129,400	0.20	25,880
Intervening area	584,300	.22	131,134
At Riverton	713,700	.22	157,014
Intervening area	471,300	1.15	542,136
At Thermopolis	1,185,000	.59	699,150
Shoshone River			
Below reservoir west of Cody	913,700	.16	146,192
Intervening area	- - -	- -	268,508
At Byron	797,500	.52	414,700

In the area between Dubois and Riverton the net volume of water contributed was 584,300 acre feet, and the concentration of this contribution was .22 tons per acre foot. Between Riverton and Thermopolis a more striking example of the higher concentrations of the inter-station contributions is found. In this intervening area the net volume contributed was 471,300 acre feet and the concentration was 1.15 tons per acre foot, or more than five times that at Riverton and almost twice the concentration at Thermopolis downstream. The high concentration of the inter-station contribution between Riverton and Thermopolis indicates that the return flow of drainage water from irrigated lands along the stream carries a higher proportion of dissolved salts than the natural runoff from precipitation. Waste flows carried by Five Mile Creek and canals and laterals from the Riverton irrigation project discharge their salt-laden waters into the Bighorn River below Riverton.

Earlier studies by Dunnewald [1] on the discharge and salt burden factors in the Bighorn River show a similar pattern to results reported for 1948.

[1] Dunnewald, T. J., Salinity conditions in the Bighorn River during the years 1938 and 1939: U. of Wyoming Agr. Exp. Station Bull. 240, pp. 7-9, July 1940.

Effects of Irrigation Development on Quality of the Water

Mountain water, such as the Wind River near Dubois, is dilute as previously noted and meets general requirements of an irrigation water. As the quality of the water is determined downstream from head to mouth, the composition of the dissolved solids in the Bighorn River is found to change from essentially calcium bicarbonate to proportionally more sodium sulfate. This is partly explained by the admixture of seepage and alkali water from side streams of the drainage area and return flows from irrigated lands. For example, Ocean Lake, largely sustained by irrigation waste waters in the Riverton project contains water in which sulfate composes 84 percent of the acid radicles and sodium accounts for 67 percent of the bases, considered as equivalents per million. A typical analysis shows a dissolved solids concentration of 2,320 parts per million, which is more than twice the maximum concentration reported for the Bighorn River in its lower reaches. The increase in salinity and corresponding decrease in alkalinity from Dubois to Custer is shown graphically as percentage values in figure 33 . Weighted results are given for the Dubois, Riverton, and Thermopolis stations,

View along lower Five Mile Creek showing great width of stream resulting from lateral corrasion.

View at the confluence of Five Mile Creek and the Bighorn River. Note how the delta of Five Mile Creek, in the foreground, has forced the Bighorn River over to its right bank.

