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COLORADO RIVER AND ITS UTILIZATION

BY

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INTRODUCTION.

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The region traversed by the Colorado and its tributaries is for many reasons of intense interest to the people of the United States. Here was the home of that forgotten people of which there is almost no record except the hieroglyphics on the rocks, the ruins of their irrigation systems, and the cliff dwellings by which they are most widely known; here were Spanish missions whose history extends back nearly to the days of Balboa and Cortez; here is the Grand Canyon, whose sublimity was first fully disclosed by Maj. Powell and his associates, who navigated it from end to end in 1869 and 1872; here are the greatest known natural bridges, so remote and inaccessible that they have only recently been discovered; here is the mighty river and its tributaries, as yet largely undeveloped, affording possibilities of extensive use for water power in its many canyons and for irrigation in its desert valleys, which need only the life-giving water to make them productive and valuable. We are interested in its mysteries, its traditions, its history, and its possible future; in the fascination of its deserts, whose immensity awes us; in the grandeur of its mountains, from the highest peaks of the Rockies on the east to the beauties of the Uinta and Wasatch mountains on the west; in the wonders of its canyons, perhaps the most famous in the world; in the range of its climate, from its short and cold summer season in Wyoming, where frosts may occur in every month of the year, to the subtropical temperatures of the valleys of Arizona, where the growing season never ends.

Its high valleys contain valuable forests and its mountains extensive deposits of minerals. At many points within its borders prosperous agricultural communities have been established, of which perhaps the best known are Montrose, Grand Junction, Farmington, Phoenix, and Yuma. The basin is crossed by four trunk-line railroads which give promise that transportation facilities will keep pace with development.

What is to be the future of this immense region? Doubtless its forests will be utilized, its mineral wealth will be exploited, its wonderful scenic beauties will be unfolded. Its greatest development must come, however, from its water resources, on which the development of its other resources must largely depend. Without the water afforded by Colorado River and its tributaries this basin would remain forever a barren desert. These rivers make possible not only the construction of large irrigation systems and the growth of towns, cities, and prosperous agricultural communities but also the generation of hydroelectric power for lighting, heating, industrial uses, and the transportation of freight and passengers.

The United States Geological Survey began the study of the water resources of the basin by establishing gaging stations on Gila River at Buttes, Ariz., in 1889. Since that time records of river discharge have been collected at 180 points in the basin. In the collection of these records and in the study of the water resources the United States Reclamation Service, the Indian Office, the Forest Service, and the Weather Bureau have cooperated. Each of these Federal bureaus has also made independent investigations of certain questions pertaining to the water resources. The Reclamation Service has investigated the available water supply for particular projects and the feasibility of proposed works that have been more or less definitely outlined. That service has also studied the possibilities of storage on the Gila, San Juan, Grand, and Green rivers, and on the Colorado below the junction of the Grand and Green. The Indian Office has investigated the available water, and its possible uses on the Indian reservations in the basin. The Forest Service has studied the water supply and possible water powers of the national forests. The Weather Bureau has collected records of precipitation, temperature, and evaporation at many points. In addition the State officials, who have had the responsibility of distributing the water among a great number of users and of recording, examining, and approving water filings, have collected a mass of information as to the present and proposed use of the streams in the basin. Much exploratory work has been done by private parties and corporations, irrigation and power projects have been examined, railroad routes have been surveyed, and the Grand Canyon has been traversed by several persons and parties since Maj. Powell made the pioneer trip. The diversion of water outside the basin to irrigate nearly half a million acres in the Salton Basin, the breach in the river banks and the diversion of the whole flow of the river to the Salton Sink with the resulting danger to and loss of valuable property in Imperial Valley, the spectacular struggle and final success of the Southern Pacific Co. in closing the breach and restoring the flow of the river to the Gulf of California, and the international questions involved in the joint use of the river by the United States and the Republic of Mexico have brought to the attention of the people of the country, as well as to State and Federal officials, first one and then another phase of the many problems involved in the utilization of Colorado River.

The information relating to the water resources that has been collected by many agencies has never been brought together so that a broad view of the possible utilization of the whole river could be obtained. Mr. La Rue has attempted the pioneer work of assembling the principal facts relating to the subject, and especially of studying the possibility of controlling the flow of the whole river by means of storage reservoirs in order to avoid further danger of overflow to the Salton Sink and to render available for profitable use the enormous quantity of water which now flows unused and largely unusable to the Gulf of California in the form of floods.

In discussing the broader problems of the basin, hundreds, yes, thousands, of the minor possibilities and even plans for expansion have necessarily been unmentioned, though future minor developments will have great local importance and in the aggregate considerable national significance. In general such projects do not preclude the larger use of the river but must be undertaken as part of that larger use.

This report does not, of course, contain the last word on the utilization of Colorado River. Additional facts will become known that may modify the conclusions here recorded. It is hoped, however, that a foundation has been laid for future comprehensive discussion and treatment that will not ignore the effects produced on the present or future utilization of the river by developments in other parts of the basin. The importance of Colorado River to the prosperity of an area extending over seven States warrants broad consideration and perhaps Federal assistance not only in the construction of large irrigation systems and incidental storage works, but also in the important phases of river control.

ACKNOWLEDGMENTS.

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The writer feels especially indebted to Messrs. F. H. Newell, Francis L. Sellew, and John F. Richardson, engineers of the United States Reclamation Service, for the results of surveys at dam sites in the Colorado River basin and for suggestions regarding the storage problems.

PHYSICAL FEATURES OF THE COLORADO RIVER BASIN.[1]

Colorado River is formed by the junction of the Grand and the Green. Green River drains a larger area than the Grand and is considered the upper continuation of the Colorado. Including the Green the river is about 1,700 miles long.

