GEOLOGICAL SURVEY CIRCULAR 292

WATER-POWER RESOURCES OF CRYSTAL RIVER, COLORADO

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MAP OF THE CRYSTAL RIVER, COLORADO, SHOWING THE LOCATION OF POWER AND STORAGE SITES

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CONTENTS

	Page
Abstract	1
Introduction	2
Purpose and scope	2
Previous investigations and reports	2
Maps	2
Future work	2
Power site index numbers	2
Geography and history	3
Present water use	3
Water supply	4
Precipitation	4
Runoff	4
Ground water	8
Transmountain diversions	8
Water utilization plan	9
Stream regulation	9
Storage sites	10
Regulated streamflow	13
Waterpower	13
Developed waterpower	13
Undeveloped waterpower	13
Unregulated waterpower	14
Regulated waterpower	16
Use of power	17
Literature cited	17

ILLUSTRATIONS

		Page
Plate 1.	Map of the Crystal River, Colorado, showing the location of power and storage sites	Frontispiece
Figure 1.	Annual distribution of precipitation at Aspen, Glenwood Springs, and Marble	4
2.	Annual distribution of runoff in the Crystal River	5
3.	Daily flow duration curve for Crystal River near Redstone	7
4.	Daily flow duration curve for Crystal River at Marble	7
5.	Area and capacity curves for the Schofield Park, Lead King, Little Snowmass Lake, Crystal, Redstone, and Marble reservoir sites	11
6.	Area and capacity curves for the Placita, Chair Mountain, Hot Springs, and Mount Sopris reservoir sites	12

ABSTRACT

The Crystal River drains the western slope of the Elk Mountains, a relatively small range in the southern Rocky Mountain province, and flows into the Roaring Fork 13 miles southeast of Glenwood Springs, Colo. The lower 7 miles of the valley is cultivated, but upstream from this stretch the valley is narrow and is used mainly for summer grazing and recreation. Above the mouth of Thompson Creek, numerous dam sites are available, but the narrow valley and steep gradient do not favor storage for regulation of streamflow. The potential power from the natural flow of the stream in an average year is estimated to be 4,750 kilowatts for 95 percent of the time; 5,102 kw for 90 percent of the time; 10,570 kw for 50 percent of the time; and 36,940 kw at mean flow. Using the regulated flow resulting from the utilization of reservoirs at Marble and Redstone, the potential power is estimated to be 26,510 kw for 90 percent of the time and 27,810 kw for 50 percent of the time.

INTRODUCTION

Purpose and Scope

This report is one of a series prepared primarily to assist in the classification of lands within the public domain as to their value in the development of hydroelectric power. The power sites to be discussed have little, if any, present value because of the relatively high cost of development. However, it is impossible to foresee changes which may make their development economically feasible. The purpose of the land classification work is to locate all possible power sites and to influence other cultural growth in such a way as to avoid interference with an orderly development of the waterpower resources of the basin.

Previous Investigations and Reports

The Redstone Marble Company investigated power sites on the Crystal River, near Redstone, and in 1909 filed two reservoir site maps, called reservoir sites no. 3 and no. 4, in the office of the State Engineer of Colorado. These maps are complete to 125 feet and 100 feet, respectively, above the water surface of the river at the dam sites and are on an assumed datum. The sites were covered more completely by a 1934 river survey map, and accordingly the earlier maps were not used in the preparation of this report. Site no. 3 is referred to in this report as the Placita reservoir site (storage site 9DF 3) and site no. 4 as the Hot Springs reservoir site (storage site 9DF 4). These sites were not developed.

Follansbee (1929, p. 170-171 and 305-307) has discussed the developed waterpower and summarized streamflow records up to 1927. The geology of the area has been discussed by Holmes (1876, p. 67), Vanderwilt (1932, p. 3-18), Vanderwilt and Fuller (1935, p. 439-464), Vanderwilt (1938), and Emmons, Cross, and Eldridge (1894), but no detailed geologic investigations have been made at any of the dam sites described in this report.

Maps

A river survey map entitled "Plan and Profile of Crystal River, Colorado, from Carbondale to Marble, Dam Site" was published by the U. S. Geological Survey in 1939. The field work was done in 1934. The scale of the map is 1:31,680 with a contour interval of 20 feet on land and 5 feet on the water surface and with topography complete to about 200 feet above the river. The Crystal River dam site (referred to in this report as the Hot Springs dam site) is shown on the map to a scale of 1:4,800 with a contour interval of 10 feet. The river survey map is published in 2 sheets, 1 plan and 1 profile. That portion of the valley upstream from Marble is shown on a U. S. Geological Survey special map entitled "Snowmass Mountain and Vicinity, Colorado." The scale is 1:31,680, and the contour interval is 50 feet. The two-mile reach of the Crystal River between Carbondale and its mouth is shown on sheet 1 of the river survey map of the Roaring Fork published in 1941 and entitled "Plan and Profile, Roaring Fork, Colorado, from Colorado River to Mile 55." The field work was done in 1938. The scale of the map is 1:31,680 with a contour interval of 20 feet on land and 5 feet on the water surface. The map is published in 5 sheets, 3 plan and 2 profile. The river survey maps are available from the U. S. Geological Survey, Denver Federal Center, Denver, Colorado, or Washington, D. C., for 10 cents a sheet, or 20 and 50 cents a set, respectively, and the special map is available at a price of 20 cents.

The Crystal River basin and surrounding areas are shown on a planimetric map of the White River National Forest, scale: 1 inch equals 4 miles, prepared by the U. S. Forest Service. This map is available from the Regional Forester, U. S. Forest Service, Denver Federal Center, Denver, Colorado, or from U. S. Forest Service offices within the White River National Forest.

Future Work

A geologic reconnaissance of all the dam sites between Thompson Creek and Marble is needed to eliminate from future consideration any sites which are obviously not feasible for geologic reasons. For all favorable sites large-scale topographic maps and detailed geologic examinations should be made.

Power Site Index Numbers

For convenience in identifying power sites in the United States, the U. S. Geological Survey has divided the country into 12 major divisions conforming to its principal drainage basins. Each of these basins has been subdivided, and each subdivision has been further divided. The major drainage basins are designated by numbers from 1 to 12, and the subdivisions and minor subdivisions are both designated by a system of lettering. Thus, the area under discussion here is in major drainage basin 9, which includes the entire basin of the Colorado River. The first or major subdivision is lettered "D," which includes the Colorado River basin above the mouth of the Green River exclusive of the Gunnison River basin. The second, or minor subdivision, is lettered "F," which includes all the basin of the Roaring Fork. Therefore, all power sites within the Roaring Fork basin, which includes the Crystal River basin, will be designated 9DF followed by a number. These numbers are assigned in chronological order; that is, the first site investigated and reported upon became site 9DF 1, the second became 9DF 2, and so on. In the Roaring Fork basin, the following index numbers have already been used in Water-Supply Paper 617: developed storage, 9DF 1 to 2; undeveloped storage, 9DF 1 to 5; developed power, 9DF 1 to 4 (sites 9DF 2, 3, and 4 described in Water-Supply Paper 617 have been dismantled); undeveloped power, 9DF 1 to 11. For this reason, the following index numbers have been assigned to sites in the Crystal River basin in this report: developed storage, none; undeveloped storage, 9DF 6 to 13; developed power, none; undeveloped power, 9DF 12 to 19.

