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WATER POWER AND IRRIGATION IN THE MADISON RIVER BASIN, MONTANA

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INTRODUCTION

During July and August, 1923, field studies were undertaken to obtain information needed in assembling and correlating data in the files of the Geological Survey regarding the utilization of water in the Madison River basin, Mont. The work consisted of reconnaissance investigations, including a plane-table survey to determine potential power resources along two sections of the river, one 18 miles long and the other 34 miles long, and a compilation of county classification records showing irrigated areas. Records of the Montana State engineer were helpful in obtaining data concerning projected irrigation development, and considerable information concerning hydroelectric power was obtained from the Montana Power Co., which owns or controls the principal hydroelectric plants in the Missouri River basin. Private engineers, business men, and many others who were interviewed in connection with the field work displayed a notable spirit of cooperation and furnished many valuable data. J. Q. Peterson, of the Geological Survey, aided in preparing the agricultural discussion, and G. R. Mansfield, also of the Survey, reviewed the section on geography and physiography and prepared the section on geology.

The principal trading points in the basin are at Three Forks, Ennis, and Norris, but there are post offices also at Cameron, Cliff Lake, Jeffers, Lyon, McAllister, Varney, Grayling, and Yellowstone. Transportation in the lower part of the river basin is afforded by the Northern Pacific and Chicago, Milwaukee & St. Paul railways. The most accessible shipping point for the remainder of the basin is at Norris, the terminus of a branch line of the Northern Pacific Railway. Fairly good highways are to be found throughout the settled parts of the basin. The Vigilante Trail to Yellowstone National Park extends into the valley across the watershed on the west side from Virginia City to Ennis, thence up the east side of the river to the Hebgen reservoir, and thence south to the west entrance of the park. The trail known as the Great White Way runs from Three Forks to Norris and Ennis, thence over the same route as the Vigilante Trail to the Hutchins ranch, in sec. 10, T. 11 S., R. 1 E., whence it crosses the river and proceeds up the west side of Madison Valley, crosses the Continental Divide to Henrys Lake, Idaho, and runs back across this divide to the west entrance of Yellowstone Park. The Banff-Grand Canyon Trail follows the same route as the Vigilante Trail. Highway bridges are located near the mouth of the river on the road from Three Forks to Logan; at a point in sec. 11, T. 3 S., R. 1 E., on the road from Norris to Bozeman; in sec. 36, T. 8 S., R. 1 W., near the mouth of Indian Creek; and at Ennis, Varney, Lyon, and the Hutchins ranch.

SUMMARY

The Madison River basin contains the internationally famous geysers of Yellowstone National Park, which are at its headwaters, and it is also well known for its trout fishing, which brings large numbers of tourists to the basin each season. In an economic sense, however, the basin is of particular interest because of its water supply, as it yields annually more than 1,400,000 acre-feet which can be used for the development of hydroelectric energy and for irrigation. The power resources are now partly developed by power plants having an installed capacity of 18,000 horsepower and storage reservoirs having a total capacity of 386,000 acre-feet. It is estimated that the undeveloped power resources on the river amount to 136,000 horsepower of electric energy. This estimate does not include potential power resources of considerable magnitude at the headquarters of the basin within Yellowstone National Park, as the scenic value of that area is regarded as sufficient to prevent present consideration of commercial development of its potential power, and such development has been prohibited by law.

Agriculture is practiced in the basin to a certain extent, but the area suitable for diversified farming is relatively small, and stock raising is the principal agricultural industry. Adverse climate, poor soil, and unfavorable topography are the limiting factors to agriculture. About 2.1 per cent of the drainage area is irrigated, and an additional 2.3 per cent is included in irrigation projects, at least part of which probably will be constructed eventually. Near the lower end of the basin certain favorably located bench lands are cultivated by dry farming and produce successful crops of small grains during

good years. In parts of the basin are flood-plain areas that may be susceptible of successful reclamation by drainage, diking, and irrigation.

GEOGRAPHY AND PHYSIOGRAPHY

Madison River is formed in Yellowstone National Park by the junction of Gibbon and Firehole rivers and flows thence a distance of approximately 140 miles to Three Forks, in southwestern Montana, where it joins Jefferson and Gallatin rivers to form Missouri River. The drainage area tributary to the river (fig. 1) is 2,590 square miles, consisting of mountain ranges, high plateaus, and relatively small areas of valley lands. The watershed for the basin, beginning at the mouth of the river on the west side, extends to and along the crest of the Jefferson Mountains, thence along the Continental Divide on the south, thence northward across plateaus and minor mountain ranges and along the Madison Range and low-lying hills to the mouth of the river.

The river basin comprises five natural subdivisions having distinct physiographic and economic features—the headwater area above the Hebgen dam, including Upper Madison Valley; the upper canyon section, which extends about 7 miles below the Hebgen dam; the middle valley section, which extends 57 miles below the upper canyon; the lower canyon section, which extends 20 miles below the middle valley; and the lower valley, which extends 18 miles below the lower canyon to the mouth of the river. These five subdivisions are convenient units for discussing the utilization of water along the river, and frequent reference to them will appear in subsequent parts of this report.

Topographically the headwater area is composed for the most part of high plateaus and mountains, with a comparatively small amount of open valley. In this area Gibbon Falls, having a head of 80 feet, and the cascades of the Firehole, with a fall of 300 feet within 2 miles, furnish potential power resources of considerable magnitude. The only water utilization in this area that is possible without encroaching on Yellowstone National Park, however, is at the Hebgen reservoir, the flow line of which extends to the park boundary. The investigations in connection with the present paper therefore practically ignored the park section of the basin.

The upper canyon section lies in a gorge walled with massive gneissic rocks rising almost vertically to an estimated height of over 500 feet above the river. Throughout this section the river channel lies along or near the left wall of the gorge, but on the opposite side of the gorge rock in place is not exposed at any point near the river, and the precipitous cliffs of the main canyon wall are in places half a mile back from the water's edge. The slopes leading to this right wall are covered with a mantle of rock fragments of undetermined

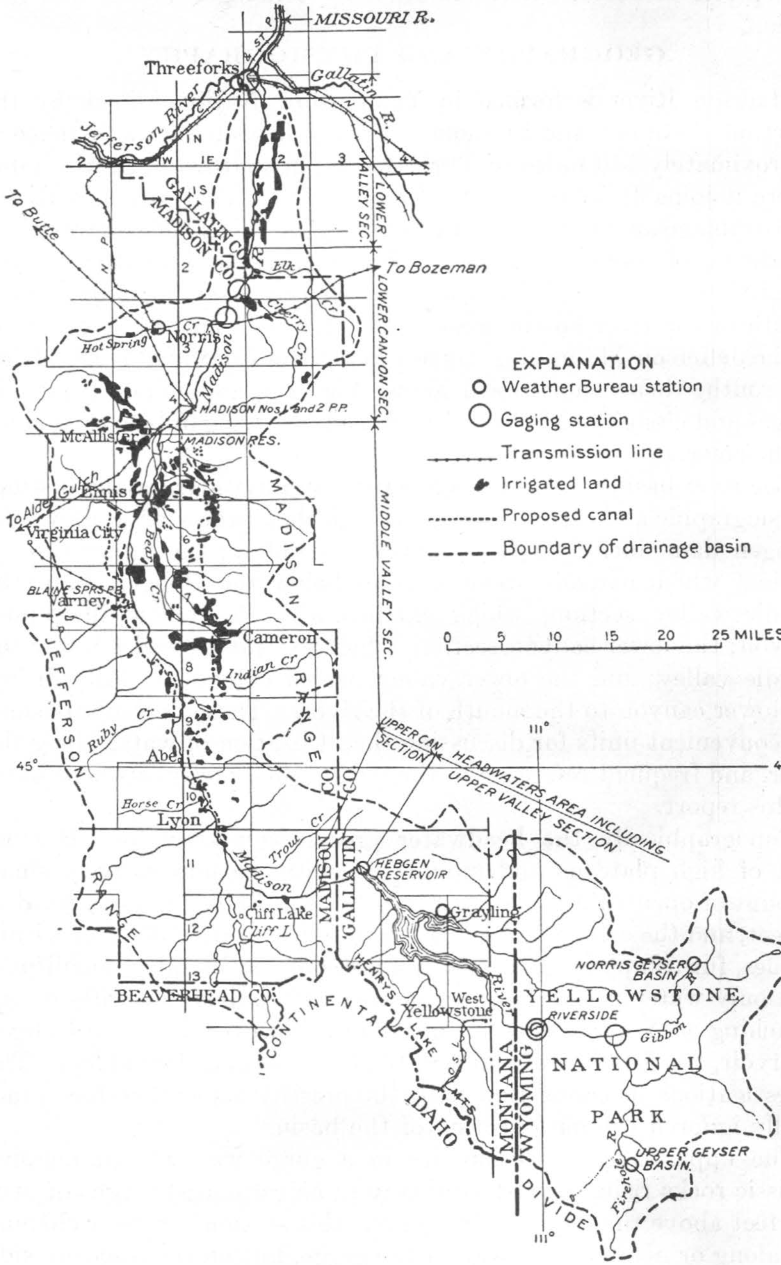

FIGURE 1.—Map of Madison River basin, Mont.

depth except at the upper end of the canyon, where the excavations for the Hebgen dam extended into solid rock at a depth of 34 feet below the river bed. Israel Hutchins, an early settler living near the upper end of the middle valley, reported that he was engaged about 15 years ago to make explorations in the upper canyon in connection with a contemplated power development. This work consisted in sinking a 74-foot shaft on the right bank about 1 mile above the mouth of the canyon at a point 100 feet higher than the water surface and 200 yards back from the river. The shaft failed to reach solid rock.

The middle valley section consists of a basin between the upper and lower canyon sections having a maximum width of 8 to 10 miles from the foothills of the Jefferson Mountains on the west to the base of the Madison Range on the east. The trough of the valley is near its west side, leaving an area on the east side which in places attains a width of 7 miles. Madison River flows through the trough of the valley in a flood plain that ranges in width from a few hundred feet in certain places near its upper end to about 3 miles at its lower end. For the most part the flood plain is flanked by a series of coarse gravel terraces stepped up to a maximum height of 150 feet above the river. The terraced topography is modified on one or both sides of the river in a stretch extending from sec. 24, T. 11 S., R. 1 E., to a point in sec. 1, T. 10 S., R. 1 W., owing to the occurrence of rhyolite. In this stretch the river occupies a channel through a valley so narrow at places as apparently to present economical cross sections for dam sites. Where the river channel follows the line between T. 10 S., R. 1 E., and T. 10 S., R. 1 W., prominent palisades of rhyolite 3 miles in length occur along the west bank. In sec. 25, T. 11 S., R. 1 E., at 50 feet above the river the width of the valley is 575 feet, and at 90 feet above the river the estimated width is 775 feet. At this point rhyolite is present on both sides of the river. Near the center of sec. 14, T. 11 S., R. 1 E., the left bank of the river follows the base of a rocky ridge 500 feet or more in height, and on the right bank there is a series of characteristic Madison Valley terraces, one 25 feet, a second 75 feet, and a third 100 feet above the river. At 60 feet above the water surface the valley is 250 feet wide, and at 100 feet above it is about 500 feet wide.