Green River heads near Fremont Peak in the Wind River Mountains, in a group of alpine lakes fed by everlasting snows. The source of Grand River is in the Rocky Mountains 5 or 6 miles west of Longs Peak. Like the Green, it is fed by a group of little alpine lakes that receive their waters directly from perpetual snow banks.

> When the summer comes this snow melts and tumbles down the mountain sides in millions of cascades. A million cascade brooks unite to form a thousand torrent creeks; a thousand torrent creeks unite to form half a hundred rivers beset with cataracts; half a hundred roaring rivers unite to form the Colorado which flows, a mad, turbid stream, into the Gulf of California.

The mouth of the Colorado is in latitude 31° 53′ and longitude 115°. The source of the Green is in latitude 43° 15′ and longitude 109° 54′ approximately. The region of country drained by the Colorado and its tributaries is about 800 miles long, from 300 to 500 miles wide, and comprises 244,000 square miles, an area nearly as large as Minnesota, Wisconsin, Iowa, Illinois, and Missouri, combined.

The region comprises two areas that are topographically distinct. The lower third of the basin is in general elevation but little above the level of the sea, though here and there ranges of mountains rise to altitudes of 2,000 to 6,000 feet. This part of the valley is bounded

[1] Abstracted from Powell, J. W., Canyons of the Colorado, Chapter I, pp. 17-37, The Chautauqua-Century Press, 1895.

on the northeast by a line of cliffs that present a bold and in many places vertical step, hundreds or thousands of feet high to the tablelands above. On the California side of the river a vast desert, which has been known as the Colorado Desert and more recently as the Salton Basin, stretches northwestward from the head of the Gulf of California a distance of 150 miles. At one time in the geologic history of this country the Gulf of California extended a long distance farther to the northwest, above the point where the Colorado now enters it, but this stream brought its mud from the mountains and hills above and bore it into the Gulf, across which it gradually erected a vast dam until the waters on the north were separated from those on the south. Then the Colorado cut a channel into the lower Gulf. The upper waters, being cut off from the sea, gradually evaporated, and the area that has come to be known as the Salton Sink was the bottom of this ancient upper gulf and thus the land is now below the level of the sea. On the Arizona side of the river desert plains are interrupted by mountains. Far to the east in New Mexico are the summits of the mountains which divide the waters of the Colorado from those of the Rio Grande. Here the Gila—the first important tributary of the Colorado—has its source. Some of the tributaries of the Gila rise in mountains in the Republic of Mexico, but the river gathers most of its waters from the great plateau to the northeast. Its sources are everywhere in pine-clad mountains and plateaus, but all the affluents descend quickly into the desert valley through which the Gila winds westward to the Colorado. In times of continued drought the bed of the Gila is dry, but the region is subject to great and violent storms, and floods roll down from the heights with marvelous force and rapidity, carrying devastation in their pathway.

Where the Colorado forms the boundary between California and Arizona it cuts through a number of volcanic rocks by black yawning canyons. Between these canyons the river has a low but rather narrow flood plain with cottonwood groves scattered here and there and a chaparral of mesquite bearing beans and thorns. A part of this desert valley, once the most desolate region of the continent, has been so redeemed by irrigation that it is now considered one of the most prosperous agricultural regions in the United States.

At 280 miles above its mouth and 162 miles above the Gila the Colorado has a second tributary, Bill Williams River,[1] which is but a muddy creek. At 183 miles above this point Virgin River joins the Colorado. Its sources are 7,000 or 8,000 feet above the sea, but it soon drops into a great sandy valley and becomes a river of flowing

[1] The United States Geographic Board has decided that this stream shall be called Williams River.

sand. In ordinary stages it is very wide but very shallow, rippling over the quicksands in tawny waves.

The country lying on both sides of the Colorado for 600 miles of its course above the Gulf of California, stretching to the Salton basin on the west and to the highlands where the Gila heads on the east, is one of singular characteristics. The plains and valleys are low, arid, hot, and naked, and the mountains scattered here and there are lone and desolate. The springs are so few that their names are household words in every Indian rancheria and every settler's home, and there are no streams but the trunk of the Colorado and the trunk of the Gila. On the mountains a few junipers and piñons are found, and cactuses, agave, and yuccas, fleshy plants with bayonets and thorns. There are no forests, no meadows, no green hills, no foliage, but clublike stems of plants armed with stilettos and bearing gorgeous flowers.

The desert valley of the Colorado, which has been described as distinct from the plateau region above, is the home of many Indian tribes. The area at the sources of the Gila, where pines and cedars grow and where creeks and valleys are found, is a part of the Apache land. In the lower valley of the Gila, the Pimas, Maricopas, and Papagos, skilled agriculturists cultivate lands by irrigation. In the same region are many ruined villages. The dwellings of these towns in the valley were built chiefly of adobe, and the fragments of the ancient pueblos have stood through centuries of storm. Other pueblos near the cliffs on the northeast were built of stone. The people who occupied them cultivated the soil by irrigation and built canals scores of miles in length and constructed reservoirs to store water. They were skilled workers in pottery. From the fibers of some of the desert plants they made fabrics with which to clothe themselves and they cultivated cotton. Still farther to the north the Chemehuevi lived partly along the river and partly in the mountains to the west, where a few springs are found. The Pimas, Maricopas, and Papagos were among the most advanced tribes found in the United States. The Chemehuevi were among the very lowest. They are the original "Digger Indians," called so by all the other tribes.

The low desert with its mountains which has thus been described is separated from the upper region of plateau by a complicated and irregular line of cliffs facing to the southwest. The different parts of this cliff have been named by the people living below as distinct mountains, but all rise to the summit of the same great plateau region.