GEOGRAPHY AND HISTORY

The Crystal River drains a comparatively narrow valley which lies between the valleys of the Roaring Fork on the east, the Gunnison River on the south, and the Colorado River on the west, and trends from south to north. The altitude of the stream where it enters the Roaring Fork is 6,050 feet, and the highest point in the basin is the summit of Maroon Peak, altitude 14,168 feet.

The Crystal River valley is one of the many beautiful spots in Colorado and is visited each summer by numerous tourists and sportsmen. The sides of the valley are steep, and the lower portions are covered with aspen and other vegetation common to the area. The higher slopes are bare rock, and the peaks are snow covered until late in summer.

The now abandoned town of Schofield, located a mile or two north of Schofield Pass, was the first settlement in the valley. It was surveyed and platted in 1879. Established a year or two later at the confluence of North and South Forks of the Crystal River, Crystal was a prosperous mining town in the 1880's with a population of approximately 500 and at least six producing silver-lead-zinc mines nearby. By 1916 the population had dwindled to 75, and today the site is completely abandoned. Marble, at the mouth of Carbonate Creek, began as a mining camp but later grew larger because of the deposits of high-grade marble nearby. Vanderwilt (1938, p. 152-174) has discussed these marble deposits, giving a detailed history of the quarrying operations and including some excellent photographs. The town reached its peak during the period 1910-13 when it had a population of 1,500; however, by 1950 its population was reduced to 8 persons. Prior to a fire in 1926, the marble-finishing mill was reputed to be the largest in the world. Placita, 7 miles downstream from Marble, was a coal-mining town. Redstone, 3 miles farther downstream was originally built as the headquarters of the Crystal River Railroad and as a processing site where coal from Coal Basin, 12 miles to the west, and from Placita was made into coke. Some 200 coke ovens were in operation there in 1902. The town is now a resort with about 40 summer homes. Carbondale, with a population of 441 in 1950, lies 2 miles southeast of the mouth of the Crystal River and is a station on the Denver & Rio Grande Western Railroad's branch line from Glenwood Springs to Aspen.

The valley is served by an all-weather road from Carbondale to Marble, with an unimproved road continuing to Crystal. A railroad, which was dismantled in 1942, ran from Carbondale to Marble.

Present Water Use

Irrigation is practiced extensively in the lower 7 miles of the valley. According to records in the Colorado State Engineer's office, 16 ditches with adjudicated rights to 318.7 cubic feet per second of water were in use during the irrigation season of 1951. Of this, 291.3 cfs was diverted from the Crystal River, 21.4 cfs from Thompson Creek, and 6.0 cfs from Thomas Creek. An estimated 60,000 acre-feet of water was diverted in that year. Eight thousand six hundred forty-five acres of land lie under these ditches, and presumably most of it was irrigated in 1951. The irrigation season in 1951 extended generally from May 15 to October 1, but two diversions from Thompson Creek were cut off on August 1, probably because of lack of water.

In addition to the above diversions, the State Game and Fish Department diverts 10 cfs from Crystal River at mile 1.5 [1] for use in a trout-rearing station. This water, which is diverted only when the river is clear, supplements 6 to 12 cfs obtained from springs on the west or left bank just above the station.

1/Where mileage is given in this report, it refers to that shown on the 1934 river survey map of the Crystal River. To obtain mileage from the mouth of the river, add 2.0 miles.

WATER SUPPLY

Precipitation

Weather records within the Crystal River basin are limited to those gathered at Marble from January 1910 to March 1917. They consist of the usual daily maximum and minimum temperature readings and daily amounts of precipitation. Nearby but out-of-basin stations are at Aspen to the east, where fragmentary records between 1888 and 1914 and complete records from October 1914 to June 1919 and June 1934 to date were obtained; and at Glenwood Springs to the north, where rather complete records have been kept since 1903. The location of these stations is shown on plate 1. Correlation between the record at Marble and that at Glenwood Springs is poor; while at Aspen and Marble, where there are only 2 years of parallel record, the correlation is better but still not close enough to permit extension of the Marble record.

The annual distribution of precipitation at Marble (see fig. 1) is typical of the region, with fairly even distribution throughout the year. The mean of 3.37 inches for January is probably somewhat higher than the long-time normal.

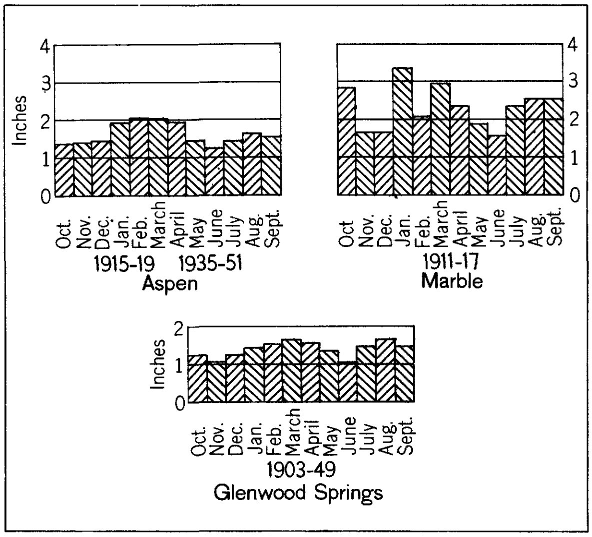

Figure 1.--Annual distribution of precipitation at Aspen, Glenwood Springs, and Marble

The record of runoff at the gaging station at Marble shows that the mean annual runoff for the area above the station for the years 1911-15 was 44 inches. Follansbee (1929) has estimated that in the mountainous regions of Colorado the precipitation exceeds runoff by 15 inches. Therefore, the mean precipitation for that part of the basin lying above Marble was about 59 inches. Since the measured mean precipitation at Marble for these same 5 years was only 27 inches, it seems likely that precipitation on the highest peaks was considerably in excess of 75 inches. In 1914, a very wet year, the runoff from the drainage area above the gaging station at Marble was 54 inches, and the precipitation at Marble was only 31.7 inches; accordingly, the precipitation on the highest peaks possibly exceeded 100 inches.

Runoff

Gaging stations have been operated by the U. S. Geological Survey at three sites on the Crystal River and one on Thompson Creek (see plate 1) as follows:

Crystal River near Carbondale	1908-9
Crystal River at Marble	1910-17
Crystal River near Redstone	1935-
Thompson Creek near Carbondale	Oct. 1, 1950-

Nine miscellaneous measurements were made on the Crystal River, and 13 were made on tributaries in the years 1907, 1908, and 1909. The results of these measurements have been published in Water-Supply Papers 249 and 269 and are summarized as follows:

Location	Date	Discharge (cfs)
Crystal River:		
At Carbondale	Dec. 20, 1907	93
1 Mile west of Carbondale	Feb. 12, 1908	100
	Feb. 29	90
	Apr. 1	120
	Apr. 4	124
At Sewell, near Carbondale	Jan. 15, 1909	111
At Hot Springs	Jan. 15	76
	Mar. 18	62
At Redstone	Jan. 14	58

Location	Date	Discharge (cfs)
Tributaries to Crystal River:		
Thompson Creek at Sewell, near Carbondale	July 18, 1908	6.6
	Aug. 25	10.2
	Sept. 9	*.5
	Oct. 30	11.2
	Dec. 3	*8
	Mar. 18, 1909	*9
	Apr. 22	40.0
Nettle Creek at Sewell, near Carbondale	Mar. 29, 1908	6
Avalanche Creek at mouth	Jan. 15, 1909	20
	Mar. 18	20
Coal Creek near Redstone	Jan. 15	6.2
	Mar. 17	11
Yule Creek at Marble	Mar. 29, 1908	6

*Estimated

In addition to these miscellaneous measurements, the flows in several irrigation ditches were measured during the same period. These measurements are also listed in Water-Supply Papers 249 and 269.