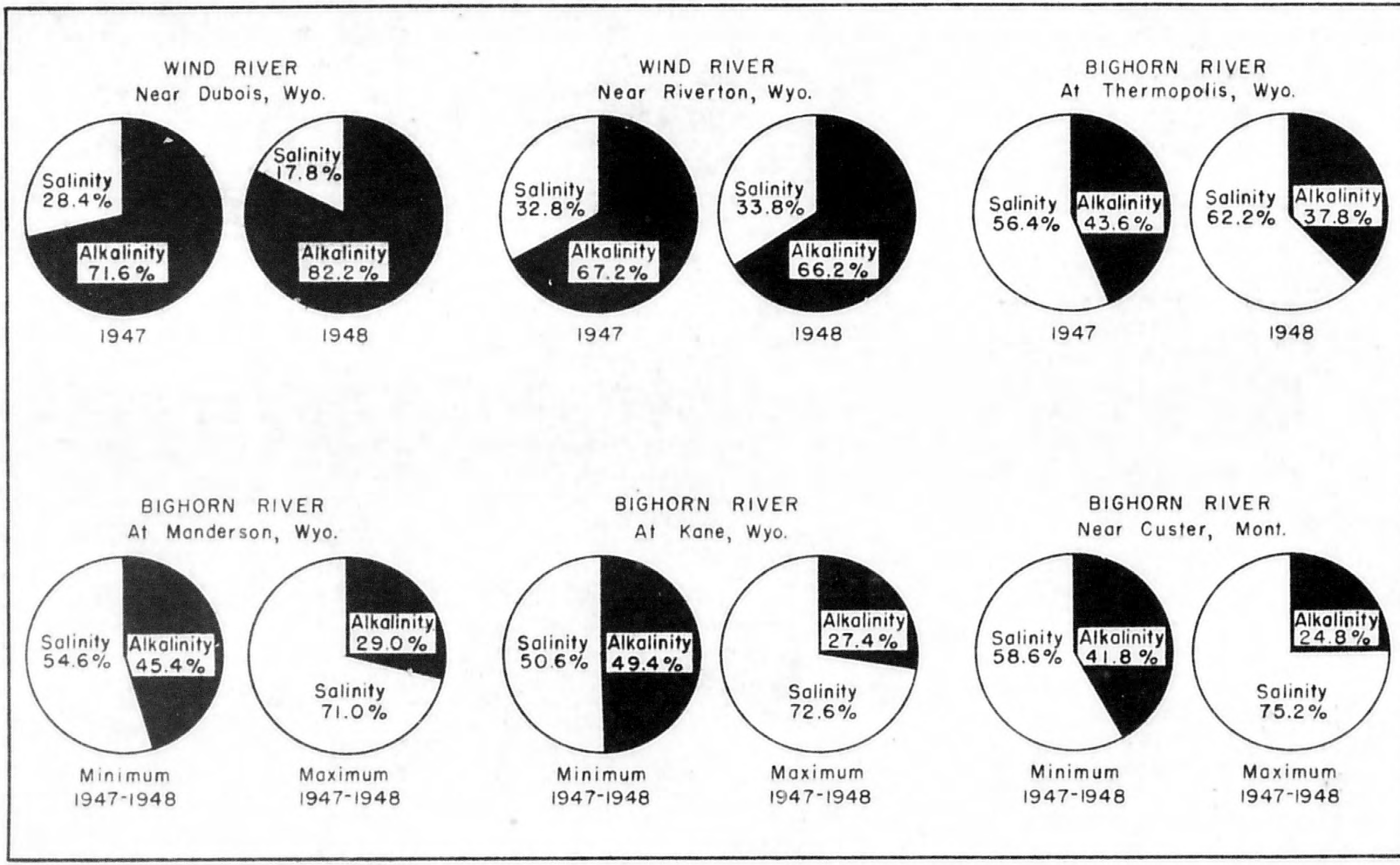
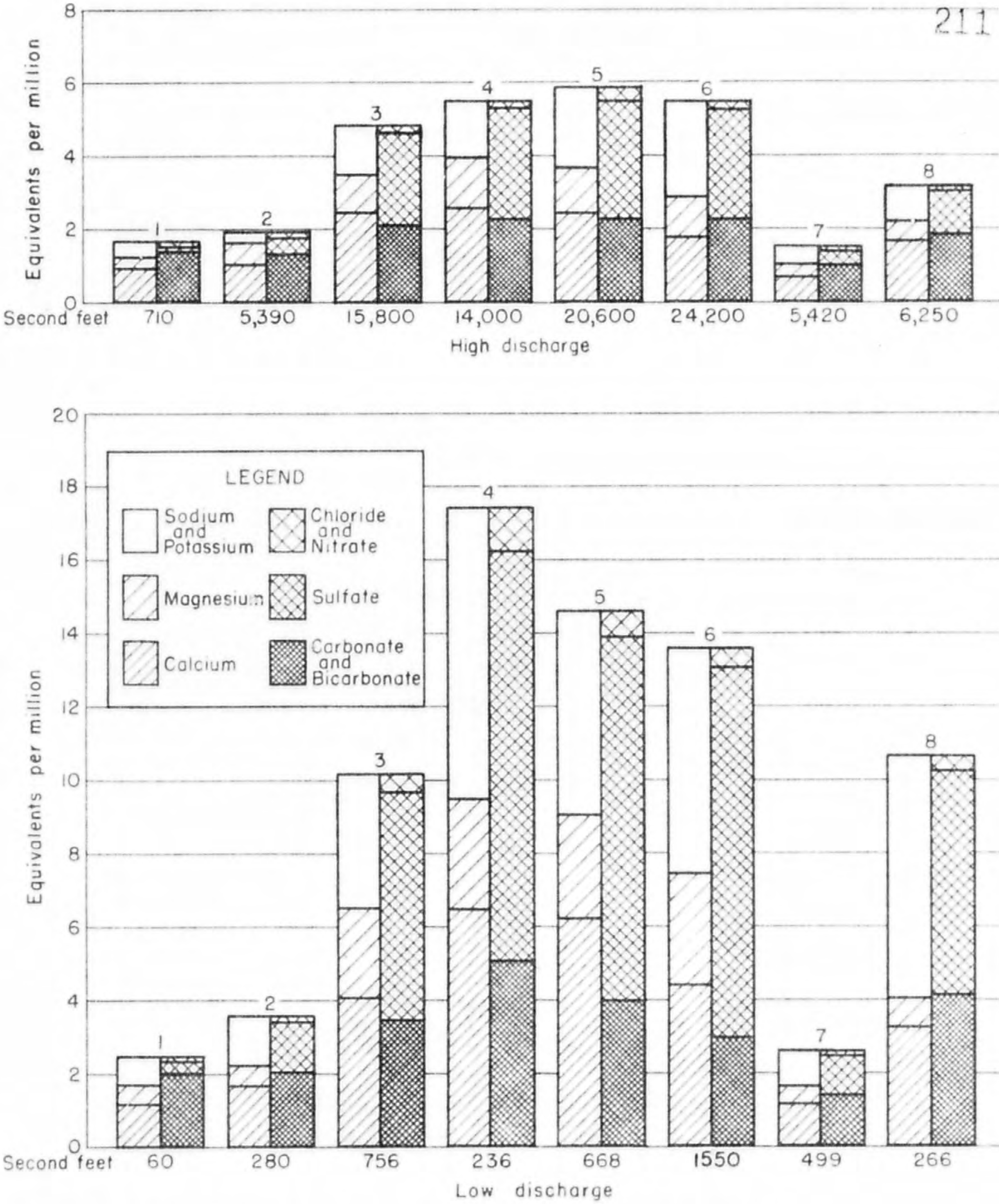