In the SW. ¼ SE. ¼ sec. 33, T. 10 S., R. 1 E., about halfway between Squaw and Second Standard creeks, the width of the valley at the water surface is 225 feet and at 30 feet above the river it is 375 feet. The left bank here is a steep talus slope 75 feet or more high, and the right bank is a typical terrace 450 feet wide leading to a second terrace about 70 feet high. In the SE. ¼ NW. ¼ sec. 18, T. 10 S., R. 1 E., the width of the valley at 30 feet above the water surface is about 450 feet and at 50 feet above about 650 feet. At this point the left bank consists of a talus slope of moderate gradient, and the right bank is a steep terrace slope 70 feet high. In the NE. ¼ sec. 12, T. 10 S., R. 1 E., the width of the valley at 30 feet above the water surface is about 400 feet; the left bank is formed by rhyolite talus spalled off from closely adjacent cliffs and the right bank by the usual gravel-covered terrace. In the SW. ¼ sec. 25, T. 9 S., R. 1 W., terraces on opposite sides of the river, the one on the left bank 100 feet high and the one on the right over 60 feet high, form narrows having a width of about 800 feet at 60 feet above river level.

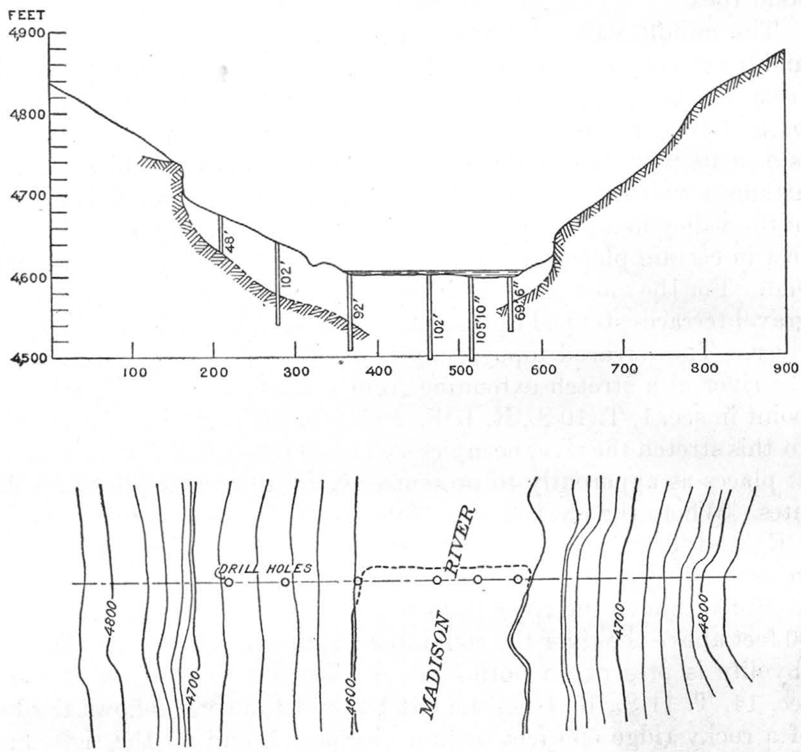

FIGURE 2.—Cross section of Madison River in lower canyon section, showing drill holes made by Montana Power Co.

The lower canyon section is a narrow rock-walled gneissic gorge similar to the upper canyon in that the walls of the gorge furnish a solid foundation for dam abutments. The river bed occupies practically the whole bottom of the canyon and consists of rock débris of undetermined depth. Through the courtesy of the Montana Power Co. a cross section of the canyon at a point in lots 3 and 4, sec. 34, T. 3 S., R. 1 E., and data obtained through exploratory boring operations along the axis of a possible dam at this point are presented in Figure 2. The drill used in these operations penetrated to a maximum of 105 feet 10 inches but failed to reach solid rock. This condition of a favorable cross section for a dam site but lack of bed-rock foundations at a moderate depth has been disclosed by similar explorations of the power company in secs. 11, 27, and 33, T. 3 S., R. 1 E., and apparently prevails throughout the lower canyon.

The lower valley is a wide plain which is in places almost level. The river is intrenched in this plain to a depth of only a few feet, and near its lower end the rapid fall that prevails throughout the greater part of the river course diminishes so much that the stream flow appears comparatively sluggish.

GEOLOGY

With respect to its general geologic and physiographic features the Madison Valley as a whole appears to be much like many inter-montane valleys farther south in Idaho. These valleys were formed by erosion and perhaps in part by downwarping or faulting in middle or earlier Tertiary time and were excavated to considerably greater depths than the present valleys. They were largely filled by middle or later Tertiary sediments (gravel, marl, etc.), partly lacustrine and partly fluviatile, which formed the so-called lake beds that are so common in these valleys and that locally overspread adjoining hills. During this epoch volcanic activity gave rise to flows of rhyolite or basalt and beds of volcanic ash. These materials are now inter-bedded here and there with the Tertiary sediments. With the revival of erosion some streams cut through the thin cover of Tertiary sedi-ments into an underlying ridge of older rocks, forming canyons, whereas the thicker sediments up and down stream were excavated so that wide valleys were developed in them. Similarly when flows of rhyolite or basalt were cut through, canyons or palisaded reaches were formed, with open reaches in the weaker lake beds upstream. The wide valleys in the lake beds have passed through several partial erosion cycles, which are marked by the terraces that are so conspicu-ous here and there, and together with their connecting canyons have been eroded to depths which are likewise greater than those of the present valleys. This erosion, which presumably occurred in early Pleistocene time, was succeeded by an epoch of aggradation, induced in part at least by more arid climatic conditions, in which the valleys and connecting canyons were partly refilled to unknown depths but in some places 200 feet or more. Since this time the climate has again become more moist, and the streams are now engaged in scouring away these fillings, though they have thus far made little progress in this work.

In the middle valley area there are narrow places with palisades of rhyolite that suggest favorable positions for dam sites. These rhyolite flows are probably to be regarded as members of the lake-bed series and are therefore doubtless underlain by Tertiary beds.

Where rhyolite appears in these palisades it has in all probability been cut through by the later stream erosion so that it does not now underlie the river bed and would therefore not be available for dam foundations. However, if at any place the flows were exceptionally thick they may not have been completely eroded through and in that event would serve for dam foundations if not too porous. Drilling would be necessary to determine the presence or absence of the rhyolite at any particular locality.

METEOROLOGY

Data on the growing season, precipitation, and temperature recorded by the United States Weather Bureau for the Madison River basin are given below. At the headwaters of the basin records have been obtained at the Hebgen dam and Grayling, in Montana, and at Norris Geyser Basin and Upper Geyser Basin, in Wyoming. The average annual precipitation along the river channel as disclosed by these records is about 20 inches. The rainfall at the crests of the mountain ranges in the basin is considerably higher, but no records of it are available. The growing season averages 24 days in length at Grayling and 78 days at the Hebgen dam. At the Upper Geyser Basin and Norris Geyser Basin stations frost records obtained in 1915 show a growing season of 53 days and 32 days respectively, but during the years 1910 to 1914 and 1916 at Norris and 1909 to 1914 and 1916 at Upper Geyser Basin frost occurred every month in the year. These data seem to be inconsistent in that the growing season at the Hebgen dam is made to appear as of excessive length in comparison to that at the other stations, but it is believed that the moderating influence of the large body of water in the Hebgen reservoir, supplied in part from hot springs, operates to lengthen the frost-free period at this station.

The remaining Weather Bureau stations in the Madison River basin are at lower altitudes—at Ennis, Meadow Creek, Norris, and Three Forks, Mont. According to the records the average growing season is 98 days long at Ennis and longer at the other stations. The precipitation, on the other hand, in general decreases with the altitude to a minimum of 11.58 inches a year at Three Forks, the least recorded in the basin. At Norris the record shows a mean annual precipitation of 17.36 inches, which has proved adequate in this area to produce successful crops of wheat and oats under dry-farming methods. A growing season of 98 days is sufficient for the production of general farm crops, but where the annual precipitation is as small as at Three Forks irrigation is necessary for successful farming.

Temperature records show prolonged periods of weather below the freezing point throughout the Madison River basin, and operation of hydraulic structures during the winter may be difficult because of interference from frazil or "slush" ice. Frazil ice will disappear when introduced into a reservoir under an ice cover and will not form for a considerable distance downstream from the outlet of the reservoir. On Madison River the operation of the Hebgen reservoir effectively eliminates frazil ice in the upper canyon, and in this section power can be developed without the possibility of interference from this source. In the middle valley frazil ice will form unless preventive measures are taken, either by the construction of reservoirs above the intakes to the power plants or by some other means of eliminating the difficulty.

Precipitation, in inches, at stations in Madison River basin

Ennis, Mont.

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1918				2.13	0.80	0.32	1.68	2.15	2.40	1.51	0.65	1.72	
1918–19	1.30	0.83	0.48	.16	.80	.26		.50		.10		.36	
1919–20		.80	2.24	.08	.88	1.92	1.64	1.40	2.75	.55	.30		
1920–21		.32	.48	.64				2.20	1.05	.45	.70	1.00	
1921–22	1.00		.40	.72	.12	.56	1.22	2.06	1.50	2.06	3.00	.50	
1922–23			.44					1.02	2.01	2.05	1.40	.25	
1923	.40	.48	.72										
Average	.90	.61	.79	.75	.65	.76	1.51	1.56	1.94	1.12	1.21	.77	12.57

Meadow Creek, Mont.

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1909												0.12	2.06
1909–10	0.16	1.76	1.15	0.50	1.40	Tr.	0.69	0.63	0.33		.08		

Grayling, Mont.

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1904									1.17	1.67	1.18	0.59	
1904–5	1.12	Tr.	1.01	0.57	0.34	1.31	0.49	2.58	1.75	1.21	.66	1.02	12.06
1905–6	.74	0.90	.69	1.37	.97		.71	2.56		.53	1.40	.73	
1906–7	.61	.36	2.11	2.07	.48	3.01	.42	1.57	2.18	1.81	1.14		
1907–8	.81	.13	.88						3.24	1.30	2.67	1.40	
1908–9	2.14	.17			1.80	.27	.39	1.86	1.19	1.74	1.05	3.08	
1909–10	.61	1.87	1.15	2.85	.56	.13	.76		.29	1.16	.24		
1910–11		1.92	1.07	2.50	.60	.79	.54	2.65	2.57	1.12	.56	.94	
1911–12	1.20	1.09	1.01	.95	.49		1.62	1.55	2.01	4.14	1.92	.47	
1912–13	2.16	.64	.40										
Average	1.17	.79	1.04	1.72	.75	1.10	.70	2.13	1.80	1.64	1.20	1.18	15.22

Hebgen dam, Mont.