The upper region, extending to above the junction of the Green and the Grand, constitutes the great plateau province. These plateaus are drained by Colorado River and its tributaries, the eastern and

GRAND CANYON OF THE COLORADO AT THE FOOT OF TOROWEAP, LOOKING EAST.

southern margin by the Rio Grande and its tributaries, and the western by streams that flow into the Great Basin and are lost in Great Salt Lake and other bodies of water that have no outlet to the sea. The general surface of this upper region is 5,000 to 8,000 feet above sea level, though the channels of the stream are commonly much lower.

For more than a thousand miles along its course the Colorado has cut for itself a deep, narrow gorge or canyon, but at some points where lateral streams join it the canyon is broken and these narrow transverse valleys divide it into a series of canyons. Virgin, Kanab, Paria, Escalante, Fremont, San Rafael, Price, and Duchesne rivers on the west, and the Little Colorado, San Juan, Grand, White, and Yampa on the east have also cut out for themselves narrow, winding gorges or deep canyons. Every river entering these has cut another canyon; every lateral creek has cut a canyon; every brook runs in a canyon; so that much of the upper part of the basin of the Colorado is traversed by a labyrinth of these deep gorges. The longest unbroken canyon through which the Colorado runs is that between the mouth of the Paria and the Grand Wash, a distance of 284 miles. (See Pls. I and II, *B*.) All the scenic features of this canyon are on a giant scale. The streams run at depths almost inaccessible. Low plateaus, dry and treeless, stretch back from the brink of the canyon. In some places the country rock is composed of richly colored and variegated marls, and here the surface is a bed of loose, disintegrated material through which one walks as in a bed of ashes. In other places the country rock is a soft sandstone, the disintegration of which has left broad stretches of drifting sand, white, golden, and vermilion. Where this sandstone is a conglomerate a paving of pebbles has been left—a mosaic of many colors, polished by the drifting sands, glistening in the sunlight.

After the canyons the most remarkable features of the country are the long lines of cliffs, scores or hundreds of miles in length—great topographic steps, many of which are hundreds or thousands of feet in height—presenting steep faces of rock, in places vertical. After one has climbed one of these steps he may descend by a gentle, perhaps imperceptible slope to the foot of another. Intermittent streams coming down the cliffs have cut many canyons or canyon valleys by which the traveler may pass from the plain below to the terrace above.

The region is further diversified by short ranges of eruptive mountains. A vast system of fissures—huge cracks in the rocks to the depths below—once extended across the country. From these crevices floods of lava have poured, covering mesas and tablelands with sheets of black basalt. Huge cinder cones—red, brown, and black—naked of vegetation, stand along the fissures, and, in contrast to the bright variegated sedimentary rocks associated with them, they form conspicuous landmarks. These canyons, obstructing cliffs, and desert wastes long prevented travelers from penetrating the country, so that it was almost unknown until the early fifties, though parts of it had been traversed by Spanish adventurers as well as by priests who sought to convert the Indian tribes to Christianity, but even in the earlier days enough had been seen to foment rumor, and many wonderful stories were told in hunter's cabin and prospector's camp—stories of parties entering the gorge in boats and being carried down with fearful velocity into whirlpools where all were overwhelmed in the abyss of waters, and stories of underground passages for the great river into which boats had passed never to be seen again. It was currently believed that the river was lost under the rocks for several hundred miles.

The Indians too have woven the mysteries of the canyons into the myths of their religion. Long ago there was a great and wise chief who mourned the death of his wife and would not be comforted, until Tavwoats, one of the Indian gods, came to him and told him his wife was in a happier land, and offered to take him there that he might see for himself if upon his return he would cease to mourn. The great chief promised. Then Tavwoats made a trail through the mountains that intervene between that beautiful land, the balmy region of the great West, and this, the desert home of the poor Numa. This trail was the canyon gorge of the Colorado. Through it he led him; and when they had returned the deity exacted from the chief a promise that he would tell no one of the trail. Then he rolled a river into the gorge, a mad, raging stream, that should engulf any that might attempt to enter thereby.[1]

EXPLORATIONS.[2]

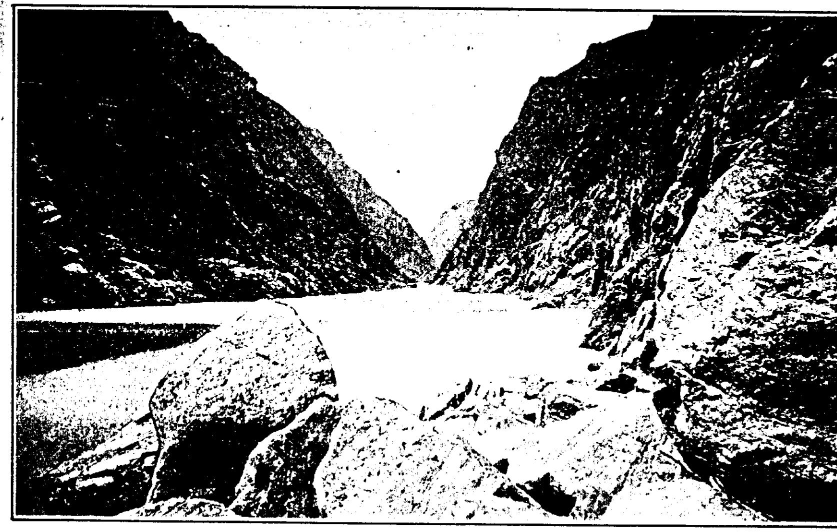
The history of exploration of the basin of the Colorado is replete with accounts of interesting and romantic incidents, with discoveries, starvations, battles, massacres, and lonely, dangerous journeys. A brief outline of the more important events, arranged in chronologic order, is here presented.

1531. As early as 1531 vague rumors were current of a large river, the mouth of which was closed by a cable stretched across from side to side.