Figure 33 Alkalinity—salinity relationship for Wind River and Bighorn River waters, Wyoming and Montana in downstream order. Values reported as maximum and minimum concentrations are for points sampled intermittently.

where daily samples were collected; values corresponding to minimum and maximum concentrations of dissolved solids are shown for Manderson, Kane, and Custer stations, sampled intermittently.

The amount of water diverted for irrigation use and the amounts subsequently returning to the river for reuse both effect the quality of the water, as has already been discussed. In addition the quality of the water varies with flow conditions. Concentration, more than composition, fluctuates with discharge - the higher concentrations as a rule corresponding to low flows. If the low-water flow is sustained mostly by ground water discharge and bank seepage, one expects to find such waters carrying relatively high quantities of salts. High-water stages, as a result of snow melt and precipitation, dilute these mineralized waters to furnish a water of lower concentration. Examples of the effect of discharge on concentration and composition are seen in figure 34 when the analyses of waters corresponding to high and low discharges are plotted graphically as equivalents per million. In such diagrams the heights of the sections are proportional to the concentrations as equivalents of the radicles.

Although the quality of surface water in the Bighorn River basin is somewhat impaired progressively downstream, largely from cultural influences, percent sodium values are not critical and dissolved solids are generally less than 1,000 parts per million even during periods of low flow. For 14 samples analyzed at Custer near the mouth of the Bighorn River, the maximum percent sodium reported is 48. At present the quality of the Bighorn River water is not adversely affected for irrigation use by return flows.



1 Wind River near Dubois, Wyo.
2 Wind River near Riverton, Wyo.
3 Bighorn River at Thermopolis, Wyo.
4 Bighorn River at Manderson, Wyo.
5 Bighorn River at Kane, Wyo.
6 Bighorn River near Custer, Mont.
7 Shoshone River below Buffalo Bill Reservoir, Wyo
8 Shoshone River at Byron, Wyo.