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1913				3.98	1.03	2.84	2.56	2.35	3.90	4.53	0.79	1.35	
1913–14	1.89	1.23	0.61	2.26	2.11	.48	.63	1.34	4.26	1.39	Tr.	1.36	17.56
1914–15	1.75	.15	1.17	2.64	2.05	1.71	2.01	5.15	2.00	3.05	.95	3.53	26.16
1915–16	.68		3.06	3.63	1.91	2.50	.95	2.71	1.61	1.23	.68	1.04	
1916–17	2.84	2.25	3.41	2.63	2.35	1.79	3.14	1.77	1.82	.32	.50	2.71	25.53
1917–18	.38	.99		4.24	2.42	2.31	1.37	1.65	2.37	3.58	1.65	3.01	
1918–19	2.70	.63	.85	1.14	3.25	1.84	1.01	1.77	.09	.77	.74	3.15	17.94
1919–20	3.76			.93		3.23	2.36	3.19	2.46	1.18	1.45	2.39	
1920–21	2.53	1.64		3.91	1.44		1.86	4.54	1.45	.78	1.79	1.12	
1921–22	.88	2.53	2.01	2.84	2.74	2.39	2.11	2.15	1.10	1.65	3.47	.25	24.12
1922–23	.40	.98	3.00	2.66	1.25	1.90	2.71	1.94	4.06	3.66	2.03	.72	25.31
1923–24	1.71	.84	2.50		2.38	2.27	.91						
Average	1.77	1.25	2.08	2.81	2.08	2.11	1.80	2.60	2.28	2.01	1.28	1.88	23.95

Precipitation, in inches, at stations in Madison River basin—Continued

Norris, Mont.

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1908				0.22	1.05	1.76	0.55	10.37	4.37	0.65	0.78	1.37	
1908-9	1.05	.04	.60	.05	.02	2.09	1.00	6.04	1.02	2.34	2.83	4.54	21.62
1909-10	.70	1.57	1.85	2.53	.51	.35	1.50	2.64	1.19	.88	1.96	2.06	17.74
1910-11	1.80	1.98	.35										
1911-12				.10	.12	1.35	1.71	2.91	1.73	.60	1.50	1.96	
1912-13	2.41	.20	.22	.19	.45	.91	.75	1.94	5.72	2.17	.27	2.54	17.77
1913-14	3.60	.34	.19	.29	.32	.18	1.29	2.15	3.77	1.18	.06	2.74	16.11
1914-15	1.04	.09	.05	.46	.04	.60	1.59	4.03	3.97	2.92	2.07	2.58	19.44
1915-16	.71	1.25	.56	.73	.57	.87	1.76	3.10	3.40	2.16	.72	1.10	16.93
1916-17	2.52	.29	.34	.55	.81	.61	2.45	3.20	2.09	.73	.13	3.08	16.80
1917-18	1.34	.25	.23	.92	.74	.49	2.24	2.30	1.45	1.33	1.25	1.29	13.83
1918-19	1.23	1.06	.36	.21	1.11	.48	1.47	1.98	.12	.09	.64	.71	9.46
1919-20	3.18	.79	.89	.37	1.06	1.70	2.29	3.74	2.58	.67	1.10	1.08	19.45
1920-21	.16	.54	.37	.42	.36	1.31	1.78	4.65	2.11	.93	.58	2.09	15.30
1921-22	.34	1.52	1.84	.64	.51	.66	3.19	3.45	2.02	1.96	2.51	.59	19.23
1922-23	.39	1.64	.80	.31	.38	1.15	1.48	2.60	2.85	1.45	1.21	1.44	15.70
1923-24	1.80	.45	.65	.46	.97	1.97	1.47						
Average	1.48	.80	.62	.53	.56	1.03	1.66	3.67	2.56	1.34	1.17	1.94	17.36

Three Forks, Mont.

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1910					0.45	0.34	1.36	1.67	1.24	0.68	0.53		
1910-11					.23	.02	.48	1.89	2.68	.27		1.34	
1911-12	1.08	0.30											
1912-13				0.21	.48	.50	1.35	1.93	3.37	2.42	.37	.42	
1913-14	1.98	1.26	0.08	.25	.31	.17	1.97	1.97	3.34	1.49	0	2.21	
1914-15	2.24	.02	.12	.28	.02	.97	.57	1.81	4.43	2.53	1.00	2.66	16.65
1915-16	.12	.63	.70	.41	.51	.38	88	.79	2.91	1.02	.80	.94	10.09
1916-17	1.21	Tr.	.59	.65	.42	.31	.97	2.18	1.33	.11	.46	1.90	10.13
1917-18	.17	.19	.45	.43	.10	.61	.37	1.13	1.39	1.22	.85	1.99	8.90
1918-19	.85	.89	.04	.11	.65	.16	.20	.44	.34	0		.44	
1919-20	1.35	.58	1.13			.36		2.70	2.27	1.41	1.00	.63	
1920-21			.06	.14		.13	.57	1.61	2.76	1.48	.93	1.81	
1921-22	.07	.81	1.30	.60	.85	.48	2.62	1.62	2.06	2.00	1.79	.81	15.01
1922-23	.31		.48	.42	.40	Tr.	.54	2.23	3.85	2.27	1.20	.47	
1923-24	.14	0			.62	.80	1.65						
Average	.87	.47	.50	.35	.42	.37	1.04	1.69	2.46	1.30	.81	1.30	11.58

Norris Geyser Basin, Wyo.

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1908				0.95	1.02	0.61	0.14					0.36	
1908-9	2.01	0.85	1.03	2.60	2.67	.48	1.28	0.60	0.73	2.25	0.84	1.92	17.26
1909-10	.69	2.11	.96	3.51	1.63	.50	.77	2.77	.19	2.06	.20	.68	16.07
1910-11	1.18	2.95	1.50	5.70	.60	1.93	2.24	2.92	2.26	.46	.68	.60	23.02
1911-12	1.35	2.79	1.08	1.18	1.35	1.74	1.05	3.23	.75	2.00			
1912-13	2.45		1.88		1.04	3.80	1.10	3.00	2.79	3.44	.25	1.81	
1913-14	2.48	2.48	.88	1.02	1.43	.48		1.50	2.04	1.51	Tr.	1.52	
1914-15			.18	.88	.48	.89	1.00	2.74	2.03	1.47		1.70	
1915-16	.80												
1918-19												2.46	
Average	1.56	2.24	1.07	2.26	1.28	1.30	1.08	2.39	1.54	1.88	.39	1.38	18.37

Riverside, Wyo.

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1908				1.26	1.24	0.59	Tr.		3.35	Tr.	2.92	0.70	
1908-9	0.72	0.55	1.71	3.60	2.26	0.74	1.19	1.57	1.33	1.81	1.12	2.74	19.34
1909-10	.83	4.53	1.09	2.63	2.46	.46	1.15	2.63	.41	.74	.12	.85	17.90
1910-11	.20	1.47	1.26	4.21	1.90			.12	3.95	1.95	1.15	.55	
1911-12	1.11	2.95					2.73	2.14	.92	1.25	1.07	.69	
1912-13	1.00	.68	1.67	2.82	.05	1.18	.40	1.81	2.37	4.02	1.25	.96	18.21
1913-14	1.44	2.90	.40	2.40	.66	.20		.38	2.59	.46	.03	2.55	
1914-15	.83	.52	.50	1.47	.80	.88	1.05		2.63	1.30	1.30	2.30	
1915-16	.70	2.59	2.10										
1918-19												3.19	
1919-20	3.74	1.20	2.27	.78	.76	2.63	1.08		2.12	1.26	1.50	2.23	
1920-21	1.29	.84		1.78	.50		2.71	3.63	.99	.72	1.48	1.32	
1921-22			2.64	1.87						1.44	2.47		
1922-23	.32	1.25		2.81	.64			2.52	2.10		.70	1.03	
1923	1.19	.57	2.09										
Average	1.11	1.67	1.57	2.33	1.13	.95	1.29	1.85	2.07	1.36	1.26	1.59	18.18

Precipitation, in inches, at stations in Madison River basin—Continued

Upper Geyser Basin, Wyo.

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1908	------	------	------	2.15	1.10	2.01	0.80	2.83	2.85	0.39	2.02	0.56	------
1908–9	4.46	0.44	------	------	1.80	.30	.55	.65	------	1.10	1.10	2.50	------
1909–10	.70	.59	0.50	2.81	1.80	.45	------	2.05	------	.94	.19	1.10	------
1910–11	.93	2.75	1.60	5.70	.84	1.02	.95	2.35	1.96	Tr.	Tr.	1.55	19.65
1911–12	.90	2.19	1.87	1.30	2.00	4.04	1.18	2.90	1.40	1.00	7.30	------	------
1912–13	1.90	------	1.40	3.65	1.44	1.30	.12	------	2.90	4.92	.85	1.43	------
1913–14	1.43	2.59	.40	------	.54	------	------	------	1.30	.08	.02	2.01	------
1914–15	.49	1.05	.62	3.30	1.21	1.20	1.30	3.18	2.01	2.01	2.37	2.88	21.62
1915–16	2.03	3.70	1.98	------	------	------	------	------	------	------	------	------	------
Average	1.60	1.90	1.20	3.15	1.34	1.52	.82	2.33	2.07	1.30	1.73	1.72	20.60

Frost data at stations in Madison River basin

Norris, Wyo.

[1910–1914, 1916, frost every month.]

Year	Last killing frost in spring	First killing frost in fall	Interval (days)
1915	July 4	Aug. 5	32

Upper Geyser Basin, Wyo.

[1909–1914, 1916, frost every month.]

1915	July 19	Sept. 10	53

Riverside, Wyo.

[1909–1917, rost every month.]

Ennis, Mont.

1918	June 1	Sept. 4	95
1919	June 2	Sept. 22	112
1920	June 4	Aug. 29	86
1921	May 28	Sept. 10	105
1922	June 1	Sept. 8	99

Grayling, Mont.

1909	June 25	July 7	12
1910	July 13	July 24	11
1911	July 13	Aug. 3	21
1912	July 10	Aug. 20	41

Hebgen dam, Mont.

1913	July 14	Sept. 10	58
1914	June 22	Sept. 1	71
1915	June 27	Sept. 9	74
1916	June 11	Sept. 14	95
1917	June 14	Sept. 1	79
1918	June 30	Sept. 16	78
1919	June 2	Sept. 22	112
1920	June 24	Aug. 29	66
1921	July 3	Sept. 5	64
1922	June 11	Sept. 8	89

Frost data at stations in Madison River basin—Continued

Norris, Mont.