The complete history and record of stream-gaging operations in the Crystal River basin are contained in the following Water-Supply Papers of the U. S. Geological Survey:

Year	Water-Supply Paper	Year	Water-Supply Paper
1908	249	1938	859
1909	269	1939	879
1910	289	1940	899
1911	309	1941	929
1912	329	1942	959
1913	359	1943	979
1914	389	1944	1009
1915	409	1945	1039
1916	439	1946	1059
1917	459	1947	1089
1935	789	1948	1119
1936	809	1949	1149
1937	829	1950	1179

The nearest long-time streamflow record is that of the Roaring Fork at Glenwood Springs. This record is complete from October 1, 1905, to the time of this writing, except for all the water year beginning October 1, 1909. This is an exceptionally good record, because warm springs above the gage keep its control practically free of ice.

The above-mentioned data are the only ones available for making estimates of streamflow at the various storage and power sites in the Crystal River basin. Therefore, these estimates are subject to considerable error, and an extensive program of stream gaging should be established several years prior to making the detailed studies that necessarily precede the actual development of the water resources of the stream.

The runoff characteristics of the Crystal River are similar to those of other Western Slope streams in Colorado without natural storage. A large part of the precipitation falls as snow and appears as runoff in the months of May through July. Seventy-five percent of the annual runoff at the gaging station near Redstone occurs in the 3-month period, while only 7 percent of the runoff occurs in the 4-month period of December through March. At Marble 78 percent of the annual runoff occurs between May 1 and July 31, while only 4 percent occurs between December 1 and March 31. The annual distribution of the runoff by months at these two stations is shown in figure 2.

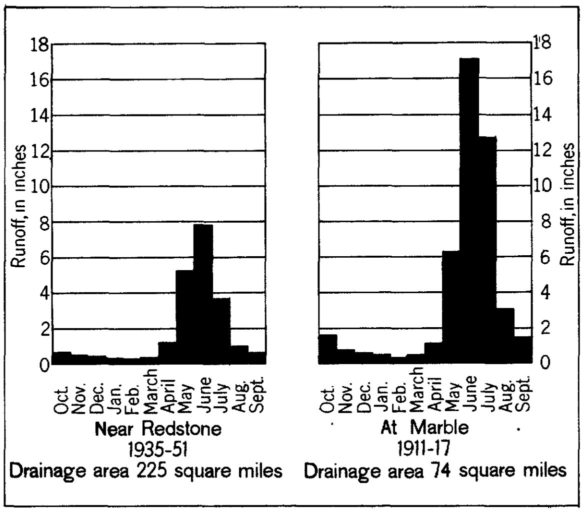

Figure 2.--Annual distribution of runoff in the Crystal River

The total annual runoff of the stream varies widely from year to year. In 1934 it is estimated to have been 162,000 acre-feet, while in 1914 it is estimated to have been 476,000 acre-feet.

The gaging station on the Crystal River near Redstone has been operated from May 1935 to the present time. The streamflow record for the period May 1935 to September 1951 was used in the preparation of this report. This record was extended to cover the period 1905-9 and 1911-34 by comparison with the record for the Roaring Fork at Glenwood Springs, using monthly mean flows. This was done primarily to determine which years should be selected as wet, average, and dry ones for more detailed study. Since daily flow duration curves are desirable in making power estimates and since daily flows were not available prior to May 1935, an effort was made to find a year in the period 1936-51 which would fit into each category. The year 1936 fits well as an average year and 1940 as a dry year, but there was no year in the period 1936-51 which compared in wetness to 1912, 1914, or 1918. In order to obtain daily flow duration estimates for a wet year during the period 1936-51, a composite curve was plotted which approximated that for the year 1914 (fig. 3). Within the period 1936-51, months that had a total flow approximately equal to corresponding months in the 1914 water year were used. The mean monthly flows during this year and the corresponding months and flows chosen, all for the gaging station near Redstone, are shown as follows:

Month	Estimated runoff (second-foot days)	Month	Runoff (second-foot days)
Oct. 1913	4,960	Oct. 1941	5,200
Nov. 1913	3,780	Nov. 1948	3,877
Dec. 1913	2,740	Dec. 1948	2,808
Jan. 1914	2,270	Jan. 1938	2,267
Feb. 1914	2,310	Feb. 1937	2,187
Mar. 1914	2,950	Mar. 1939	2,774
Apr. 1914	7,970	Apr. 1939	7,237
May 1914	55,220	May 1941	47,036
June 1914	83,820	June 1938	66,530
July 1914	60,580	June 1950	59,030
Aug. 1914	8,510	Aug. 1943	8,708
Sept. 1914	4,880	Sept. 1939	4,885
Totals	239,990		212,539

In the following discussion, the capital letter Q is used to represent flow of water in second-feet and P to represent power in kilowatts. The percentage of time that flow or power would be available is indicated by a number immediately following the letter. For example, Q50 indicates the flow available 50 percent of the time.

Significant flows at Redstone (from fig. 3)

Year	Q95		Q90		Q50		Qmean	
	cfs	cfs per sq mile	cfs	cfs per sq mile	cfs	cfs per sq mile	cfs	cfs per sq mile
Dry	53	0.24	58	0.26	96	0.43	268	1.19
Average	62	.28	66	.29	110	.49	395	1.76
Wet	67	.30	73	.32	148	.66	588	2.61

Mean flow 15 years (1936-50)	393 second-feet
Mean flow 44 years (estimated)	406 second-feet
Drainage area above station	225 square miles

The gaging station at Marble was in operation from November 1, 1910, to September 30, 1918; however, only gage heights are available for the water years 1916 and 1918. Daily flow duration estimates were computed for the 4 years 1912-15, and the significant data therefrom are presented in figure 4.