1539. Francisco de Ulloa sailed from Acapulco July 8, 1539, with a fleet of three vessels, and after many difficulties reached shallow water at the head of the Sea of Cortes (now known as the Gulf of California). This seems to have been the first visit of Europeans to the mouth of the Colorado. Ulloa did not see the river but surmised that one might be there.

1540. Hernando de Alarcón sailed in May, 1540, to explore the region north of New Spain, and at last reached the head of the Sea of Cortes. He says: "And it pleased God that after this sort we came to the very bottom of the bay, where we found a very mighty river, which ran with so great fury of a stream that we could hardly sail against it." [3] Here began the acquaintance of Europeans with the river now known as the Colorado of the West. Alarcón proceeded up the Colorado in small boats to a point about 100 miles above the mouth of Gila River.

[1] Powell, J. W., op. cit., pp. 35-37.
[2] Information given under this heading was obtained largely from Dellenbaugh, F. S., The romance of the Colorado River, New York, 1902.
[3] Spelling modernized.



A. SOCKDOLOGER RAPIDS, GRAND CANYON OF THE COLORADO.

B. GRAND CANYON OF THE COLORADO AT THE FOOT OF TOROWEAP, LOOKING WEST.

1540. Melchior Díaz, in the fall of 1540, explored the Colorado and surrounding country in the vicinity of the Chocolate Mountains. At about the same time (1542) Don López de Cárdenas discovered the Grand Canyon. The canyons of the river, however, remained unexplored for 329 years thereafter—until 1869.

1605. Don Juan de Oñate, governor of New Mexico, made a trip from the village of San Juan on the Rio Grande to the Colorado in the vicinity of Williams River and went down the Colorado to the Gulf.

1618. Zalvidar, with Padre Jiménez and 47 soldiers, went out to Moki and thence to the Rio de Buena Esperanza (Colorado River), but they evidently encountered Marble Canyon and soon returned.

1680 to 1711. Padre Eusibio Francisco Kino,[1] an Austrian by birth and a member of the Jesuit order, made many journeys over the whole of northern Sonora and the southern half of Arizona, then comprising the Pimeria Alta, the upper land of Pimas, and Papagueria, the land of Papagos. His base of explorations was the mission of Dolores, which he established in Sonora in 1687. For some 30 years Kino labored in this field with tireless energy.

1744. Padre Jacobo Sedelmair went down the Gila from Casa Grande to the great bend, and thence across to the Colorado at about the mouth of Williams River, but his journey was no more fruitful than those of his predecessors in the last two centuries.

1768–1776. Francisco Garcés made five expeditions. The first was made in 1768 and the second in 1770, but in these journeys he did not reach the Colorado. In the third, in 1771, he went down the Gila to the Colorado and descended the Colorado along its banks, possibly to the mouth. In the fourth, in 1774, he went with Capt. Anza to the Colorado and to the Mission of San Gabriel in California near Los Angeles. In his fifth and most important expedition, in 1775–76, he again accompanied Capt. Anza, who was bound for the present site of San Francisco there to establish a mission. At Yuma Garcés left the Anza party, went down to the mouth of the Colorado, and then up along the river to Mohave, and after another trip out to San Gabriel he started on the most important part of all his journeys from Mohave to the Moki towns, the objective point of all expeditions eastward from the Colorado. Leaving Mohave June 4, 1776, Garcés struck eastward across Arizona and passed near the rim of the Grand Canyon, though he did not then see it. Garcés found his way down to the Little Colorado by means of a side canyon and got up again on the other side in the same way. On July 2 he arrived at the pueblo of Oraibi. The natives refused to allow him to remain at Oraibi and he left on July 4. He reached the Colorado again July 25, his journey having proved absolutely fruitless so far as missionary work was concerned, and he arrived at his mission of Bac, September 17, 1776.

1776. On July 29, 1776, another even greater expedition was begun at Santa Fe by the Fray Padre Francisco Silvestre Vélez Escalante, in his search for a route to Monterey. Escalante believed a better road existed to Monterey by way of the north than by the middle route, and a further incentive to journey that way was probably the rumors of large towns in that direction.

The party went by way of Abiquiu and Chama River and reached the San Juan about where it first meets the north line of New Mexico; thence they crossed several tributaries to the head of Dolores River, which they descended for 11 days. The party made its way across Grand River, the Book Plateau, and White River, to the Green (called the San Buenaventura), which was forded apparently near the foot of Split Mountain Canyon. Following

[1] Spelled also Kühn, Kühne, Quino, and in several other ways. Dellenbaugh (op. cit., p. 80) says that Kühn or Kühne is probably the correct form, but long usage gives preference to Kino.

the course of the river down some 10 leagues, they went up the Uinta (now called Duchesne) and finally crossed the Wasatch Range, coming down the western side, evidently by way of what is now known as Spanish Fork, to Utah Lake, then called by the natives Timpanogos. Here they heard of a greater lake to the north, but instead of seeking it they turned southwesterly in what they considered the direction of Monterey through Sevier River valley, calling the Sevier the Santa Isabel, and kept down along the western edge of the high plateaus. It was by this time the 7th of October, and Escalante concluded that it would be impossible to reach Monterey before winter set in; he therefore persuaded his companions that it would be best to strike for the Moki towns in Arizona.

Going on southward past what is now Parowan, they came to the headwaters of a branch of the Virgin, in Cedar Valley, and this they followed down to the main stream, which they left flowing southwesterly. The place where they turned from it was probably about at Toquerville. Trying to make their general course southeast, they passed over the country now known as Kanab, Ninemile Valley, Kaibab Plateau, Horse Rock Valley, and Vermilion Cliffs, and at length struck the Colorado at Marble Canyon. Twice they succeeded in descending to the river but were unable to cross. On November 8, 1776, they reached the ford now known as the Crossing of the Fathers, about 35 miles north of Lee Ferry, a few miles north of the Utah-Arizona State line. From this crossing to the Moki towns Escalante had a plain trail, and on reaching Santa Fe he and his party had completed a circuit of more than 1,500 miles, mainly through unknown country. This is one of the most remarkable explorations ever carried out in the West.