Year	Last killing frost in spring	First killing frost in fall	Interval (days)
1909	June 11	Sept. 23	104
1910	May 2	Aug. 24	114
1911	May 11	Sept. 17	129
1912	May 7	Sept. 21	137
1913	May 19	Sept. 24	128
1914	May 12	Oct. 5	146
1915	Apr. 9	Oct. 6	180
1916	May 11	Sept. 28	140
1917	May 31	Oct. 17	139
1918	May 29	Sept. 27	121
1919	May 6	Oct. 8	155
1920	June 1	Oct. 21	142
1921	May 14	Sept. 10	119
1922	May 12	Oct. 14	155
1923	May 15	Oct. 12	150

Three Forks, Mont.

Year	Last killing frost in spring	First killing frost in fall	Interval (days)
1910	June 3	Aug. 25	83
1911	May 31	Sept. 19	111
1913	May 17	Sept. 20	126
1914 [a]	May 5	Oct. 7	155
1915 [a]	May 6	Sept. 20	137
1916 [a]	June ?	Sept. 14	?
1917 [a]	June 5	Oct. 17	134
1918 [a]	May 22	Sept. 16	117
1918	May 29	Sept. 4	98
1919 [a]	June 2	Sept. 22	112
1920 [a]	July 8	Aug. 19	42
1921 [a]	May 14	Oct. 7	146
1922 [a]	May 31	Sept. 29	121

[a] Record obtained near Three Forks.

Mean monthly temperature, in degrees Fahrenheit, at stations in Madison River basin

Norris Geyser Basin, Wyo.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1904	------	------	------	33.4	41.2	------	------	------	48.6	------	------	------	------
1905	------	15.1	------	------	------	------	56.8	57.2	49.0	35.4	25.4	8.4	------
1906	11.6	14.8	13.8	33.6	42.4	46.1	55.8	54.0	46.6	38.4	22 6	25.4	33.8
1907	14.5	24.4	26.4	32.5	39.4	48.0	57.2	54.6	45.6	40.8	25.6	16.8	35.5
1908	13.0	21.4	22.1	34.8	40.2	43.3	54.2	50.0	44.2	32.9	24.0	------	------
1909	18.8	------	22.0	24.0	33.8	------	54.4	55.2	44.4	36.0	28.2	7.6	------
1910	7.2	10.2	30.8	37.7	42.0	49.7	54.8	50.4	46.4	37.6	25.4	15.4	------
1911	13.2	10.0	23.0	28.2	39.8	49.0	51 8	49.5	43.8	30.5	16.6	------	------
1912	14.7	13.6	15.2	29.2	37.2	------	50.8	------	------	38.6	------	------	------
1913	------	------	15.3	30.8	40.1	49.0	51.6	53.2	------	30.0	25.6	11.4	------
1914	17.6	15.0	22.8	33.5	43.4	47.8	55.4	51.7	42.5	39.9	30.6	10.9	34.3
1915	12.0	19.6	25.3	40.0	40.5	44.4	50.0	50.6	42.5	32.1	------	------	------
1916	------	------	------	33.9	39.4	53.5	50.7	49.8	41.0	------	------	------	------
1917	------	------	------	------	------	------	------	------	------	33.2	29.6	------	------
1919	------	------	------	------	------	------	------	------	44.0	------	------	------	------
Mean	13.6	16.0	21.7	32.6	40.0	47.9	53.6	52.4	44.9	35.5	25.4	13.7	33.1

Riverside, Wyo.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1905	------	------	------	------	------	------	55.9	57.5	50.2	31.8	26.2	13.2	------
1906	17.6	21.1	20.6	34.2	43.2	45.9	55.9	55.2	47.6	38.2	23.8	24.9	35.7
1907	13.1	24.6	27.0	33.0	39 4	46.3	56.6	------	47.0	42.6	25.1	16.0	------
1908	12.6	19.9	23.7	35.2	41.2	46.8	57.8	52.1	44.8	34.5	23.6	14.6	33.9
1909	20.8	19.0	25.8	28.7	38.6	51.2	56.8	58.2	47.7	35.8	28.0	8.5	34.9
1910	10.4	12.2	------	------	43.5	52.0	59.9	53.7	49.4	40.8	29.9	17.4	------
1911	------	11.6	24.8	------	42.2	53.0	52.7	52.0	49.2	36.2	18.9	------	------
1912	------	------	------	33.0	41.1	53.6	54.8	53.6	41.6	32.2	20.6	11.2	------
1913	------	------	------	------	------	46.6	------	51.4	49.0	33.0	25.7	12.4	------
1914	19.9	17.8	25.8	37.4	47.2	49.4	68.4	54.5	46.8	40.5	28.6	9.9	37.2

Mean monthly temperature, in degrees Fahrenheit, at stations in Madison River basin—Continued

Riverside, Wyo.—Continued

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1915	13.4	24.1	28.2	41.5	41.4	46.3	52.6	56.4	45.0	40.8	21.2	14.2	35.4
1916	8.1	19.8	28.0	33.6	37.0	46.4	57.2	53.9	45.0	33.8	17.2	11.9	32.7
1917	7.2	16.3	12.4	------	38.8	------	58.4	53.8	49.0	34.6	29.2	------	------
1918	------	------	30.3	33.4	45.4	------	------	------	------	------	------	------	------
1919	------	------	------	------	------	------	------	------	48.0	27.6	18.4	9.6	------
1920	14.8	15.2	19.6	25.8	38.4	47.3	55.9	53.8	44.6	34.3	24.0	16.1	32.5
1921	15.4	17.6	26.2	28.2	41.8	51.6	55.2	53.1	41.4	------	------	20.8	------
1922	------	------	------	30.0	43.0	------	57.0	57.1	------	------	18.2	------	------
1923	------	------	------	------	41.5	46.4	55.2	48.8	46.2	32.6	24.8	9.0	------
Mean	13.9	18.3	24.4	32.8	41.5	48.8	56.9	54.1	46.6	35.6	23.7	13.9	34.2

Upper Geyser Basin, Wyo.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1904	------	------	------	------	41.6	48.0	54.6	55.2	48.2	40.4	30.7	18.4	------
1905	19.0	21.2	32.0	34.6	39.2	49.8	57.9	62.1	50.0	30.2	26.5	12.2	36.2
1906	17.4	20.6	19.8	33.8	41.2	45.6	55.5	54.6	52.4	41.9	23.3	------	------
1907	12.1	22.3	25.4	31.4	38.6	44.4	56.0	55.1	48.6	43.6	28.2	77.8	35.3
1908	16.6	20.4	22.2	36.3	40.6	46.2	58.2	53.8	47.3	34.0	26.6	------	------
1909	------	------	21.8	------	34.2	47.2	------	------	44.3	35.4	28.2	8.7	------
1910	------	13.4	------	38.6	43.2	53.2	59.2	53.5	49.5	42.0	26.0	15.4	------
1911	11.2	3.6	21.6	25.8	40.8	51.4	54.5	50.9	48.0	35.3	19.8	------	------
1912	19.5	11.1	21.4	29.9	40.3	52.5	50.6	51.8	38.2	34.2	------	13.0	------
1913	9.4	------	19.4	30.7	43.2	55.4	------	------	47.2	35.4	25.9	18.0	------
1914	16.2	18.1	26.3	35.8	45.3	48.7	------	54.3	46.2	39.0	34.2	11.4	------
1915	15.4	22.4	29.2	41.9	39.8	44.2	51.0	56.2	45.8	38.5	23.8	14.2	35.2
1916	9.6	21.7	28.2	34.6	36.7	46.2	57.2	54.2	46.8	------	------	------	------
Mean	14.6	17.5	24.3	33.9	40.4	48.7	55.5	54.7	47.1	37.5	26.6	14.3	34.6

Ennis, Mont.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1918	22.1	23.6	37.8	38.2	47.1	64.4	64.4	60.8	55.4	49.2	32.1	27.2	43.5
1919	29.2	23.4	33.8	45.6	52.3	63.8	69.9	66.1	55.4	35.3	29.3	19.5	44.5
1920	27.4	26.6	28.3	36.9	48.2	56.4	66.2	63.2	55.7	43.2	30.8	27.8	42.6
1921	26.8	30.6	36.1	40.6	49.4	62.2	65.6	65.1	51.2	49.4	33.4	23.8	44.5
1922	16.4	17.7	30.4	38.8	49.5	62.2	64.0	66.7	59.4	49.3	30.4	20.6	42.1
1923	26.6	21.0	29.2	40.0	51.0	56.8	67.6	61.8	57.2	39.5	35.9	22.0	42.4
Mean	24.8	23.8	32.6	40.0	49.6	61.0	66.3	64.0	55.7	44.3	32.0	23.5	43.1

Grayling, Mont.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1904	------	------	------	------	------	47.9	53.4	53.6	46.0	39.2	28.4	14.6	------
1905	------	8.5	27.8	33.8	42.0	47.5	53.8	55.0	46.4	31.0	24.0	6.6	------
1906	12.9	16.6	------	33.4	43.2	45.7	54.6	53.0	46.0	35.0	21.4	22.4	------
1907	------	19.4	26.5	32.4	41.2	46.1	53.4	50.4	------	41.2	24.4	13.4	------
1908	------	------	------	------	------	46.0	55.5	51.2	46.0	34.2	23.6	------	------
1909	------	14.8	23.4	27.3	39.2	50.8	54.3	55.3	47.1	36.7	25.4	5.0	------
1910	8.6	9.4	30.6	38.4	------	50.9	57.8	51.0	47.4	------	26.2	13.8	------
1911	14.5	7 9	23.4	30.6	42.2	51.4	52.5	51.2	43.6	32.4	15.8	14.6	------
1912	14.3	14.0	------	31.8	39.8	51.1	52.0	50.2	37.8	33.0	25.0	14.7	------
Mean	12.6	12.9	26.3	32.5	41.3	48.6	54.1	52.3	45.0	35.3	23.8	13.1	33.2