Figure . Chemical analyses in equivalents per million of Wind River, Bighorn River, and Shoshone River waters, Wyoming and Montana for periods of high and low discharge.

Chemical Character of Miscellaneous Lake and Stream Waters

Briefly noted are analyses made during the course of the investigation of the water in Ocean Lake and small streams tributary to the Bighorn River.

Ocean Lake near Riverton, Wyoming

Ocean Lake is the result of waste flows draining irrigated lands developed under the Riverton irrigation project. The lake water has a high concentration of dissolved solids composed mostly of sodium and sulfate. Three analyses show concentrations exceeding 2,000 parts per million of dissolved solids. A sample analyzed from Sand Butte lateral flowing into the lake, while showing about the same concentration as the lake and outlet waters had a lower percent sodium value. Results of analyses in both parts and equivalents per million are given in tables 12 and 13 .

Owl Creek and Tributaries

Several samples from Owl Creek and its North and South forks were analyzed. South Fork of Owl Creek above the Anchor damsite is a dilute calcium bicarbonate water as shown by Nos. 541 and 2852 in tables 14 and 15 . The upper reaches of North Fork show a similar but somewhat more concentrated water (No. 2849). Below the confluence of the forks the creek water becomes progressively more mineralized reaching a maximum concentration of 4,160 parts per million near its mouth above the Bighorn River. Sample No. 2848 shows the composition of this water.

Nowood and Paintrock Creeks

Nowood Creek enters the Bighorn River below Manderson and the composition of the creek water at this point reflects the contribution of Paintrock Creek, its principal tributary. Near Hyattville, water from Paintrock Creek shows the typical properties of a mountain stream. The water is low in

TABLE 12. CHEMICAL ANALYSES, IN PARTS PER MILLION

OF WATERS FROM OCEAN LAKE, WYOMING

Sample number	1158	1161	1163
Date of collection . . 1947	Sept. 23	Sept. 23	Sept. 23
Silica (SiO_2)	0.0	0.0	4.0
Iron (Fe)	.01	.01	.01
Calcium (Ca)	143	140	247
Magnesium (Mg)	49	48	61
Sodium (Na) Potassium (K)	532	521	402
Percent sodium	67	67	50
Bicarbonate (HCO_3)	152	148	278
Sulfate (SO_4)	1,390	1,360	1,370
Chloride (Cl)	100	100	56
Fluoride (F)	.6	.7	.8
Nitrate (NO_3)	.2	.2	6.0
Boron (B)	.16	- - -	- - -
Dissolved solids: Sum - ppm.	2,290	2,240	2,280
Hardness as $CaCO_3$: Total	558	547	867
Noncarbonate	433	426	639
Specific conductance (Micromhos at 25° C.) . . .	3,110	3,080	2,930
pH	8.2	8.2	8.3

Sample No. 1158: Collected from lake

Sample No. 1161: Collected from reservoir outlet

Sample No. 1163: Collected from Sand Butte lateral ¼ mile above lake

TABLE 13 CHEMICAL ANALYSES, IN EQUIVALENTS PER MILLION

OF WATERS FROM OCEAN LAKE, WYOMING

Sample number	1158	1161	1163
Date of collection 1947	Sept. 23	Sept. 23	Sept. 23
Calcium (Ca)	7.14	6.99	12.32
Magnesium (Mg)	4.03	3.95	5.02
Sodium (Na) Potassium (K)	23.12	22.67	17.46
Bicarbonate (HCO_3)	2.49	2.43	4.56
Sulfate (SO_4)	28.94	28.32	28.52
Chloride (Cl)	2.82	2.82	1.58
Fluoride (F)	.03	.03	.04
Nitrate (NO_3)	.01	.01	.10