1779–1781. The authorities, importuned by Capt. Palma, the Yuma chief whose devotions and piety had so delighted Garcés, had decided to establish on the Lower Colorado two nondescript settlements, a sort of cross between mission, pueblo, and presidio. Garcés therefore went to Yuma again in 1779 to prepare the way, and in 1780 two of the hybrid affairs were started. One, at what is now Fort Yuma, was called Puerto de la Purísima Concepción, after the little canyon near by which had been so named by Garcés, a canyon 50 feet deep and 1,000 feet long; the other, about 8 miles down, was called San Pedro y San Pablo de Bicuner. There were four padres; Garcés and Barraneche at the upper station and Díaz and Moreno at the lower. Each place had 8 or 10 soldiers, a few colonists, and a few laborers. The Spaniards were obliged to appropriate some of the best lands to till for the support of the missions, and this fact, together with the general poverty of the establishments when he had expected something fine, disgusted Palma and exasperated him and the other Yumas. In June, 1781, Capt. Moncada, lieutenant governor of Lower California, arrived with soldiers and recruits en route for California settlements and encamped opposite Yuma. After some of these people had been sent forward or back as the plans demanded, Moncada remained at the camp with a few of his soldiers. On the 17th of July, without a sign preliminary to the execution of their wrath, Capt. Palma and all his band threw piety to the winds and annihilated with clubs Moncada's camp and most of the men in the two missions. Garcés, who had never been to Palma and his people anything but a kind and generous friend, and his assistant, Barraneche, were at first spared, but the rabble declared these two were the worst of all, and under this pressure Palma yielded. The military expeditions sent to avenge the massacre were unsuccessful and the missions on the Colorado were ended. Nearly half a century passed before the face of white man was again seen at the mouth of the river.

1808. Two years after the return of the famous Lewis and Clark expedition Andrew Henry crossed over the south pass into the valley of Green River in Wyoming.

1824. Gen. William Henry Ashley having previously organized a fur-trading company in St. Louis, then the center of all western commerce, had established himself in Green River valley with a large band of expert trappers.

1825. In 1825 Ashley had established a camp at the mouth of Henrys Fork, near Flaming Gorge. During this year Ashley and his party constructed boats to go down the Green for the purpose of trapping beaver. The trip was successful through Flaming Gorge and Horseshoe Canyon, but in Red Canyon their boats were wrecked in a cataract now known as Ashley Falls. Ashley and his party left the river at Browns Park. This was, no doubt, the first attempt to navigate Green River.

1825 to 1839. During this period the Colorado basin was visited by many trappers and explorers. Some of the most prominent were James O. Pattie and his father (1825), R. W. H. Hardy (1826), Jedediah Smith (1826), Kit Carson, one of the greatest scouts and trappers (1826), Ewing Young, trapper (1827), William Wolfskill (1830), Capt. Bonneville (1832), and Thomas J. Farnham (1839).

By the time the third decade of the nineteenth century was fairly begun the trappers were crossing in considerable numbers from the headwaters of the Missouri and the Platte into the valleys of the Colorado and the Columbia.

1840. By the year 1840 the great western wilderness had been traversed throughout by Americans. Only the canyons of the Colorado remained, at least below the mouth of Grand River, almost as much of a problem as before the fur trade was born.

1842. In 1842 Frémont came up the North Platte and Sweetwater Branch, crossing from that stream by the South Pass over to the headwaters of the Colorado. Frémont's explorations of the Colorado and the West covered the period 1842 to 1846.

1847 to 1852. In 1847 the Mormons crossed the Colorado River basin and settled in Salt Lake Valley. In 1849 the discovery of gold in California led many emigrants to cross the Colorado River basin. In 1851 Fort Yuma was established. According to Lieut. Hobbs, the first steamboat came up the Colorado to Yuma in 1850, frightening the Yumas so that they ran for their lives, exclaiming that the devil was coming, blowing fire and smoke out of his eyes and nose and kicking back with his feet in the water. This was the stern-wheel steamboat *Yuma*, which evidently antedated the *Uncle Sam*, usually credited with being the first steamboat on the Colorado. In 1851 George A. Johnson came to the mouth of the Colorado on the schooner *Sierra Nevada*.

1857. Lieut. Ives with the steamboat *Explorer* and Capt. Johnson with the steamboat *Colorado* navigated Colorado River to a point called "the head of navigation." The highest point reached by Lieut. Ives was Vegas Wash; Capt. Johnson took his boat to a point several miles above Vegas Wash.

1859. During the year 1859 Capt. Macomb was sent to examine the junction of the Green and Grand. For a considerable distance he followed from Santa Fe almost the same trail that Escalante had traveled 83 years previously. Dr. J. S. Newberry, the eminent geologist, who had been with Lieut. Ives, was one of this party. Macomb and Newberry succeeded in forcing their way within 6 miles of the junction, there to be completely baffled and turned back.

1866. In 1866 another attempt was made to navigate the Colorado above Mohave. Capt. Rogers, who for four years had been on the Lower Colorado, took the steamboat *Esmeralda*, 97 feet long and drawing 3½ feet of water, up as far as Callville, near the mouth of the Virgin, which was several miles above the highest point attained by Ives in his skiff, but little if any farther than Johnson had come with his steamboat.

1868. During the winter of 1868 and 1869 Maj. John Wesley Powell made several important journeys in connection with his purpose of exploring the great walled river; one was southward as far as Grand River; a second followed White River to its junction with the Green; and a third went northward around the base of Uinta Mountains, skirting the gorges afterward named Lodore, Whirlpool, and Red Canyon. In these travels he formed his plans for an attempt to explore fully the remarkable string of chasms. Funds for the proposed expedition were furnished by the State institutions of Illinois and the Chicago Academy of Sciences—none by the Federal Government, so that this was in no way a Government expedition, except that Congress passed a joint resolution authorizing him to draw rations for 12 men from western Army posts.