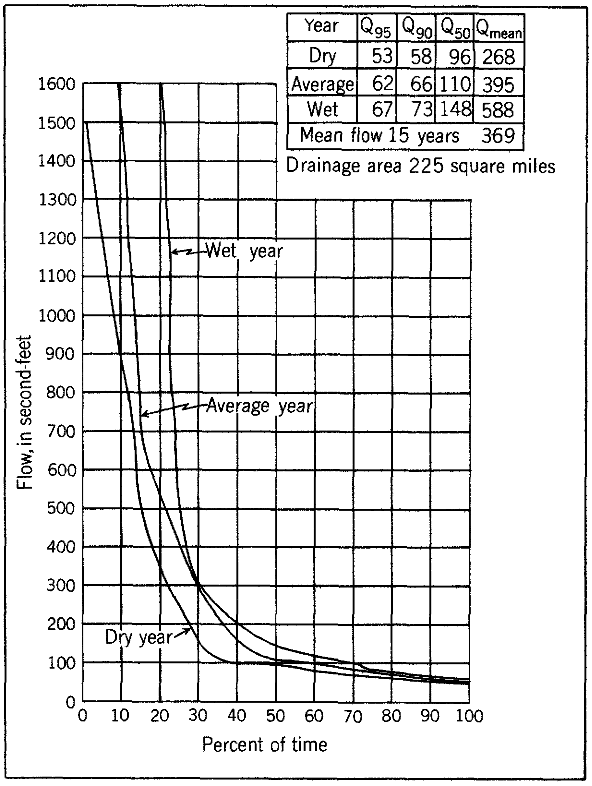

Figure 3.--Daily flow duration curve for Crystal River near Redstone

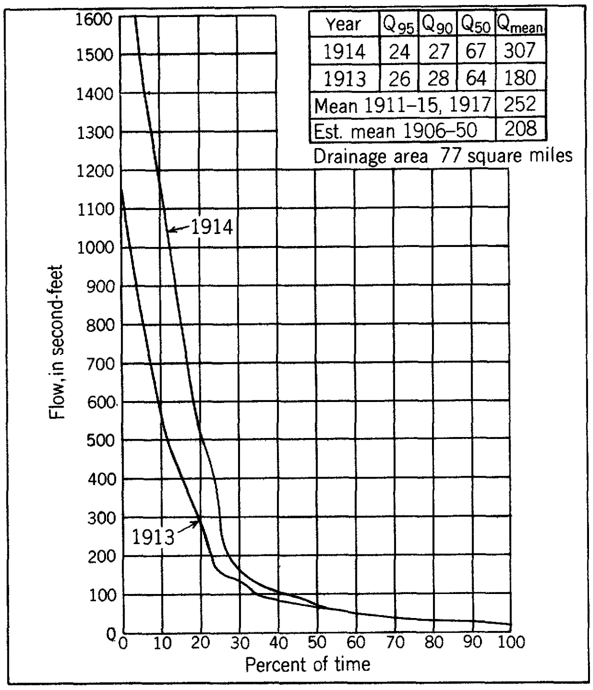

Figure 4.--Daily flow duration curve for Crystal River at Marble

Significant flows at Marble (from fig. 4)

Year	Q95		Q90		Q50		Qmean	
	cfs	cfs per sq mile	cfs	cfs per sq mile	cfs	cfs per sq mile	cfs	cfs per sq mile
1912	26	0.34	27	0.35	72	0.94	280	3.64
1913	26	.34	28	.36	64	.83	180	2.34
1914	24	.31	27	.35	67	.87	307	3.99
1915	22	.29	22	.29	72	.94	314	4.08
1912-15	23	.30	26	.34	68	.88	245	3.18
Estimated average	25	0.32	27	0.35	68	0.88	230	2.99

Comparison of these data with those for the streamflow at the station near Redstone indicates that the unit flow available 95 and 90 percent of the time in an average year is approximately the same at the two stations, but that the unit flow available 50 percent of the time in an average year is 80 percent greater at Marble and the mean unit flow in an average year is 70 percent greater at Marble.

Streamflow estimates at the several power sites (see pl. 1) have been made from these data for an average year. The flow for the sites at and upstream from Marble was determined by multiplying the unit runoff at Marble by the drainage area above the sites. For those sites below Marble, the Q95, Q90, Q50, and Qmean flows at each of the two stations were plotted against their respective drainage areas on rectangular coordinate paper. The flows for intermediate sites and the site below the Redstone gaging station were then read from the straight lines connecting each pair of points. As with any method that relies solely on drainage area ratios for streamflow estimates, this method is subject to large errors. Miscellaneous discharge measurements should be made at each proposed point of diversion before more detailed power studies are undertaken.

Estimated streamflow in an average year

Power site index no.	Drainage area sq mile	Q95 cfs	Q90 cfs	Q50 cfs	Qmean cfs
9DF 12	39.8	13	14	35	119
9DF 13	46.7	15	16	41	140
9DF 14	77	25	27	68	230
9DF 15	94	29	31	72	250
9DF 16	106	31	34	76	263
9DF 17	162	47	50	92	327
9DF 18	168	48	51	93	332
9DF 19	215	60	65	108	388

The maximum discharge of the Crystal River at both the gaging stations near Redstone and at Marble occurs during the period of melting snow. Although the area is subject to summer storms in late July and August, these storms are localized and do not cause excessive runoff in the main stream. During the summer of 1952, several such storms caused washouts along the side streams and closed the roads for short periods. High water on Avalanche Creek washed out the road to the Avalanche Creek Campground and marooned campers for several days. The maximum discharge during the period of record (1935-52) at the gaging station near Redstone was 4,400 cfs or 19.6 cfs per square mile on June 21, 1938. At Marble the maximum discharge observed during the period of record (1911-15 and 1917) was 2,380 cfs or 30.9 cfs per square mile on June 25, 1917.

Ground Water

In 1942 the Geological Survey established a network of key observation wells in order to make available current information on general ground water conditions throughout the country. The wells were selected because the fluctuations of water level in them are believed to be typical of the general fluctuations that occur in the parts of the country in which the wells are situated. Two such wells, located in the Crystal River area, were added to this network on September 10, 1942. Well 79 is located near the mouth of the Crystal River on the right bank of the Roaring Fork in the NW$\frac{1}{4}$NE$\frac{1}{4}$ sec. 29, T. 7 S., R. 88 W., and well 79A is located near the mouth of Thompson Creek, on the west side of the Crystal River valley, in the SW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 27, T. 8 S., R. 88 W. The water levels in these wells have been published in the following Water-Supply Papers:

Year	Water-Supply Paper
1942 - - - - - - - - - -	948
1943 - - - - - - - - - -	990
1944 - - - - - - - - - -	1020
1945 - - - - - - - - - -	1027
1946 - - - - - - - - - -	1075
1947 - - - - - - - - - -	1100
1948 - - - - - - - - - -	1130
1949 - - - - - - - - - -	1160
1950 - - - - - - - - - -	1169

TRANSMOUNTAIN DIVERSIONS

At the time of this writing, no water was being diverted from the basin except a small amount for irrigation which was used in the Roaring Fork valley immediately across the divide southwest of Carbondale.

It has been suggested that water could be diverted from near the headwaters (at or above the confluence of the North and South Forks of the Crystal River) through the divide into the Gunnison River basin and then by means of a system of canals and tunnels through the Continental Divide into the Arkansas River basin. Such a development would be very expensive, but the need for additional water is becoming very acute in the Arkansas River basin, and the demand may become great enough to justify the high costs involved.

It has also been suggested that water could be diverted from the Crystal River near Redstone and carried by means of a system of canals and tunnels through the divide between the headwaters of Thompson Creek and Divide Creek to irrigate lands on the south side of the Colorado River between the Roaring Fork and Horsethief Creek near Debeque, Colo. This project would require storage, probably at either the Redstone or Placita reservoir sites on the Crystal River and would, if developed, greatly reduce the potential power downstream from the point of diversion.