Hebgen dam, Mont.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1913	------	------	21.0	36.8	46.0	53.8	56.4	59.6	------	27.8	24.1	12.4	------
1914	18.9	16.0	27.2	37.8	48.8	52.1	61.3	60.7	48.4	40.6	30.6	7.6	37.5
1915	13.0	23.3	29.4	44.4	44.4	50.3	57.4	61.6	47.4	42.4	26.2	15.6	38.0
1916	4.7	18.8	30.2	37.8	41.0	50.6	63.3	60.8	51.5	36.5	20.0	8.6	35.3
1917	7.3	16.5	14.8	30.6	41.7	51.4	65.4	60.6	54.8	40.2	34.2	------	------
1918	12.6	14.7	28.4	32.7	43.4	58.6	59.6	56.8	52.6	42.8	26.4	15.2	37.0
1919	12.7	16.5	27.2	39.0	48.5	59.4	------	63.0	54.2	32.4	19.8	------	------
1920	15.6	12.4	22.6	30.4	42.6	53.6	62.3	59.4	49.4	37.6	24.8	------	------
1921	15.6	19.1	------	32.6	44.4	57.2	61.6	59.6	46.0	43.6	31.2	17.6	------
1922	6.0	11.4	27.3	29.5	43.3	56.5	59.5	61.6	54.0	43.4	23.7	15.8	36.0
1923	16.6	8.4	14.6	33.0	44.6	51.5	62.8	58.1	54.3	36.6	29.6	12.0	35.2
Mean	12.3	15.7	24.3	35.0	44.4	54.1	61.0	60.2	51.3	38.5	26.4	13.1	36.4

Mean monthly temperature, in degrees Fahrenheit, at stations in Madison River basin—Continued

Norris, Mont.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1908	30.8	30.8	35.4	49.8	49.8	56.0	70.7	65.8	59.8	44.4	37.2	27.4	46.5
1909	21.8	28.9	35.6	39.8	48.8	61.4	67.6	68.5	57.5	47.8	35.0	17.3	44.2
1910	21.2	22.5	44.9	50.4	55.1	------	71.2	66.6	------	52.3	------	30.9	------
1911	27.8	25.0	41.2	42.6	50.3	61.2	65.1	62.4	------	43.3	30.7	24.9	------
1912	26.8	30.6	22.6	43.1	51.6	61.9	64.8	64.5	50.7	43.2	40.9	27.5	------
1913	25.2	18.8	29.8	46.4	52.6	60.7	66.4	68.7	57.6	42.9	39.4	27.0	------
1914	33.3	28.4	39.2	44.7	54.2	58.6	69.7	67.8	58.0	48.8	43.6	23.4	47.5
1915	28.0	35.5	37.8	51.0	49.3	55.7	61.2	68.1	53.6	51.8	36.0	29.6	46.5
1916	10.4	30.5	40.3	45.4	46.9	57.4	69.2	66.4	57.6	40.9	32.2	21.2	43.2
1917	20.9	26.2	26.9	38.8	49.0	59.0	71.6	67.4	60.6	48.3	43.0	34.1	45.5
1918	24.6	26.5	41.0	40.2	49.1	66.6	66.4	64.6	54.2	49.4	33.3	28.6	45.4
1919	31.2	26.6	35.6	44.6	54.2	65.8	72.4	69.9	59.2	39.4	30.2	21.6	45.9
1920	28.9	26.6	28.8	34.7	47.8	55.4	66.7	65.8	54.8	43.8	31.2	28.0	42.7
1921	28.5	31.4	34.3	39.5	44.6	57.8	65.4	68.0	52.8	52.1	37.2	26.5	44.8
1922	19.1	20.2	35.2	41.2	51.7	65.6	68.1	70.8	63.8	51.6	32.8	21.0	45.1
1923	29.4	21.6	32.0	42.7	52.4	58.8	69.4	64.2	58.6	41.0	37.0	23.7	44.2
Mean	25.5	26.9	35.0	43.4	50.5	60.1	67.9	66.8	57.1	46.3	36.0	25.8	45.1

Three Forks (near), Mont.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1910	------	------	46.6	50.0	54.2	63.2	68.0	61.4	------	------	------	------	------
1911	------	23.1	41.6	44.0	52.6	64.8	65.7	------	------	------	------	------	------
1912	23.5	28.8	------	------	------	------	------	------	------	------	------	------	------
1913	23.0	16.8	28.8	45.4	53.8	61.9	64.5	67.0	55.9	41.2	36.0	20.2	------
1914	31.5	28.0	37.6	43.8	52.2	56.0	66.0	62.6	54.0	43.4	37.6	16.9	44.1
1915	21.4	31.1	34.6	49.4	48.4	52.8	58.4	65.0	49.7	47.2	31.1	24.0	43.8
1916	−3.0	23.2	37.2	42.6	44.0	54.2	65.6	62.2	52.0	37.8	26.2	12.8	37.9
1917	15.0	17.0	19.6	37.6	47.3	55.0	69.5	64.4	58.7	44.3	37.2	24.7	40.9
1918	19.4	20.7	37.2	39.1	47.4	65.0	63.6	62.2	54.2	47.4	26.6	25.8	42.4
1919	28.8	19.4	30.8	44.7	52.6	64.4	69.3	67.2	55.4	33.4	25.4	12.4	42.0
1920	27.5	31.8	31.9	40.0	54.0	59.6	66.6	64.5	55.2	40.3	25.1	27.2	43.6
1921	27.6	32.4	38.1	40.8	50.7	61.3	67.0	65.8	51.0	50.8	33.0	21.8	45.0
1922	19.2	16.2	32.6	42.6	52.3	60.8	62.9	67.3	59.4	48.0	------	20.0	------
1923	30.0	17.0	34.4	42.4	52.9	59.7	70.0	67.0	56.8	43.2	37.0	------	------
Mean	22.0	23.5	34.7	43.3	51.0	59.9	65.9	64.7	54.8	43.4	31.5	20.6	42.9

SOILS AND DRAINAGE

The character of the soil is one of the limiting factors to water utilization in the Madison River basin. Large areas of land that is otherwise valuable for agriculture and susceptible of irrigation are nonarable because of poor soil or almost total absence of soil, and the same condition is a source of difficulty in the operation of canals. Drainage problems arise where arable land in the flood plain is overflowed as a result of slush-ice gorges during winter. The scope of this paper does not contemplate a detailed analysis of either soils or drainage conditions, and the discussion of these factors will be limited to a general sketch based on reconnaissance observations in the middle and lower valleys.

The flood plain of the middle and lower valleys has a surficial cover which ranges from cobblestones to fine alluvium, but the alluvium is confined chiefly to the lower end of the middle valley and the greater part of the lower valley. The terraces of the middle valley have in general a surficial cover of coarse gravelly soil, which in places rests upon a poorly cemented aggregate of sand, gravel, and boulders.

Streams tributary to Madison River that flow across these terraces have built up alluvial fans which extend out from the base of the mountains and foothills on either side of the valley. The soil of these alluvial fans is in part similar to the river-bottom alluvium, being friable and having considerable fertility. The cobblestone and gravelly areas have practically no agricultural value except for grazing.

Canals constructed through the terrace gravel are subject to a high rate of seepage loss, as disclosed by two measurements made July 30, 1923, by Fred C. Scobey and F. M. Ingerson, of the Department of Agriculture, in cooperation with the authors of the present paper. These measurements were made at points in the Valley Garden ditch, which was constructed prior to 1890 to convey water from a point near the Blaine Springs power plant, in T. 7 S., R. 1 W., to land northwest of Ennis. In the section measured the ditch is excavated in terrace gravel and cemented gravel and boulders. The measurements were made almost simultaneously in wooden box flumes approximately 2.3 miles apart, and the computed discharge at the upper point was 12.5 second-feet and at the lower point 11.4 second-feet. The difference, 1.1 second-feet, represents a reduction in flow of 8.8 per cent, which is due entirely to seepage losses. At a point on the east side of the valley below the mouth of Indian Creek, in T. 8 S., R. 1 W., an attempt was made at one time to divert water from Madison River through a canal to terrace land on the east side. The canal was constructed for several miles through characteristic terrace gravel but has been abandoned, apparently because of the perviousness of this material.

In the flood-plain areas of the middle and lower valleys the water table is maintained at shallow depths to a considerable extent, if not entirely, by flooding from slush-ice gorges during winter. The result is beneficial to farming in places, but in most of the area the water table lies so near the surface as to render the land moist and incapable of producing remunerative crops, and therefore the land is used only for grazing. The subsurface material of the moist areas is coarse gravel, cobblestones, and boulders, through which water percolates easily; hence the land apparently could be efficiently drained by open canals excavated to this material. Some drainage has already been accomplished with satisfactory results, but a large part of the land is not reclaimed, and it is believed that diking and drainage of such land is a meritorious project which should receive more careful study.

WATER SUPPLY

Stream-flow records in Madison River basin obtained by the Geological Survey are summarized on pages 17–22. The run-off from about half of the headwater area is shown by the record for the gaging station at Riverside station, near Yellowstone. An interesting feature disclosed by this record is the comparatively uniform flow of the river throughout the year. Apparently, this uniformity is due to the fact that the drainage area above the gaging station contains a large number of geysers and hot springs that have a fairly constant flow throughout the year and that eliminate ice interference except during periods of extraordinary cold weather, by maintaining a water temperature above freezing. Discharge records obtained at Hebgen by the Montana Reservoir & Irrigation Co. are available for the period October, 1909, to September, 1923. The annual run-off as determined from these records is about twice that shown by the Riverside record of the Geological Survey for the years that simultaneous records are available. The records also indicate that the ratio between the discharges at the two stations varies widely during the year, but in the absence of other data equally satisfactory the flow at Hebgen has been taken as double that at Riverside. The discharge 90 per cent of the time at Riverside is 413 second-feet or more, and the discharge 50 per cent of the time is 510 second-feet or more. The corresponding discharges at Hebgen are therefore about 825 second-feet and 1,020 second-feet. These figures are approximate only but are used in preference to the record obtained by the Montana Reservoir & Irrigation Co. because information is lacking that would show to what extent that record was affected by the operation of the Hebgen reservoir.

The records for the Red Bluff and Norris gaging stations show the run-off from practically the same drainage area, the only difference being that the flow of the small stream called Cherry Creek is not included in the earlier records for the station near Red Bluff. The drainage area of Cherry Creek is 90 square miles, or less than 4 per cent of the total area above the two stations, and the run-off per square mile from the creek basin is small in comparison to that from the larger area. Estimates of water supply can therefore be made from these records on the assumption that they were obtained at the same point, as the error of less than 4 per cent involved in such an assumption can be disregarded. Most of the records for these stations were obtained prior to the storage development, which would affect any records now obtained at the same stations. They indicate a discharge of 1,200 second-feet or more 90 per cent of the time during the periods 1890 to 1893 and 1897 to 1906. The discharge 50 per cent of the time is 1,430 second-feet or more for the first period and 1,570 second-feet or more for the second period; the mean is 1,500 second-feet.

The Geological Survey records are as follows:

Monthly discharge of Madison River near Yellowstone, Mont., for the years ending September 30, 1913–1922

[Location, Riverside station, about 4 miles east of Yellowstone, Mont.]