Sample No. 1158: Collected from lake

Sample No. 1161: Collected from reservoir outlet

Sample No. 1163: Collected from Sand Butte lateral ¼ mile above lake

TABLE 14 CHEMICAL ANALYSES, IN PARTS PER MILLION

OF WATERS FROM OWL CREEK AND TRIBUTARIES, WYOMING

Sample number	542	2848	2849	2851	541	2852	2850
Date of collection. 1947	July 2	Sept. 2	Sept. 2	Sept. 2	July 1	Sept. 2	Sept. 2
Silica (SiO_2)	18	26	36	33	17	19	17
Iron (Fe)	.02	.02	.80	.0	.02	.65	.0
Calcium (Ca)	102	370	21	158	11	12	92
Magnesium (Mg)	38	186	6.8	70	6.1	5.4	44
Sodium (Na)	102	610	28	190	3.4	10	51
Potassium (K)	6.8					2.0	
Percent Sodium	34	44	43	38	12	28	21
Bicarbonate (HCO_3)	207 a/	359	128	392	57	77	254
Sulfate (SO_4)	432	2,530	33	723	10	8.7	293
Chloride (Cl)	13	59	.4	13	1.6	1.5	5.0
Fluoride (F)	.3	.8	.4	.7	.1	.7	.2
Nitrate (NO_3)	2.0	.7	.5	.6	.5	.5	.4
Boron (B)	.17	-	-	-	.01	-	-
Dissolved solids: Sum - ppm.	811	3,960	190	1,380	79	108	642
Hardness as $CaCO_3$: Total	411	1,690	80	682	53	52	410
Noncarbonate	241	1,400	0	361	6	0	202
Specific conductance (Micromhos at 25° C)	1,170	4,240	283	1,790	116	148	904
pH	8.5	7.8	7.5	7.6	8.3	7.0	7.8

a/ Contains equivalent of 2.0 parts CO_3

Sample No. 542: Owl Creek near Lucerne, ¼ mile above mouth

Sample No. 2848: Owl Creek; 15 feet upstream from mouth where Owl Creek enters Bighorn River

Sample No. 2849: North Fork Owl Creek; 0.6 mile upstream from gaging station; Sec. 7, T8N, R1W

Sample No. 2851: North Fork Owl Creek at mouth; 100 yards upstream from junction with South Fork Owl Creek

Sample No. 541: South Fork Owl Creek, ¼ mile above Anchor damsite

Sample No. 2852: South Fork Owl Creek ¼ mile above Anchor damsite

Sample No. 2850: South Fork Owl Creek, 400 yards above confluence with North Fork Owl Creek

TABLE — CHEMICAL ANALYSES, IN EQUIVALENTS PER MILLION

OF WATERS FROM OWL CREEK AND TRIBUTARIES, WYOMING

Sample number	542	2848	2849	2851	541	2852	2850
Date of collection 1947 . .	July 2	Sept. 2	Sept. 2	Sept. 2	July 1	Sept. 2	Sept. 2
Calcium (Ca)	5.09	18.46	1.05	7.88	.55	.60	4.59
Magnesium (Mg)	3.13	15.30	.56	5.76	.50	.44	3.62
Sodium (Na)	4.41	26.52	1.22	8.25	.15	.44	2.21
Potassium (K)	.17					.05	
Bicarbonate (HCO_3) . . .	3.39	5.88	2.10	6.42	.93	1.26	4.16
Sulfate (SO_4)	8.99	52.68	.69	15.05	.21	.18	6.10
Chloride (Cl)	.37	1.67	.01	.37	.04	.04	.14
Fluoride (F)	.02	.04	.02	.04	.01	.04	.01
Nitrate (NO_3)	.03	.01	.01	.01	.01	.01	.01

Sample No. 542: Owl Creek near Lucerne, ¼ mile above mouth

Sample No. 2848: Owl Creek; 15 feet upstream from mouth where Owl Creek enters Bighorn River

Sample No. 2849: North Fork Owl Creek; 0.6 mile upstream from gaging station; Sec. 7, T8N, R1W

Sample No. 2851: North Fork Owl Creek at mouth; 100 yards upstream from junction with South Fork Owl Creek

Sample No. 541: South Fork Owl Creek, ¼ mile above Anchor damsite

Sample No. 2852: South Fork Owl Creek ¼ mile above Anchor damsite

Sample No. 2850: South Fork Owl Creek, 400 yards above confluence with North Fork Owl Creek dissolved solids (102 parts per million), low in sulfate, rich in bicarbonate, and is primary alkaline, with the alkalies exceeding the equivalents of strong acids. Hyattville is above any major diversions for irrigation. Downstream at a point approximately 150 feet above its confluence with Nowood Creek, the water has changed remarkably. As noted in tables 16 and 17 the water here is about 13 times more concentrated, (1,330 parts per million), high in sulfate, poor in bicarbonate, and is secondary saline. Return irrigation flows account for much of the higher concentrations in the lower reaches of Paintrock Creek. The water from Nowood Creek below its confluence with Paintrock Creek is somewhat less concentrated as a result of the diluting action of the Nowood water.