1869. On May 24, 1869, Maj. Powell and his party left Green River, Wyo., on their voyage down the Green and the Colorado to the mouth of the Virgin. There were 12 men in the party; three of the four boats were of oak, 21 feet long, and one was of light pine, 16 feet long. During the last week in August, Powell reached his goal, the mouth of Virgin River. Here he left the party, but the others continued down the river to the Gulf, which they reached before the end of September, 1869. Although Powell had demonstrated the possibility of passing alive through the 1,000-mile stretch of canyons on the Green and the Colorado, the scientific results of his hazardous voyage were not what he desired. Owing to numerous disasters many instruments had been lost and he had been prevented by this as well as many other circumstances from fully accomplishing his intentions. For this reason he determined to make another descent if he could obtain pecuniary aid from the Government. Congress appropriated a sum for a second expedition.

1871. On May 22, 1871, Powell left Green River, Wyo., on his second voyage down the Green and the Colorado. This voyage of exploration of the canyons on the main stream and its tributaries was completed to Lee Ferry in the second week of October. Lee Ferry is at the mouth of Paria River, at the head of Marble Canyon, in Arizona. Here the boats were cached and the party spent the winter in the vicinity of Kanab.

1871. While the Powell party was making its second voyage down the Green and the Colorado another expedition was being made up the Colorado. Lieut. Wheeler, topographical engineer of the War Department, started from Fort Mohave September 16, 1871, to explore the Colorado to the mouth of Diamond Creek, which he reached October 22. It required four weeks of extremely hard work to make the voyage up the Colorado from Fort Mohave to the mouth of Diamond Creek, whereas members of the party made the trip from the mouth of Diamond Creek to Fort Mohave in five days.

1872. On August 17, 1872, Maj. Powell returned to his boats at the mouth of the Paria and started on his second voyage through the Grand Canyon. On reaching the mouth of Kanab Creek, Powell decided to end the river work on account of the extreme high water, which made the rapids in the second granite gorge impassable. The topographic, geologic, and geodetic work of the survey did not cease with his departure from the river but was continued in the territory adjacent to the Grand Canyon.

1877. The Southern Pacific Railroad was completed to the Colorado at Yuma, Ariz., in 1877.

1883. The Atlantic & Pacific Railroad crossed the Colorado at Needles in 1883. The Rio Grande Western crossed the Green in Gunnison Valley, Utah, in 1883; the Union Pacific had been constructed to Green River, Wyo., in 1869.

1889. A new railroad was proposed from Grand Junction, Colo., down the Colorado through the canyons to the Gulf of California, a distance of 1,200 miles. At that time it was difficult to procure coal on the Pacific coast and it was thought that this "water-level" road, crossing no mountains, would be profitable in bringing the coal from Colorado to the Golden Gate. A company was organized with Frank M. Brown as its president, and surveys were started as the preliminary to the construction of the Denver, Colorado Canyon & Pacific Railway. Brown and his party started from Green River, Utah, on May 25, 1889, to continue the railroad survey down the Colorado, the survey down the Grand having been completed to its mouth. The chief engineer of the proposed railroad was Robert Brewster Stanton. The difficulties encountered in conducting the surveys through Cataract Canyon were enormous. The line was carried to the mouth of the Paria. Boats were not suitable for the river work, and it was decided not to attempt to carry the railroad survey into Marble Canyon. A reconnaissance investigation of this canyon, however, was attempted, and just below the Soap Creek Rapids, in Marble Canyon, Brown, the president of the railroad company, was drowned. A few days later two other members of the party were lost in the river. This second disaster caused Stanton to resolve to leave the river. The remaining members of the party climbed from Marble Canyon at the point known as Veseys Paradise. On July 19, 1889, the party reached the surface of the country, 2,500 feet above the river. By November 25, 1889, Stanton had organized a new party to continue the railroad survey. The trip through the lower canyons on the Colorado was completed March 17, 1890.

1891–1894. Since the Stanton party several successful and unsuccessful descents have been made. The first was the "Best party," representing the Colorado, Grand Canyon & Improvement Co., with eight men and two boats similar to those used by Stanton on his second voyage. The expedition left Green River, Utah, July 10, 1891. The trip was successful to Lee Ferry. No men were lost. The expedition was abandoned at this point.

In 1891 the steam launch *Major Powell*, 35 feet long, equipped with two 6-horsepower engines driving twin screws, was brought out in the summer from Chicago by way of Rio Grande Western Railway to the crossing of Green River and was launched in September of that year. A screw was soon broken and the attempt to go down the river abandoned. In 1892 another effort was made, which was also given up after a few miles, but in 1893 the *Major Powell* was taken down to the junction of the Green and Grand and back, making a second trip in April. Several other steamboats were later put on the river, the *Undine* being the most pretentious. She was wrecked trying to run upstream on Grand River above Moab. In 1894 Lieut. C. L. Potter made a successful voyage from Diamond Creek to the mouth of the Virgin.

1895. September 20, 1895, N. Galloway and William Richmond started from Green River, Wyo., and made the trip to Lee Ferry in flat-bottomed boats. In September, 1896, they started again from Henry Fork, Wyo., and went to the Needles, reaching there February 10, 1897. Since that time Galloway has made several successful descents.

1896. In August, 1896, George F. Flavell and a companion left Green River, Wyo., and successfully descended the Colorado to Yuma, Ariz., in flat-bottomed boats, reaching there December, 1896.