Month	Discharge in second-feet			Run-off in acre-feet
	Maximum	Minimum	Mean	
1913				
June 16–30	1,180	974	1,050	31,200
July	1,570	681	917	56,400
August	1,020	681	759	46,700
September	775	635	704	41,900
The year	1,570	635	831	176,000
1913–14				
October	823	635	711	43,700
November	775	635	699	41,600
December	635	546	586	36,000
January	676	522	582	35,800
February	625	522	572	31,800
March	574	471	531	32,600
April	882	522	656	39,000
May	1,400	625	1,030	63,300
June	1,240	676	895	53,300
July	676	574	605	37,200
August	625	522	537	33,000
September	882	522	579	34,500
The year	1,400	471	667	482,000
1914–15				
October	882	574	637	39,200
November	574	471	517	30,800
December	522	471	510	31,400
January	522	471	474	29,100
February	522	471	482	26,800
March	522	471	484	29,800
April	831	522	670	39,900
May	882	522	678	41,700
June	1,040	471	636	37,800
July	574	370	447	27,500
August	574	420	451	27,700
September	522	420	452	26,900
The year	1,040	370	537	389,000
1915–16				
October	522	420	447	27,500
November	471	420	441	26,200
December	471	420	456	28,000
January	522	420	455	28,000
February	471	420	431	24,800
March	574	420	489	30,100
April	728	471	579	34,500
May	1,110	676	873	53,700
June	1,770	994	1,290	76,800
July	1,210	558	736	45,300
August	666	518	556	34,200
September	574	471	526	31,300
The year	1,770	420	606	440,000
1916–17				
October	728	522	562	34,600
November	574	471	510	30,300
December	522	471	520	32,000
January	574	420	499	30,700
February	625	471	524	29,100
March	625	522	539	33,100
April	707	451	548	32,600
May	1,410	440	885	54,400
June	1,950	780	1,310	78,000
July	1,300	640	863	53,100
August	642	49[illegible]	542	33,300
September	579	49[illegible]	513	30,500
The year	1,950	420	652	472,000

Monthly discharge of Madison River near Yellowstone, Mont., for the years ending September 30, 1913–1922—Continued

Month	Discharge in second-feet			Run-off in acre-feet
	Maximum	Minimum	Mean	
1917–18				
October	543	462	496	30,500
November	491	440	477	28,400
December 1–8	491	491	491	7,790
July	682	497	572	35,200
August	497	486	496	30,500
September	682	462	488	29,000
1918–19				
October	816	492	570	35,000
November	545	400	483	28,700
December	503	392	445	27,400
January	458	376	386	23,700
February	416	376	391	21,700
March	530	416	444	27,300
April	750	416	541	32,200
May	972	570	764	47,000
June	684	370	472	28,100
July	420	316	366	22,500
August	450	370	388	23,900
September	450	370	393	23,400
The year	972	316	471	341,000
1919–20				
October	524	360	432	26,600
November	503	376	419	24,900
December	532	----------	396	24,300
January	408	353	380	23,400
February	392	353	388	22,300
March	432	353	401	24,700
April	458	376	410	24,400
May	1,220	432	779	47,900
June	1,440	662	1,050	62,500
July	723	491	548	33,700
August	546	400	450	27,700
September	513	400	437	26,000
The year	1,440	353	507	368,000
1920–21				
October	491	410	441	27,100
November	570	392	442	26,300
December	476	----------	442	27,200
January	476	----------	438	26,900
February	458	392	413	22,900
March	476	392	429	26,400
April	589	392	469	27,900
May	1,350	506	994	61,100
June	1,370	590	993	59,100
July	686	480	541	33,300
August	535	440	479	29,500
September	579	450	485	28,900
The year	1,370	392	548	397,000
1921–22				
October 1–8	460	450	451	7,160
June	1,160	590	869	51,700
July	638	430	529	32,500
August	568	410	453	27,900
September	430	335	379	22,600

Monthly discharge of Madison River near Red Bluff, Mont., for the years ending September 30, 1890–1893, 1897–1903

[Location, 1890–1893, 1½ miles below Hot Springs Creek, 4 miles from Red Bluff, at Hayward Bridge; moved in May, 1897, to point below Cherry Creek, at Black's ranch.]

Month	Discharge in second-feet			Run-off in acre-feet
	Maximum	Minimum	Mean	
1890				
January			[a] 1,200	73,800
February			[a] 1,200	66,600
March			[a] 1,200	73,800
April 4–30	2,580	1,370	1,620	96,400
May	6,420	3,060	4,820	297,000
June	6,360	3,780	4,980	296,000
July	3,660	1,720	2,520	155,000
August	1,640	1,380	1,540	94,500
September	1,580	1,420	1,470	86,300
1890–91				
October	1,520	1,420	1,500	92,300
November	1,470	1,280	1,380	82,200
December	1,520	1,280	1,400	86,200
January	1,580	1,240	1,410	86,500
February	1,580	1,260	1,440	79,700
March	1,790	1,470	1,630	100,000
April	1,960	1,640	1,770	106,000
May	4,260	1,790	3,390	208,000
June	4,620	3,780	4,170	248,000
July	3,660	1,160	2,040	126,000
August	1,640	1,200	1,430	87,900
September	1,380	1,240	1,310	77,900
The year	3,660	1,160	1,910	1,380,000
1891–92				
October	1,470	1,240	1,350	83,100
November	1,470	1,280	1,400	83,300
December	1,240	1,070	1,140	69,900
January	1,380	1,240	1,300	80,300
February	1,640	1,330	1,500	86,500
March	1,640	1,330	1,490	91,500
April	1,420	1,240	1,300	77,100
May	2,580	1,330	1,450	89,400
June	5,940	2,820	4,900	292,000
July	5,340	1,790	3,220	198,000
August	1,880	1,280	1,520	93,400
September	1,420	1,330	1,360	80,900
The year	5,940	1,070	1,850	1,330,000
1892–93				
October	1,420	1,280	1,330	81,600
November	1,420	1,330	1,420	84,700
December	1,420	1,240	1,320	81,400
January	1,380	1,160	1,230	75,600
February	1,960	1,030	1,290	71,400
March	1,200	1,030	1,080	66,500
April	1,240	910	1,020	60,600
May	1,520	1,070	1,330	81,500
June	3,180	1,580	2,420	144,000
The period	3,180	910	1,380	747,000
1897				
January			[a] 1,600	98,400
February			[a] 1,600	88,900
March			[a] 1,600	98,400
April			[a] 1,900	113,000
May 2–17, 27–31	8,610	3,300	4,930	205,000
June	8,610	2,700	4,430	264,000
July	3,000	2,000	2,550	157,000
August	2,000	1,600	1,680	103,000
September	1,600	1,520	1,540	91,900

[a] Estimated.

Monthly discharge of Madison River near Red Bluff, Mont., for the years ending September 30, 1890–1893, 1897–1903—Continued

Month	Discharge in second-feet			Run-off in acre-feet
	Maximum	Minimum	Mean	
1897–98				
October	1,800	1,450	1,630	100,000
November			[a] 1,700	101,000
December			[a] 1,700	105,000
May 7–31	6,380	2,960	4,830	297,000
June	8,000	3,450	6,000	357,000
July	4,420	2,800	3,620	223,000
August	3,120	2,150	2,680	165,000
September	2,800	2,150	2,260	134,000
1898–99				
October	2,310	2,150	2,160	133,000
November 1–14			2,150	128,000
April 16–30	2,960	2,640	2,840	169,000
May	6,050	1,180	3,050	188,000
June	10,300	6,050	8,380	499,000
July	8,650	2,800	5,160	317,000
August	3,610	2,150	2,730	168,000
September	2,150	2,150	2,150	128,000
1899–1900				
October	1,820	1,820	1,820	112,000
November [a]			1,820	109,000
March [a]			860	52,900
April	2,530	860	1,760	105,000
May	5,660	3,000	4,260	262,000
June	5,380	2,080	3,600	214,000
July	2,080	1,640	1,860	114,000
August	1,850	1,640	1,670	102,000
September	1,850	1,640	1,690	101,000
1900–1901				
October	1,850	1,850	1,850	114,000
November	1,850	1,640	1,660	98,800
December	1,640	1,640	1,640	101,000
April	2,280	1,900	1,960	117,000
May	8,320	2,820	5,080	313,000
June	5,400	2,400	3,360	200,000
July	2,400	1,650	2,010	124,000
August	1,900	1,480	1,560	96,000
September	1,480	1,480	1,480	87,800
1901–2				
October	1,480	1,480	1,480	90,700
November	1,650	1,480	1,520	90,200
December			1,480	90,700
March 23–31			[a] 910	16,200
April	2,080	910	1,440	85,400
May	6,140	1,570	3,000	185,000
June	6,440	2,880	4,340	258,000
July	3,450	1,570	2,440	150,000
August	1,570	1,180	1,360	83,700
September	1,360	1,360	2,360	80,900
1902				
October	1,360	1,360	1,360	83,600
November 1–8			1,360	21,600

[a] Estimated.

Monthly discharge of Madison River near Norris, Mont., for the years ending September 30, 1903–1906, 1910, and 1911

[Location, 3 miles below Red Bluff station, including Cherry Creek]

Month	Discharge in second-feet			Run-off in acre-feet
	Maximum	Minimum	Mean	
1903				
January			[a] 1,300	79,900
February			[a] 1,300	72,200
March			[a] 1,300	79,900
April	1,700	1,440	1,620	96,500
May	3,360	1,700	2,280	140,000
June	6,140	3,510	5,060	301,000
July	3,510	1,700	2,140	132,000
August	1,440	1,050	1,260	77,400
September	1,220	1,050	1,100	65,200
The period	6,140	1,050	2,450	1,040,000
1903–4				
October	1,220	1,050	1,210	74,300
November	1,220	1,220	1,220	72,600
December			[a] 1,200	73,800
January			[a] 1,200	73,800
February			[b] 1,200	69,000
March	1,760	1,100	1,290	79,200
April	2,010	1,100	1,430	85,300
May	6,740	2,010	3,740	230,000
June	6,740	3,860	5,610	334,000
July	3,860	1,760	2,670	164,000
August	1,760	1,410	1,530	94,200
September	1,520	1,300	1,360	80,600
The year			1,980	1,430,000
1904–5				
October	1,410	1,300	1,350	82,800
November	1,300	1,300	1,300	77,400
December			[a] 1,200	73,800
March 12–31	1,540	1,320	1,460	58,000
April	1,540	1,540	1,540	91,600
May	2,120	900	1,570	96,500
June	3,970	2,000	3,200	190,000
July	3,000	800	1,840	113,000
August	1,320	1,100	1,180	72,400
September	1,210	1,100	1,170	69,700
1906				
October	1,100	1,100	1,100	67,600
November 1–25	1,100	1,100	1,100	54,500
The period	1,100	1,100	1,100	122,000
1910				
August 12–31	1,750	850	1,310	52,000
September	1,750	1,050	1,360	80,900
The period	1,750	850	1,340	133,000
October	2,020	1,270	1,560	95,900
November 1–20	2,300	1,050	1,430	56,700
The period	2,300	1,050	1,500	153,000

[a] Estimated. [b] Mean for 26 days taken as mean for month.