WATER UTILIZATION PLAN

The water resources of the Crystal River can be developed in any one of several ways, and the plan finally chosen will be selected after a rather detailed, rigid analysis of the relative needs for municipal and industrial water supply, irrigation, and waterpower. These various needs and their relative importance change with the passage of time, and such an analysis of them is neither warranted nor practical in a report such as this. Instead, an attempt will be made to show the magnitude of the streamflow, the amount of storage available, and estimate the power which could be produced from the natural flow and utilizing storage to increase the low water flow.

Below mile 5.1, which point is 0.4 mile upstream from the mouth of Thompson Creek, diversion for irrigation utilize such a large part of the flow during the irrigation season that power development is not practical. Above this point, practically all the 2,530 feet of head up to the junction of the North and the South Forks of the Crystal River can be developed.

The flow of the Crystal River is rather low in winter and early spring, and the firm power from a run-of-river plant would be small. However, if the power were to be used within the valley, the peak demand would occur in the summer and fall during the vacation and hunting seasons when the flow is higher.

To illustrate the power possibilities utilizing run-of-river plants and to show the regulatory effect of storage, two plans of development are presented in this report. The first, or natural-flow plan, provides for the development of all but 32 feet of the 2,530 feet of head available between mile 5.1 and the confluence of the North and South Forks of the Crystal River. All this 2,498 feet of head would be utilized in diversion-and-conduit-type developments with dams just high enough to provide for the diversion works. Eight such plants have been selected and assigned power site index numbers 9DF 12 through 9DF 19.

The second or regulated-flow plan, provides for developing the same head as in the natural-flow plan except for the loss incurred through fluctuations of the water level in the proposed reservoirs. The tailrace of a plant upstream from a reservoir must be at or above the altitude of the water level when the reservoir is full. As the water level drops in the reservoir, some loss in head occurs. Storage reservoirs are proposed at Marble and at Redstone with powerplants several miles downstream from each of the dams. Six run-of-river plants, in addition to the two plants mentioned above, are proposed. These sites are not necessarily the most favorable ones on the stream, but they serve to show the magnitude of the waterpower available. The dam and powerhouse sites for the two plans are the same except as indicated in the discussion under regulated power.

STREAM REGULATION

There are no developed storage sites in the Crystal River basin at this time. The valley of the Crystal River is narrow with a comparatively steep gradient. Accordingly, the ratio of the cost of dam construction to the amount of storage provided will be high for all sites. At present, very little private property would be damaged by the construction of the suggested high dams. Culture in the basin consists almost entirely of summer cottages, a few ranches, and the Carbondale-Marble road. Thus the inundation damage at all sites would be small and would compensate, to some degree, for the high cost of the dams.

As might be expected in a narrow valley such as this one, there are a number of dam sites. Since the topography on the 1934 river survey map is, in general, complete to 200 feet above the stream level, it has been possible to compute reservoir capacities for dams to at least that height for the six reservoir sites below Marble. For the four sites above Marble, capacities were computed from areas planimetered on the Snowmass Mountain and Vicinity special map, and these could be computed for any desired height of dam.

These 10 storage sites, together with data pertinent thereto, are shown in the table below, first the seven on the main stem in downstream order, then the two in the North Fork basin, and finally the one on the South Fork. The sites are numbered in downstream order except for sites 9DF 3 and 9DF 4, which had already been assigned those numbers by Follansbee in 1929 (see pl. 1). Figures 5 and 6 which follow the table show area and capacity curves for all 10 sites listed in the table. All the sites are in the White River National Forest.

Storage Sites

Undeveloped storage sites in the Crystal River basin

Storage site name and index no.	Location of dam site: River mile	Location of dam site: Land description sec.	T.	R.	Altitude of river surface at dam site (feet)	Probable maximum flow line (feet)	Remarks
Crystal, 9DF 6	33.1	unsurveyed 27	11 S.	87 W.	8,880	9,250	Dam site is a few hundred feet below the confluence of the North and South Forks of the Crystal River. Very little flowage damage.
Marble, 9DF 7	27.7	26	11 S.	88 W.	7,908	8,100	Dam site is about a quarter of a mile downstream from the mouth of Carbonate Creek and would flood the near-ghost town of Marble.
Chair Mountain, 9DF 8	24.3	20	11 S.	88 W.	7,640	7,900	Dam site is about a quarter of a mile downstream from the mouth of Rapid Creek and would require relocation of road and flood one ranch.
Placita, 9DF 3	20.1	6	11 S.	88 W.	7,400	7,700	Dam site is about half a mile downstream from ghost town of Placita. The town site, one abandoned coal mine, and two roads would be flooded.
Redstone, 9DF 9	15.2	16-17	10 S.	88 W.	7,125	7,340	Dam site is located about 1 mile downstream from town of Redstone. The town, the Osgood estate, and the road would be flooded.
Hot Springs, 9DF 4	12.5	33	9 S.	88 W.	6,903	7,160	Dam site is about 1¼ mile upstream from the mouth of Avalanche Creek. Some ranch land and the road would be flooded.
Mount Sopris, 9DF 10	9.6	21	9 S.	88 W.	6,650	6,900	Dam site is about 1½ mile downstream from the mouth of Avalanche Creek. The road would be flooded.
Lead King, 9DF 11	See remarks	unsurveyed land			9,550	9,900	Dam site is at mile 1.3 on the North Fork of the Crystal River. Flowage damage would be extremely light.
Little Snowmass Lake, 9DF 12	See remarks	unsurveyed land			10,940	11,250	Dam site is on an unnamed tributary which flows from the north into the North Fork of the Crystal River 2.2 miles upstream from its confluence with the South Fork. No appreciable flowage damage.
Schofield Park, 9DF 13	See remarks	unsurveyed land			10,180	10,500	Dam site is on the South Fork of the Crystal River about 2½ miles upstream from its confluence with the North Fork. No appreciable flowage damage.