Water Temperature

Increased significance is being given to water supplies and to water temperatures in that these conditions along with other considerations are often limiting factors in industrial development. Studies of conditions affecting living aquatic organisms include evaluation of long-range temperature records. Temperature measurements are reported with the results of analyses in ~~figures to~~ Appendix II, and are shown graphically in plates 73 to 80 .

Summary

The Bighorn River drainage basin from headwaters to mouth shows a constantly changing pattern in the quality of its surface waters. Return flows from irrigated areas alter the composition and properties of the river water considerably. From Dubois downstream a progressive decrease in silica, calcium, and bicarbonate, and a progressive increase in sulfate and alkalies are noted. However, percent sodium is below 60, even in low

TABLE 16 CHEMICAL ANALYSES, IN PARTS PER MILLION

OF NOWOOD AND PAINTROCK CREEK WATERS, WYOMING

Sample number	17852	17854	17853
Date of collection 1947	Sept. 12	Sept. 11	Nov. 12
Silica (SiO_2)	12	7.7	25
Iron (Fe)	.08	.08	.02
Calcium (Ca)	146	18	199
Magnesium (Mg)	55	9.0	68
Sodium (Na)	68	3.4	113
Potassium (K)	7.6	1.6	12
Percent sodium	20	8	24
Bicarbonate (HCO_3)	202	102	292
Sulfate (SO_4)	550	4.0	756
Chloride (Cl)	6.0	1.0	6.0
Fluoride (F)	.2	.4	.4
Nitrate (NO_3)	1.8	1.5	2.5
Boron (B)	.22	.11	.28
Dissolved solids: Sum - ppm.	946	102	1,330
Hardness as $CaCO_3$: Total	590	82	776
Noncarbonate	424	0	537
Specific conductance (Micromhos at 25° C.) .	1,300	185	1,690
pH	7.6	7.9	7.6

Sample No. 17852: Nowood Creek near Manderson

Sample No. 17854: Paintrock Creek near Hyattville

Sample No. 17853: Paintrock Creek at point 150 feet above confluence with Nowood Creek