Monthly discharge of Madison River near Three Forks, Mont., for the year 1895

[Location, at bridge of Northern Pacific Railway about half a mile east of railway station at Three Forks]

Month	Discharge in second-feet			Run-off in acre-feet
	Maximum	Minimum	Mean	
January			[a] 1,500	92,200
February			[a] 1,500	86,300
March			[a] 1,600	98,400
April	1,980	1,690	1,820	108,000
May	3,680	1,830	2,220	137,000
June	8,180	4,420	6,360	379,000
July	4,720	1,690	2,720	167,000
August	1,820	1,380	1,510	93,000
September	1,520	1,430	1,470	87,400
October	1,480	1,380	1,430	88,100
November			[a] 1,400	83,300
December			[a] 1,400	86,100

[a] Estimated.

Monthly discharge of Gibbon River near Yellowstone, Mont., for the years ending September 30, 1913–1916

[Location, at the Wylie Gibbon lunch station in Yellowstone National Park, about 2 miles below Gibbon Falls]

Month	Discharge in second-feet			Run-off in acre-feet
	Maximum	Minimum	Mean	
1913				
June 22–30	280	253	272	4,860
July	454	152	216	13,300
August	227	120	155	9,530
September			123	7,320
The period	454	120	177	35,000
1913–14				
October	148	101	128	7,870
November	132	101	115	6,840
December	112	87	95.3	5,860
January	92	90	91.8	5,640
February	91	84	86	4,780
March	113	87	91.8	5,640
April	219	116	159	9,460
June 15–30	250	162	188	5,970
July	162	101	135	8,300
August	148	66	86.2	5,300
September	175	84	111	6,600
1914–15				
October	175	101	125	7,690
November	107	84	88.2	5,250
December	123	71	86.1	5,290
January	108	71	81.5	5,010
February	80	68	73.4	4,080
March	92	62	68.5	4,210
April	175	92	146	8,690
May	204	92	143	8,790
June	234	92	138	8,210
July	101	71	88.7	5,450
August	112	71	83.2	5,120
September	92	77	86.2	5,130
The year	234	62	101	72,900
1915–16				
October	92	72	83.6	5,140
November	84	72	78.6	4,680
December	92	78	82.7	5,080
January	118	78	95.2	5,850
February	109	84	94.6	5,440
March	162	92	113	6,950
April	175	100	130	7,740
July	188	139	155	7,070
August	162	109	132	8,120
September	118	100	104	6,190

STORAGE

Storage in the Madison River basin is provided in the Hebgen and Madison reservoirs. The Hebgen reservoir was completed in 1915 by erecting a dam in unsurveyed T. 11 S., R. 3 E. Montana meridian, near the upper end of the upper canyon of the river. The area within the flow of the reservoir at high water is 13,400 acres, and the maximum storage capacity is 346,000 acre-feet. The dam is an earth-fill structure with a concrete core 87.5 feet in height above the original channel. The foundation of the core wall is on solid rock at a maximum depth of 35 feet below the original channel surface. The crest of the dam is 718 feet in length, and the structure contains 298,900 cubic yards of material. The altitude of the spillway is 6,491.5 feet, of the channel 6,418.5 feet, and of the crest of the dam 6,506 feet. The stored water is released through a 12-foot outlet pipe at a point 19 feet above the lowest point in the reservoir. The Madison reservoir is near the head of the lower canyon, in T. 4 S., R. 1 E., and was completed in 1905. This reservoir has a high-water flowage area of 4,000 acres and a capacity of 40,000 acre-feet; at the altitude of the spillway the area is 2,920 acres and the capacity 5,400 acre-feet. The dam is a rock-filled crib overflow structure 47 feet in height above its foundation and 31 feet above the original channel surface. The foundation of the dam rests on unconsolidated rock débris, which occupies the bottom of the canyon. These reservoirs are owned by the Montana Reservoir & Irrigation Co., a subsidiary of the Montana Power Co., and the data given here were obtained from the holding company.

The seepage loss from the Hebgen reservoir is insufficient to alter materially the regulation of Madison River obtainable from the reservoir, but evaporation reduces its effective storage capacity. No data on evaporation from the reservoir are available, and the only near-by points from which such data have been obtained are Bozeman, Mont., and Mud Lake, Idaho. The average evaporation at Bozeman for the seven months April to October during 1900 to 1912 was 24.08 inches. At Mud Lake, Idaho, where the meteorologic conditions that control evaporation are comparable to those at Bozeman, a mean annual loss of about 36 inches by evaporation from the lake occurred during 1921, 1922, and 1923. The Hebgen reservoir has a higher altitude and cooler climate than either Bozeman or Mud Lake; hence the rate of evaporation at that point should be materially lower. Probably a reasonable estimate for the annual evaporation from the Hebgen reservoir would be about 24 inches.

Records of stream flow obtained by the Montana Reservoir & Irrigation Co. during the low-water period from July 1, 1910, to April 30, 1912, together with due allowance for loss through evaporation, show that the maximum continuous flow obtainable with storage regulation at Hebgen is 1,100 second-feet. These records also indicate that during years of abnormally high run-off the same flow is maintained without storage regulation, and in actual practice the reservoir would provide sufficient regulation to maintain a higher usable flow, because there are fluctuations in demand. Estimates of potential power available in the upper canyon and middle valley sections based on a continuous flow of 1,100 second-feet are therefore conservative. During the same low-water period (July 1, 1910, to April 30, 1912) a continuous flow of 110,000 acre-feet per month, or about 1,830 second-feet, could have been maintained at the Madison reservoir outlet without altering the regulation at Hebgen. The Red Bluff and Norris records indicate that low-water periods may occur during which the regulated flow obtainable would be smaller than 1,830 second-feet, but it is not believed that the difference would materially reduce the output of power plants designed on the basis of this figure. The records on which this discussion is based indicate that the use of the Hebgen reservoir to maintain a continuous flow of 1,100 second-feet at its outlet results in nearly the same flow at the Madison reservoir as would result if Hebgen stored water were used only for regulation of flow at the Madison River dam, the difference being less than 3 per cent.

Summary of water-supply data for Madison River

	Drainage area [a] (square miles)	Flow obtainable for power (second-feet)		
		With existing storage	Without storage	
			90 per cent of the time	50 per cent of the time
Three Forks	2,590	([b])	([b])	([b])
Norris	2,380	1,830	1,200	1,500
Madison reservoir	2,170	1,830	1,095	1,370
Hebgen reservoir	911	1,100	825	1,020
Riverside	410	([c])	413	510

[a] Measured from Three Forks and Yellowstone Park topographic maps and Madison forest map.
[b] Run-off at Three Forks approximately the same as Norris.
[c] Above reservoirs.

WATER RIGHTS

The low-water flow of Madison River is controlled by power interests without interference with irrigation interests, and no cause has arisen for adjudication of the water rights of the main stream. Furthermore, there is no present prospect of any disturbance on account of irrigation development, because the diversions for irrigation are comparatively small and are made to a large extent during periods when the supply available is more than adequate for all needs. Probably this situation will not be materially altered by any future extension in irrigation development. All the tributaries of Madison River, however, in areas where irrigation is practiced are entirely appropriated during periods of normal flow.

The power interests are represented by the Montana Power Co., which owns the Hebgen and Madison reservoirs, the only storage sites on Madison River. These reservoirs are operated primarily for regulation on Missouri River and not in such a manner as to provide for complete development of the potential power resources on Madison River. The conflict which thus exists might be eliminated by developing storage on Bighole River, and it is believed that a project of that kind will be undertaken eventually, although probably not unless or until the demand for irrigation becomes sufficient to justify it. For the purpose of the present discussion, it will be assumed that the storage facilities on Madison River are to be used primarily to regulate Madison River and only incidentally to regulate Missouri River. Such an assumption permits a determination of the potential value of the water resources of the Madison River basin without regard to the economic value of the storage in connection with the development of Missouri River.

IRRIGATION

The location of the irrigated lands in the Madison River basin is shown on Figure 1. The principal crops produced on these lands at present are alfalfa, wheat, and oats, and the average yields per acre are 2½ tons, 20 to 25 bushels, and 40 to 50 bushels respectively. Some of the irrigated land is used to produce crops of native hay, of which the yield is about 1 ton to the acre. The total area irrigated is about 35,000 acres, most of it in the middle valley. In that section Indian, Bear, Cedar, and Jackass creeks, tributaries from the east, and Wigwam, Blaine Springs, and Meadow creeks, tributaries from the west, are the principal sources of water for irrigation, and practically all the normal flow available from these streams during the irrigation season is diverted. A comparatively small quantity of water is obtained by direct diversion from Madison River, chiefly for use on land in the flood plain. One bench-land area of 1,910 acres west of Ennis is irrigated from the river under a canal owned by the Madison Valley Irrigation District. According to the annual report of the Montana Irrigation Commission for 1920, this canal was completed and used in 1920 at a cost of approximately $18 an acre and may be extended later to include a total area of 3,200 acres.

A scheme has been proposed for irrigating an area of 5,000 to 7,000 acres of good land in the middle valley on Eightmile bench, south of the Madison Valley Irrigation District and west of Ennis, in T. 6 S., Rs. 1 and 2 W. Montana meridian. A canal 20 miles long, diverting from Madison River above the mouth of Ruby Creek in lot 5, sec. 13, T. 9 S., R. 1 W., would be required. A scheme called the Madison irrigation project was proposed several years ago to embrace an area of about 30,000 acres of smooth, gently sloping bench land on the east side of the middle valley. This scheme contemplates a 40-mile canal diverting from Madison River in sec. 3, T. 11 S., R. 1 E., and ending on Jack Creek in T. 5 S., R. 1 E. The approximate location of these canals is shown on Figure 1, and if constructed as proposed they will probably be capable of delivering water to all the nonirrigated arable land in the middle valley that may be susceptible of successful irrigation. The principal difficulty to be overcome in connection with these projects will be encountered in preventing excessive loss from seepage in a canal excavated through terrace gravel.

In the lower valley irrigation canals can be constructed with little difficulty, and several have been built on both sides of Madison River. The soil is good, but at present irrigation is limited mainly to land near the rim of the valley plain, where good natural drainage exists. Further development of irrigation in this section is believed to be in large measure dependent upon drainage and diking.