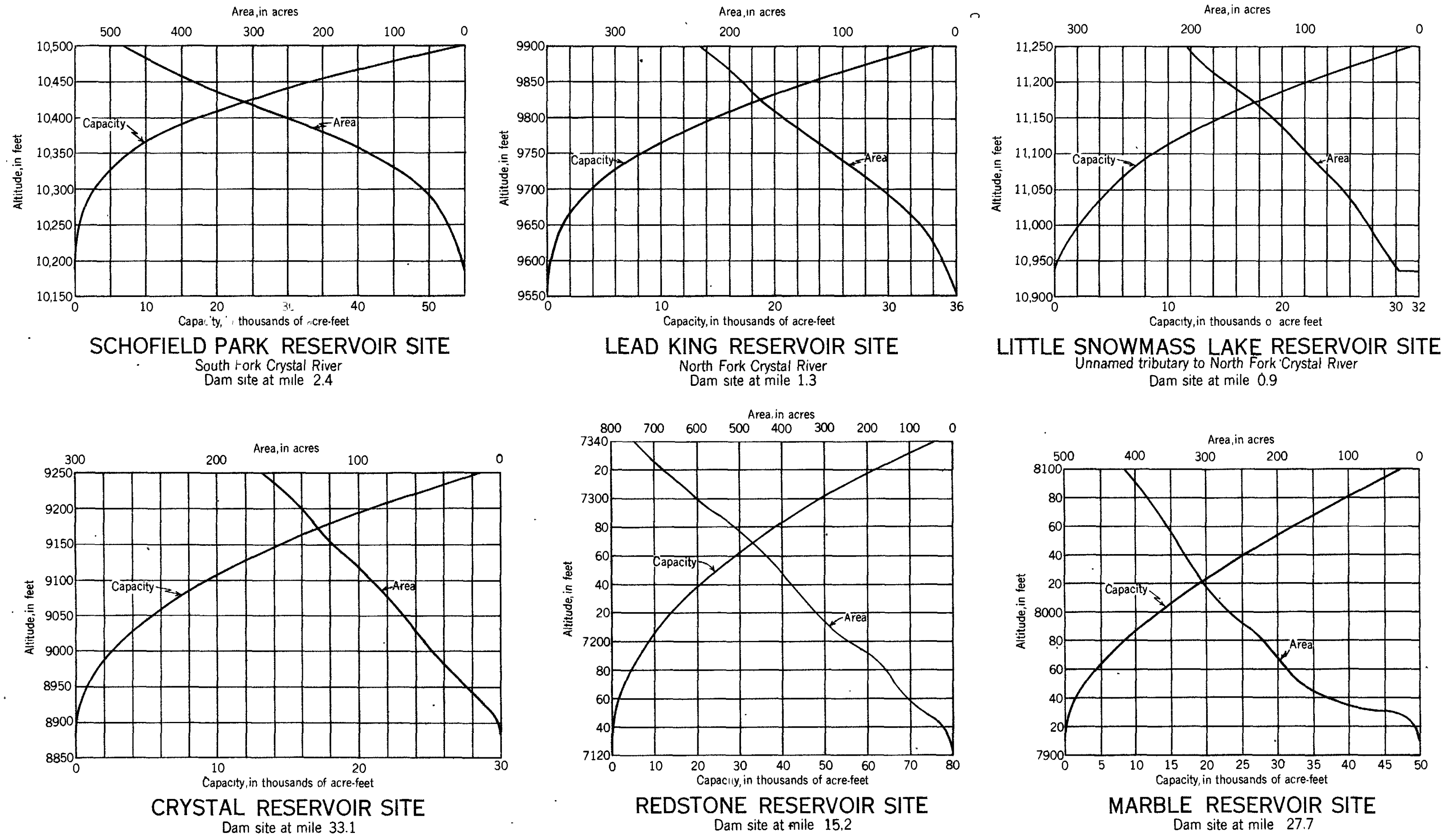

Figure 5.--Area and capacity curves for the Schofield Park, Lead King, Little Snowmass Lake, Crystal, Redstone, and Marble reservoir sites

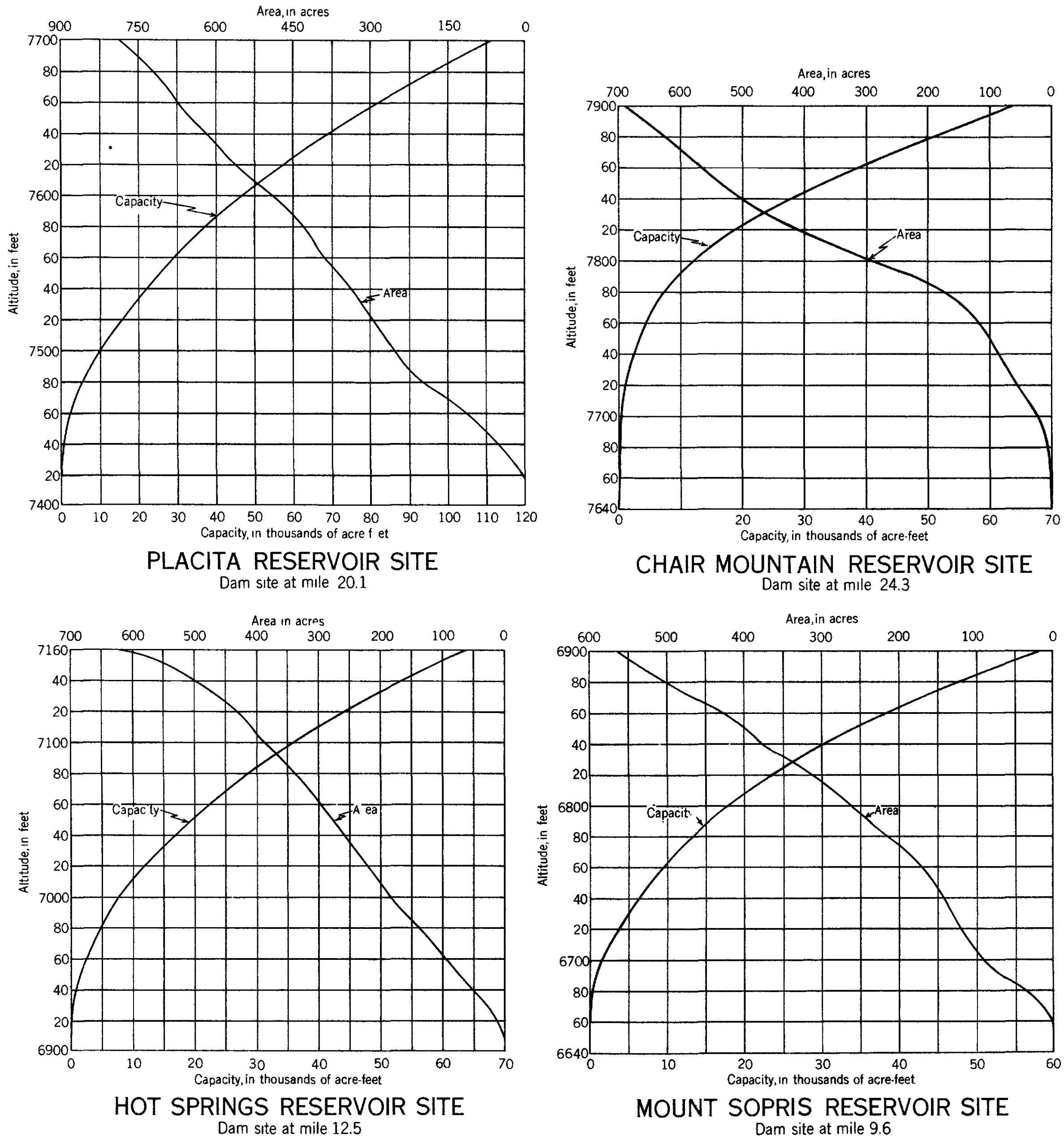

Figure 6.--Area and capacity curves for the Placita, Chair Mountain, Hot Springs, and Mount Sopris reservoir sites

These undeveloped sites are not the only ones in the basin but do cover all the storage possibilities on the main stem and on the North and South Forks. The U. S. Bureau of Reclamation has investigated sites on Thompson Creek and its tributaries and on Prince Creek but had not released the results of these investigations at the time of this writing. Possibly other sites exist on Avalanche, Coal, Yule, and Carbonate Creeks.