1907. In 1907 three miners, Charles Russell, E. R. Monett, and Albert Loper, with three steel boats, each 16 feet long, left Green River, Utah, September 20, to make the descent. Loper and one damaged boat were left at Hite, near the mouth of Fremont River, while Russell and Monett proceeded. In the beginning of the Grand Canyon they lost a boat, but with the remaining one, after various disasters, finally made their exit from the Grand Canyon January 31, 1908. Their boats of steel were unsuited to the river work.

1909. Julius F. Stone and N. Galloway left Green River, Wyo., September 12, 1909, making a successful descent through the many canyons of the Green and the Colorado.

1911. September 8, 1911, Ellsworth and Emery Kolb left Green River, Wyo., on a photographic trip down the Green and the Colorado. The trip was a complete success. Interesting pictures were obtained, many of which showed the party shooting various rapids. The Kolbs landed at Needles January 18, 1912.

Although many successful descents have been made through the canyons of Green and Colorado rivers the dangers of such a trip must not be overlooked. In making this trip at the present time it is necessary to take every precaution to make sure that the equipment is complete. No pains should be spared in providing the proper kind of boats. Life preservers should be provided, and even at the present time, with the settlements along the river, care should be taken to provide sufficient food.

POPULATION.

An estimate of the population of the Colorado River basin in 1915 and a list of the principal cities are presented in the following tables:

Estimated population in Colorado River basin, 1915.

Arizona	200,000	Wyoming	30,000
Colorado	127,000	Nevada	7,000
Utah	47,000	California	2,000
New Mexico	44,000	Mexico	75

Population of important cities in Colorado River basin, 1910.

Tucson, Ariz	13,193	Gallup, N. Mex	2,204
Phoenix, Ariz	11,134	Silverton, Colo	2,153
Grand Junction, Colo	7,754	Glenwood Springs, Colo	2,019
Globe, Ariz	7,083	Telluride, Colo	1,756
Rock Springs, Wyo	5,778	St. George, Utah	1,737
Prescott, Ariz	5,092	Ouray, Colo	1,644
Morenci, Ariz	5,010	Green River, Wyo	1,313
Clifton, Ariz	4,874	Las Vegas, Nev	1,275
Durango, Colo	4,686	Steamboat Springs, Colo	1,227
Nogales, Ariz	3,514	Gunnison, Colo	1,026
Yuma, Ariz	2,914	Price, Utah	1,021
Lowell, Ariz	2,500	Fruita, Colo	881
Jerome, Ariz	2,394	Kemmerer, Wyo	843
Winslow, Ariz	2,381		

COMPARISON WITH THE BASIN OF THE NILE.

As the Colorado is often called the Nile of America, a brief comparison of these two river systems is interesting.

Like the Colorado, the Nile carries an enormous quantity of silt. By the deposition of silt each river has built up a delta cone at its mouth. The soil of the deltas is exceedingly fertile and wonderful

crops can be grown. The climate of the Nile Valley is similar to that of the valley of the lower Colorado. The precipitation is small and crops can not be raised without irrigation. Every kind of crop grown in the valley of the Nile in Egypt can be grown in the region of the lower Colorado.

The principal crops in the lower Colorado region, including Imperial Valley, are cotton, alfalfa, barley, corn, and melons. Dates are also grown successfully in Imperial Valley.

Comparison of the Nile[1] and the Colorado.

Total area of the Nile basin	square miles	1,112,000
Total area of the Colorado River basin	do	244,000
Length of the Nile (source of Kagera to sea)	miles	3,946
Length of the Colorado (source of Green to Gulf)	do	1,700
Total fall in the Nile (source to mouth)	feet	6,600
Total fall in the Colorado (source to mouth)	do	14,000
Irrigable area of Nile Valley in Egypt	acres	6,663,000
Irrigable area of the Colorado below Virgin River[2]	do	2,734,000
Area irrigated in Nile Valley in Egypt in 1913	do	5,351,000
Area irrigated in Colorado River basin below Virgin River[2] in 1913	do	367,000
Mean annual run-off of the Nile at Cairo, Egypt	acre-feet	68,000,000
Mean annual run-off of the Colorado at Yuma, Ariz	do	17,000,000

Principal crops grown in valley of the Nile in Egypt.[3]

	Acres.
WINTER SEASON.	
Clover (about)	1,400,000
Wheat (about)	1,250,000
Beans (about)	550,000
Barley (about)	400,000
SUMMER SEASON.	
Cotton	1,650,000
Millets and maize	170,000
Sugar cane	50,000
Rice	240,000
Various	73,000
FLOOD SEASON.	
Millets and maize	1,700,000
Rice	50,000
Gardens and orchards cover	30,000

The most valuable tree in the country is the date palm, of which there are 6,000,000 bearing fruit. Of these 4,200,000 are in Upper Egypt and 1,800,000 in Lower Egypt.

[1] Willcocks, William, The Nile in 1904.
[2] Areas in the Gila and Williams River basins excluded.
[3] Willcocks, William, and Craig, J. I., Egyptian irrigation, vol. 1, p. 110, 1913.

WATER SUPPLY.

GAGING STATIONS.

The Geological Survey has maintained in the basin of Colorado River the gaging stations named in the following list. The stations are arranged in downstream order. The main stem of the river is determined by measuring or estimating its drainage area—that is, the headwater stream whose drainage area is largest is considered the continuation of the main stream, and local changes in name and lake surface are disregarded. All stations from the source to the mouth of the main stem of the river are presented first, and those on the tributaries in regular order from source to mouth follow, the streams in each tributary basin being listed before those of the next basin below.

NOTE.—Dash after a date indicates that station was being maintained Sept. 30, 1915. Period after a date indicates discontinuance.