TABLE 17 CHEMICAL ANALYSES, IN EQUIVALENTS PER MILLION

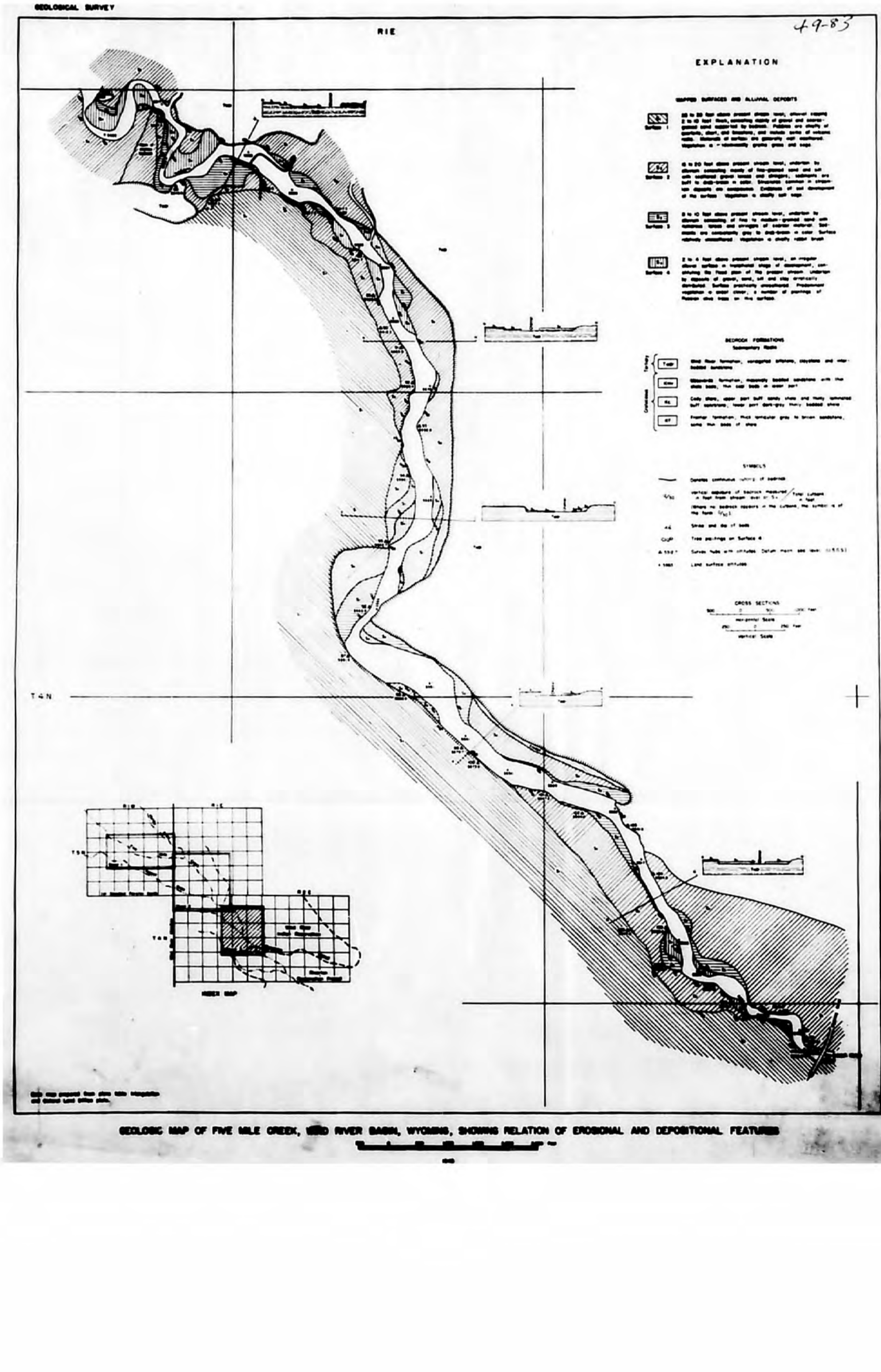
OF NOWOOD AND PAINTROCK CREEK WATERS, WYOMING

Sample number	17852	17854	17853
Date of collection . . 1947 . . .	Sept. 12	Sept. 11	Nov. 12
Calcium (Ca)	7.29	.90	9.93
Magnesium (Mg)	4.52	.74	5.59
Sodium (Na)	2.97	.15	4.93
Potassium (K)	.19	.04	.31
Bicarbonate (HCO_3)	3.31	1.67	4.79
Sulfate (SO_4)	11.45	.08	15.74
Chloride (Cl)	.17	.03	.17
Fluoride (F)	.01	.02	.02
Nitrate (NO_3)	.03	.03	.04

Sample No. 17852: Nowood Creek near Manderson

Sample No. 17854: Paintrock Creek near Hyattville

Sample No. 17853: Paintrock Creek at point 150 feet above confluence with Nowood Creek flows, and the concentration of the river water seldom exceeds 1,000 parts per million of dissolved solids. Completion of proposed reservoirs and expansion of present irrigation development will be expected to further modify the quality of river water available for irrigation and other uses. At present the average concentration of dissolved solids at Thermopolis is approximately three times that at Dubois, while the concentration at Kane exceeds five times the Dubois value. The average concentration at Custer downstream near the mouth is somewhat lower than that at Kane due to the more dilute Shoshone River water entering the Bighorn River below Kane.



GEOLOGIC MAP OF FIVE MILE CREEK, WIND RIVER BASIN, WYOMING, SHOWING RELATION OF EROSIONAL AND DEPOSITIONAL FEATURES

View downstream Sheep Mountain Canyon.

View of the Bighorn Canyon looking downstream from the mouth of Porcupine Creek. The notch in The Bighorn Arch on the skyline to the right marks the point of greatest depth of the canyon.