Regulated Streamflow

Since many of these storage sites are alternative ones or can be developed to altitudes which would inundate sites upstream therefrom, and because of the limits of the available water supply, not all of them will be utilized. However, the information available at this time is not sufficient to eliminate any of the sites, and the land affected by all of them is therefore classified as valuable for the development of hydroelectric power.

The following illustrative scheme of development is presented to show the potential power made available by storage developed at the Marble and Redstone sites and with flows regulated to produce a maximum of firm power and no allowance made for evaporation.

A dam constructed at the Marble dam site (9DF 7) 192 feet high to altitude 8,100 feet would provide usable storage of 45,000 acre-feet and dead storage of 2,500 acre-feet. The altitude of the water surface of the reservoir would vary from 7,945 to 8,100 feet with a mean altitude of 8,040 feet. In an average year, the flow available from the reservoir at power site 9DF 14 for 90 and 50 percent of the time (Q90 and Q50) would be 148 cfs.

The regulation at Marble would, of course, change the streamflow at downstream sites, and it is estimated that the regulated flow at power sites 9DF 15 and 16 in an average year would be:

Power site index no.	Q90 (in cfs)	Q50 (in cfs)
9DF 15	152	157
9DF 16	155	161

A dam constructed at the Redstone dam site (9DF 9) 215 feet high, to altitude 7,340 feet, would give a usable storage capacity of 73,600 acre-feet and dead storage of 2,900 acre-feet. The altitude of the pool would vary from 7,170 feet to 7,300 feet with a mean altitude of 7,280 feet. This reservoir would re-regulate the flow of the river, already regulated at Marble, and in an average year the estimated outflow from the proposed reservoir to power site 9DF 17 would be 331 cfs for 100 percent of the time since this amount of storage capacity gives complete regulation.

The regulated flow at power site 9DF 18 is the same as at the Redstone dam site since there is no significant inflow in the 2.7-mile reach between the sites.

In an average year the regulated flow at site 9DF 19 is estimated to be 345 cfs 90 percent of the time and 348 cfs 50 percent of the time. The East Mesa Ditch diverts 31.8 cfs from the river near mile 9.3, which point is between the location of the diversion dam and the powerhouse of this site. This reduces the Q90 flow available for power to 313 cfs but does not affect the Q50.

WATERPOWER

Developed Waterpower

Developed power sites 9DF 2 and 9DF 3 on the Crystal River and Yule Creek, respectively, have been described by Follansbee (1929). Both plants were owned by the Consolidated Colorado Yule Marble Company and were used to supply power to the town of Marble and the quarrying and finishing operations in that vicinity and to furnish power for the operation of the electric railroad which operated between the finishing mill in Marble and the quarries. Both plants were dismantled in 1942. Power site 9DF 4, also described by Follansbee (1929) has been dismantled, too.

Undeveloped Waterpower

Between the confluence of the North and South Forks of the Crystal River and the mouth of the stream near Carbondale, the difference in elevation is 2,830 feet in a river distance of 33.1 miles. The river gradient varies from 40 feet to the mile in the first 4 miles above Carbondale to 470 feet to the mile in the 0.8 mile immediately upstream from Marble, with an average fall throughout the 33.1 miles of 82 feet to the mile. Inasmuch as a large amount of water is diverted for irrigation below mile 5.1, it is not practical to develop the head below this point, which is 0.4 mile upstream from Thompson Creek. Because of rather low flows during the winter from about the first of December through March, without storage the potential firm power is small.

Unregulated Waterpower

In the estimates of power that f' llow, computations have been made using he formula P equals 0.068QH where:

P equals the power in kilowatts
Q equals the available water in second-feet,
H equals the gross head in feet from the top of the penstock to the tailrace of the powerhouse.

This formula assumes an over-all efficiency of 80 percent.

The following illustrative scheme of development of the unregulated flow of the Crystal River is presented to show the potential power in an average year. Because of the severity of the winters and the lateness of springs, diversion should be by means of tunnel or covered conduit.

Eight sites have been chosen to develop 2,498 feet of the available head, which is all but 32 feet of the difference in elevation between the confluence of the North and South Forks and mile 5.1 The loss of head in tunnels or conduits has been assumed to be 5 feet per mile. The following sites are discussed in detail in downstream order:

Power site 9DF 12.--The point of diversion is at the confluence of the North and South Forks at mile 33.1, where a low dam would divert water into a tunnel or conduit that would follow the north, or right bank, to a point above a powerhouse at mile 29 5. The altitude at the intake is 8,880 feet and 8,320 feet at the tailrace. A loss of head in the tunnel or conduit of 17 feet has been assumed, leaving a gross head of 543 feet from the top of the penstock to the tailrace. The streamflow and potential power at this site are:

Percent of time	Flow (in cfs)	Power (in kw)
95	13	480
90	14	517
50	35	1,290
Mean	119	4,390

The drainage area above the point of diversion is 39.8 square miles.

Power site 9DF 13.--The point of diversion is at the tailrace of site 9DF 12 at mile 29 5. This site is identical with site 9DF 2 of the Consolidated Colorado-Yule Marble Company which has been described by Follansbee (1929, p. 170). This plant has been dismantled. A pipe or tunnel 0.8 mile long would deliver the water to a powerhouse at mile 28.7 at the town of Marble, where the tailrace altitude would be 7,940 feet. With an assumed loss of head in the tunnel or conduit of 4 feet, the gross head would be 376 feet. The streamflow and potential power at this site are:

Percent of time	Flow (in cfs)	Power (in kw)
95	15	384
90	16	409
50	41	1,050
Mean	140	3,580

The drainage area above the point of diversion is 46.7 square miles.

Power site 9DF 14.--The point of diversion for this site is at mile 27.7, a quarter of a mile below the mouth of Carbonate Creek, where the water-surface altitude is 7,908 feet. A tunnel or conduit would carry the water 3.4 miles to a point above a powerhouse at mile 24.3, where the tailrace altitude would be 7,640 feet. Allowing 17 feet for loss of head in the tunnel or conduit, the gross head would be 251 feet. The streamflow and potential power at this site are:

Percent of time	Flow (in cfs)	Power (in kw)
95	25	427
90	27	461
50	68	1,160
Mean	230	3,930

The drainage area above the point of diversion is 77 square miles.

Power site 9DF 15.--The point of diversion is at mile 24.3 at the Chair Mountain dam site and at the tailrace of site 9DF 14, where the wa er-surface altitude is 7,640 feet. A tunnel or conduit .2 miles long would carry the wa er to a point above a powerhouse at m le 20.1 at the Placita dam site where the tailr ce altitude would be 7,400 feet. Allowing 21 feet for loss of head in the tunnel or conduit, the gross head would be 219 feet. The streamflow and potential power a this site are:

Percent of time	Flow (in cfs)	Power (in kw)
95	29	432
90	31	462
50	72	1,070
Mean	250	3,720

The drainage area above the point of diversion is 94 square miles.

Power site 9DF 16.--The point of diversion for this site is at mile 20.1 at the tailrace of site 9DF 15 at the Placita dam site, where the water-surface altitude is 7,400 feet. A canal or tunnel 4.9 miles long along the right or east hillside would carry the water to a point above the powerhouse 1 mile north of or downstream from Redstone at mile 15.2 at the Redstone dam site, where the water-surface altitude is 7,125 feet. Allowing 25 feet for loss of head in the tunnel or conduit, the gross head would be 250 feet. The streamflow and potential power at this site are:

Percent of time	Flow (in cfs)	Power (in kw)
95	31	527
90	34	578
50	76	1,290
Mean	263	4,470

The drainage area above the point of diversion is 106 square miles.