Investigations have been made by the United States Bureau of Reclamation[1] to determine the feasibility of diverting water from Madison River to bench lands between Madison and Jefferson rivers and west of Missouri River in Prickly Pear and Crow Creek valleys. A total area of 148,000 acres is physically irrigable by means of a canal diverting from Madison River in the lower canyon near the mouth of Hot Spring Creek. The construction work required consists of a 600,000-acre-foot reservoir created by enlarging the Madison reservoir, 16 miles of tunnel, 4 miles of siphon pressure pipe, 27¾ miles of concrete-lined canals, 99.5 miles of earth canal, and one drop of 70 feet and another of 260 feet. The scheme has been abandoned and is mentioned here merely as a matter of historical interest. The cost of an undertaking of this kind would be prohibitive for lands of the character susceptible of irrigation in this region, and probably there is not sufficient unappropriated water available for diversion from Madison River to irrigate 148,000 acres. A similar scheme proposed more recently contemplates the use of water from Jefferson River for irrigating the same areas, but it involves construction difficulties of nearly equal magnitude.

WATER POWER

GENERAL CONDITIONS

Water power is one of Montana's most valuable natural resources and contributes very largely to the welfare of the State. Statistics compiled by the Geological Survey in 1924 show that the power already developed amounts to a total capacity of 345,000 horsepower, which makes Montana sixth among the United States in installed water-power plant capacity. During 1923 the output of the Montana plants was 1,139,000,000 kilowatt-hours, of which 50,883,000 kilowatt-hours, or 4.5 per cent, was produced in the Madison River basin. It has been estimated by the Geological Survey that the potential water power in Montana amounts to 2,550,000 horsepower with the unregulated stream flow available 90 per cent of the

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[1] U. S. Recl. Service Fifth Ann. Rept., p. 167, 1906.

time and 3,700,000 horsepower with the unregulated flow available 50 per cent of the time. The undeveloped power resources on Madison River amount to about 3.5 per cent of the estimated total potential power for the State.

Practically all the developed water power in the Madison River basin is generated at the Madison No. 2 plant of the Montana Power Co. and distributed over a system of transmission lines interconnected with other power plants of the company or associated concerns to supply the commercial market of central and western Montana. This market includes the mining operations of the Anaconda Copper Co. and others at Butte, the Anaconda smelter, and electrolytic and other plants at Great Falls, as well as street railways, municipal lighting, irrigation pumping, and the operation of the electrified portion of the Chicago, Milwaukee & St. Paul Railway. Although fluctuations in mining operations have affected the demand for power, there has been an increase in the power consumption in this region during the last decade, and it probably is safe to predict that a continued increase in the power demand will eventually lead to additional power development on Madison River.

DEVELOPED WATER POWER

The Madison No. 1 plant of the Montana Power Co. is in the lower canyon immediately below the Madison reservoir dam, in lot 5, sec. 20, T. 4 S., R. 1 E. This plant was completed in 1901 and remodeled in 1907. The installation consists of two horizontal-turbine water wheels having a total capacity of 3,000 horsepower supplied with water through a 10-foot wood-stave pipe. The electrical equipment includes two 3-phase 60-cycle 1,500-volt generators having a combined rated output of 2,000 kilowatts. During recent years this plant has been operated only occasionally, and in 1923 it was idle.

The Madison No. 2 plant of the Montana Power Co. is at a point in lot 5, sec. 17, T. 4 S., R. 1 E., 7,500 feet downstream from the Madison reservoir dam. This plant was completed in 1906. It is operated under a head of 110 feet with water conveyed through one 10-foot and one 12-foot wood-stave pipe, both of which terminate in a concrete pressure chamber whence the water is conducted through 9-foot steel penstocks to four horizontal-turbine water wheels having a rated capacity of 3,600 horsepower each at 300 revolutions a minute. The water wheels are direct-connected to four 4,000-volt 3-phase 60-cycle generators having a rated output of 2,250 kilowatts each. The plant contains eleven transformers, in three of which the current is stepped up to 102,000 volts and in the other eight to 46,200 volts.

A small plant installed at the outlet of the Hebgen dam on unsurveyed land in what will probably be sec. 23, T. 11 S., R. 3 E., affords power for the dam and appurtenances. Another plant, owned by the Economy Power Co., in sec. 18, T. 7 S., R. 1 W., generates current for municipal lighting in Virginia City. This plant, which has been in operation 14 years, obtains its water supply from Blaine Springs. The installation consists of one 450-kilowatt 2,200-volt 5-pole generator with four termini at 118 amperes each, operating at a speed of 600 revolutions a minute, generating 3-phase 60-cycle current, with three 150-kilowatt transformers which step the current up to 16,500 volts for transmission. The generator is direct-connected to a 600-horsepower horizontal Leffel turbine. The exciter unit consists of a 125-kilowatt 125-volt 100-ampere generator operated at 750 revolutions a minute by a 2-inch double-nozzle Pelton wheel. Water is delivered to the turbine through a 3-foot wood-stave pipe.

UNDEVELOPED WATER POWER

The potential power resources of the Madison River basin which may have commercial value lie along the main stream in the two canyon sections and the upper 27 miles of the middle valley. The fall in the upper canyon is estimated at 29 feet to the mile on the basis of data showing the altitude of the river channel at Hebgen as furnished by the Montana Reservoir & Irrigation Co. and the altitude at the mouth of the canyon as determined by the plane-table survey in the middle valley. The potential power in the canyon, therefore, at an over-all plant efficiency of 70 per cent, is 1,900 horsepower to the mile with the flow available 90 per cent of the time, 2,370 horsepower to the mile with the flow available 50 per cent of the time, and 2,550 horsepower to the mile with the available storage regulation. The total potential power in the canyon on the basis of these estimates would be 13,700 horsepower with 90 per cent flow 17,000 horsepower with 50 per cent flow, and 18,400 horsepower with storage regulation. The 27-mile power section of the middle valley extends from the mouth of the upper canyon, in sec. 35, T. 11 S., R. 2 E., down to a point in sec. 36, T. 8 S., R. 1 W. In this section Madison River is intrenched in a narrow trough between terraces and has a fall determined by plane-table survey ranging from 25 feet to nearly 40 feet to the mile and aggregating 800 feet. The total potential power for the 27 miles at a plant efficiency of 70 per cent is approximately 53,000 horsepower with 90 per cent flow, 65,000 horsepower with 50 per cent flow, and 70,000 horsepower with storage regulation. All these estimates are based on the flow of Madison River at Hebgen, with no allowance for additional flow from tributaries, which would add somewhat to the potential power.

The physical conditions in the upper canyon and the upper 27 miles of the middle valley (see p. 3) would permit the development of part of the fall in the river by means of dams of sufficient height to eliminate difficulties from frazil ice, but in addition conduits would be required. The available foundations, however, appear to be unsatisfactory for masonry dams. In the upper canyon rock-crib structures could be built, but the opportunities for dams in the middle valley are somewhat less favorable. The conduits would traverse talus slopes or pass through terrace gravel and would require lining to prevent excessive loss from seepage. The best opportunity for developing power in the sections under discussion involves the construction of a diversion dam about 1 mile above the mouth of the upper canyon and a 6-mile conduit extending down the right side of the canyon and across a middle-valley terrace to a point in the SE. ¼ sec. 24, T. 11 S., R. 1 E., where a static head of 310 feet can be obtained. The power output of such a development at a plant efficiency of 70 per cent would be 20,000 horsepower with 90 per cent flow, 25,000 horsepower with 50 per cent flow, and 27,000 horsepower with storage regulation.

Below the 27-mile section of the middle valley a 6-mile conduit could be constructed from a point on the right bank of Madison River in sec. 24 or 25, T. 8 S., R. 1 W., to a point on the upper edge of a middle-valley terrace where a static head of 120 feet would be available, which might be utilized for developing power. There is no dam site at the point of diversion, however, and the canal if constructed probably would be of greater value for irrigation than for power. The alinement of the canal required for this development is identical with that of the canal described on page 15, which has never been completed.

The upper canyon is practically devoid of any economic value other than its power resources. The Vigilante Trail to Yellowstone Park traverses the canyon but could be relocated at little expense. A right of way through the canyon was granted to the Montana Railway Co. in 1887, but the grant was declared forfeited in 1915 for nonuse, and there is no present prospect that a railroad will be built through the canyon. In the upper 27 miles of the middle valley there is some agricultural land along the river, but such land would offer no serious impediment to power development.

The undeveloped power of the lower canyon constitutes its principal economic value. A total fall of 220 feet occurs in the 10-mile section from the tail-water of Madison No. 2 power plant to the center of sec. 11, T. 3 S., R. 1 E. The potential power in this 10-mile section at a plant efficiency of 70 per cent is 21,000 horsepower with 90 per cent flow determined from the Red Bluff-Norris record, 26,400 horsepower with 50 per cent flow, and 32‘000 horsepower with available storage regulation at the Hebgen and Madison reservoirs. The explorations of the Montana Power Co. for dam foundations in this canyon indicate that the depth to bedrock is too great to permit the economical development of power by a high dam resting on bedrock. Whether grouting of the rock débris that overlies the bedrock in the canyon would be practicable as a preliminary step to the building of a high dam has not been determined. If a high dam is impracticable, the only alternative method of development would be to construct two or more low diversion dams similar to that for the Madison reservoir, with conduits or tunnels. Development by this method would be expensive, for the conduits would in places have to be carried through solid rock. In the remainder of the lower canyon the total fall is 110 feet and the potential power at a plant efficiency of 70 per cent is 10,600 horsepower with 90 per cent flow, 13,200 horsepower with 50 per cent flow, and 16,000 horsepower with storage regulation. The field investigations indicated that the only opportunity for developing power in this lower end of the canyon is probably by diversion from the river in sec. 11, T. 3 S., R. 1 E., through a conduit extending to a power house on the left bank near sec. 30, T. 2 S., R. 2 E. A static head of about 80 feet could be obtained, and the estimated potential power is 7,680 horsepower with 90 per cent flow, 9,600 horsepower with 50 per cent flow, and 11,700 horsepower with available storage regulation. Difficult rock excavation would be encountered in the first 2 miles of the conduit, and one side stream would have to be crossed.

The total estimated undeveloped power on Madison River is 98,300 horsepower with 90 per cent flow, 121,600 horsepower with 50 per cent flow, and 136,400 horsepower with storage regulation. These estimates cover the main stream only. The region has a commercial market that is being abundantly supplied with water power from other sources at a lower cost than is possible by further power development on Madison River; hence the value of the undeveloped power of the stream at present is more theoretical than practical. Changes in this situation are certain to occur in the future, but the extent of such changes can not be foreseen. It is regarded as safe, however, to predict the development to some extent of the potential power resources of two sections, the 10-mile section in the lower canyon below the tailrace of Madison No. 2 plant and the section involving the dam and conduit at the lower end of the upper canyon and the upper end of the middle valley.

With the exception of streams in Yellowstone Park, the only tributary of Madison River known to be valuable for water power is Blaine Springs Creek, the potential power of which is being developed by the Economy Power Co. The potential power in Yellowstone Park is eliminated from consideration, because the scenic beauty of that part of the basin is a resource of value to the entire United States, and this beauty would be marred if not entirely destroyed by commercial development of the water power. Such development has therefore been prohibited by law.