Power site 9DF 17.--The point of diversion is at mile 15.2 at the tailrace of site 9DF 16 at the Redstone dam site, where the water-surface altitude is 7,125 feet. A tunnel or canal 2.7 miles long would carry the water to a point above a powerhouse at mile 12.5 at the Hot Springs dam site, where the tailrace altitude would be 6,903 feet. Allowing 13 feet for loss of head in the tunnel or conduit, the gross head would be 209 feet. The streamflow and potential power at this site are:

Percent of time	Flow (in cfs)	Power (in kw)
95	47	668
90	50	710
50	92	1,310
Mean	327	4,650

The drainage area above the point of diversion is 162 square miles.

Power site 9DF 18.--The point of diversion at this site is at mile 12.5 at the tailrace of site 9DF 17 at the Hot Springs dam site, where the water-surface altitude is 6,903 feet. A tunnel or conduit 2.9 miles long would carry the water to a point above a powerhouse at mile 9.6 at the Mount Sopris dam site, where the tailrace altitude would be 6,650 feet. Allowing 15 feet for loss of head in the tunnel or conduit, the gross head would be 238 feet. The streamflow and potential power at this site are:

Percent of time	Flow (in cfs)	Power (in kw)
95	48	777
90	51	825
50	93	1,500
Mean	332	5,370

The drainage area above the point of diversion is 168 square miles.

Power site 9DF 19.--The point of diversion is at mile 9.6 at the tailrace of site 9DF 18 at the Mount Sopris dam site, where the water surface altitude is 6,650 feet. A tunnel or conduit 4.6 miles long would carry the water to a point above a powerhouse at mile 5.0, about 0.4 mile above the mouth of Thompson Creek, where the water-surface altitude is 6,368 feet. Allowing 23 feet for loss of head in the tunnel or conduit, the gross head would be 259 feet. The streamflow and potential power at this site are:

Percent of time	Flow (in cfs)	Power (in kw)
95	60	1,060
90	65	1,140
50	108	1,900
Mean	388	6,830

The drainage area above the point of diversion is 215 square miles.

Summary.--The total power available without storage on the Crystal River is:

P95 (available 95 percent of the time)	4,755 kw
P90 (available 90 percent of the time)	5,102 kw
P50 (available 50 percent of the time)	10,570 kw
Pmean (utilizing the mean flow)	36,940 kw

Regulated Waterpower

A dam at the Marble site and one at the Redstone site, as described in the section on stream regulation, would materially increase the low water flow. In the following discussion, potential power is estimated for the same sites as in the foregoing section with the changes in head and length of tunnel or conduit made necessary by the construction of the dams. In computing the head on the plants immediately below the two reservoirs, the mean altitude of the pool (the level of the pool when one-half the live storage has been withdrawn) is used.

Power site 9DF 12.--This site is above all regulation.

Power site 9DF 13.--The streamflow at this site is not affected by regulation, but the powerhouse would be moved upstream to mile 29.2, immediately above the mouth of Lost Trail Creek, where the tailrace altitude would be 8,100 feet, the maximum pool altitude of the proposed Marble reservoir. The tunnel or conduit required would be about 0.3 mile long, and the gross head 220 feet. The streamflow and potential power at this site are estimated to be:

Percent of time	Flow (in cfs)	Power (in kw)
90	16	239
50	41	613

Power site 9DF 14.--Storage of 45,000 acre-feet would be developed at this site (storage site 9DF 7) by a dam at mile 27.7 with a maximum pool altitude of 8,100 feet and a mean pool altitude of 8,040 feet. The powerhouse would be at mile 24.3 with a tailrace altitude of 7,640 feet. Allowing for an estimated 17-foot loss of head in the conduit or tunnel, the mean gross head on the plant would be 383 feet. The regulated streamflow and potential power are estimated to be:

Percent of time	Flow (in cfs)	Power (in kw)
90	148	3,850
50	148	3,850

Power site 9DF 15.--The locations of diversion dam, conduit, and powerhouse would be the same for this site as previously given for unregulated streamflow. The gross head on the plant would be 219 feet. The regulated streamflow and potential power are estimated to be:

Percent of time	Flow (in cfs)	Power (in kw)
90	152	2,260
50	157	2,340

Power site 9DF 16.--The location of the diversion dam for this site would be the same as for the unregulated scheme of development. The powerhouse would have to be moved upstream to the head of the Redstone reservoir site at mile 19.1, where the tailrace elevation would be 7,340 feet. A conduit 1 mile long would be required, and the gross head on the plant, allowing for a 5-foot loss of head in the conduit would be 55 feet. The streamflow and potential power at this site are estimated to be:

Percent of time	Flow (in cfs)	Power (in kw)
90	155	580
50	161	602

If the Redstone reservoir site was part of the development, power sites 9DF 15 and 16 could very logically be combined with a negligible loss of power and at considerable saving in equipment.

Power site 9DF 17.--Storage of 73,600 acre-feet would be developed at this site (storage site 9DF 9) by a dam 215 feet high at the Redstone dam site at mile 15.2. The maximum pool altitude would be 7,340 feet, and the mean pool altitude 7,280 feet. The powerhouse would be located at mile 12.5 with a tailrace altitude of 6,903 feet. Allowing 13 feet for loss of head in the tunnel or conduit, the mean gross head on the plant would be 364 feet. This storage is enough to give 100 percent regulation in an average year and a uniform flow of 331 second-feet. The potential power under these conditions would be 8,190 kw for 100 percent of the time.

Power site 9DF 18.--The location of the diversion dam, conduit, and powerhouse would be the same as given previously under unregulated power. The gross head would be 238 feet, and the streamflow and potential power are estimated to be:

Percent of time	Flow (in cfs)	Power (in kw)
90	331	5,360
50	331	5,360

Power site 9DF 19.--The location of the diversion dam, conduit, and powerhouse would be the same as given previously under unregulated power. The gross head would be 259 feet, and the streamflow and potential power are estimated to be:

Percent of time	Flow (in cfs)	Power (in kw)
90	313	5,510
50	348	6,130

Allowance has been made for 31.8 cfs to be bypassed through East Mesa Ditch during the irrigation season.

Summary of potential power utilizing storage:

P90 (available 90 percent of the time)	26,510 kw
P50 (available 50 percent of the time)	28,370 kw

Use of Power

The town of Carbondale is served by The Carbondale Light & Power Company, a small local utility, which purchases the power from the Public Service Company of Colorado at a point near Glenwood Springs. The demand is mainly for residential and commercial use with little or no industrial use. The valley from Carbondale to Redstone is served by a line owned by the Holy Cross Electric Association, Inc., a Rural Electrification Administration affiliate. The power is obtained from the U. S. Bureau of Reclamation plant at Green Mountain Dam on the Blue River through a wheeling agreement with the Public Service Company of Colorado. The demand is for general farm use and, in Redstone, residential use, primarily in the summer. The valley above Redstone has no electric service.

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