Green River (head of Colorado River), near Kendall, Wyo., 1910–1912.
Green River near Daniel, Wyo., 1915–
Green River at Green River, Wyo., 1895–1906; 1915.
Green River near Bridgeport, Utah, 1911–
Green River at Jensen, near Vernal, Utah, 1903–1906; 1914–
Green River at Ouray, Utah, 1904–5; 1913–1915.
Green River at Green River (formerly Blake), Utah, 1894–1899; 1905–1911.
Green River at Little Valley near Green River, Utah, 1910–
Colorado River at Bulls Head, near Mohave, Ariz., 1902–3.
Colorado River at Hardyville, Ariz., 1905–1907.
Colorado River at Yuma, Ariz., 1891–
  Horse Creek at Daniel, Wyo., 1915–
  Cottonwood Creek near Marbleton, Wyo., 1915–
  New Fork (head of East Fork) at Pinedale Crossing, near Cora, Wyo., 1905.
  New Fork at Alexanders ranch, near Cora, Wyo., 1910–11.
  New Fork near Boulder, Wyo., 1915–
  East Fork at Newfork, Wyo., 1905–6; 1915–
    Pine Creek near Pinedale, Wyo., 1904–1906; 1910–1912; 1915–
    Pole Creek near Fayette, Wyo., 1904–1906.
    Pole Creek near Pinedale, Wyo., 1910.
      Fall Creek at Fayette, Wyo., 1904–5.
    Boulder Creek near Boulder (Newfork), Wyo., 1904–1906; 1915–
  North Piney Creek near Marbleton, Wyo., 1915–
    Middle Piney Creek near Marbleton, Wyo., 1915–
  La Barge Creek at La Barge, Wyo., 1915–
  Fontenelle Creek near Fontenelle, Wyo., 1915–
  Big Sandy Creek at Leckies ranch, near Big Sandy, Wyo., 1910–
  Big Sandy Creek near Eden, Wyo., 1911–
  Big Sandy Creek near Farson, Wyo., 1915–
    Dutch Jo Creek at Dutch Jo Ranger station, near Big Sandy, Wyo. 1911–1912.
    Squaw Creek near Big Sandy, Wyo., 1911–1912.
    Little Sandy Creek near Eden, Wyo., 1911–12.
  Blacks Fork near Urie, Wyo., 1913–
  Blacks Fork above Hams Fork, near Granger, Wyo., 1896–7.
  Blacks Fork below Hams Fork, at Granger, Wyo., 1897–1900.

Colorado River tributaries—Continued.
  Beaver Creek at Myer's ranch, near Ladore, Colo., 1910–11.
  Vermilion Creek at Bassett's ranch, near Ladore, Colo., 1910–11.
  Yampa River at Yampa, Colo., 1910–1913.
  Yampa River at Steamboat Springs, Colo., 1904–1906; 1910–1913.
  Yampa River at Craig, Colo., 1901–2; 1904–1906; 1910–1913.
  Yampa River near Maybell, Colo., 1904–5; 1910–1912.
    Terrible Creek:
      Trout Creek at Pinnacle, Colo., 1910–11.
    Soda Creek at Steamboat Springs, Colo., 1910–11.
    Elk River at Hinman Park, Colo., 1912–13.
    Elk River near Clark, Colo., 1910–1913.
    Elk River near Trull, Colo., 1904–1906; 1910–1913.
      Mad Creek near Steamboat Springs, Colo., 1912–13.
    Sage Creek:
      Fish Creek at Dunkley, Colo., 1910–11.
    Elk Head Creek near Craig, Colo., 1906; 1910–1913.
    Fortification Creek at Craig, Colo., 1905–6; 1910–1913.
    Williams Fork near Pyramid, Colo., 1910–11.
    Williams Fork at Hamilton, Colo., 1904–1906; 1910–
    Milk Creek near Axial, Colo., 1904–5.
    Little Snake River [Middle Fork] near Battle Creek, Colo., 1912–13.
    Little Snake River at Dixon, Wyo., 1910–1913.
    Little Snake River near Maybell, Colo., 1904.
      South Fork of Little Snake River near Battle Creek, Colo., 1912–13.
      Slater Creek at Baxter ranch, near Slater, Colo., 1912–13.
      Slater Creek near Slater, Colo., 1910–1912.
      Beaver Creek:
        Willow Creek near Baggs, Wyo., 1912–13.
      Fourmile Creek near Baggs, Wyo., 1912–13.
  Ashley Creek above Dry Fork, near Vernal, Utah, 1911–
  Ashley Creek below Dry Fork, near Vernal, Utah, 1900–1904; 1911–
    Dry Fork of Ashley Creek at Vernal, Utah, 1904.
  Vernal Milling & Lighting Co.'s canal at Vernal, Utah, 1913–14.
  North Fork of Duchesne River (head of Duchesne River), above Forks, Utah, 1904.
  Duchesne River at Myton, Utah, 1899–
    West Fork of Duchesne River above Forks, Utah, 1904.
    Rock Creek (East Creek) 10 miles above mouth, Utah, 1904.
    Strawberry River above mouth of Indian Creek, in Strawberry Valley, Utah, 1903–1906; 1909–10.
    Strawberry River below mouth of Indian Creek, in Strawberry Valley, Utah, 1908–9.
    Strawberry River at Theodore, Utah, 1908–1910; 1914–
      Indian Creek in Strawberry Valley, Utah, 1905–6; 1909–10.
        Trail Hollow Creek in Strawberry Valley, Utah, 1909–10.
      Currant Creek, 13 miles above mouth, Utah, 1904.
      Currant Creek, 3 miles above mouth, Utah, 1904.
        Red Creek above Narrows, Utah, 1904.
    West Fork of Lake Fork (head of Lake Fork), 10 miles above Forks, Utah, 1904.
    Lake Fork below Forks, Utah, 1904; 1907–1910.
    Lake Fork near Myton, Utah, 1900–1903; 1907–
      East Fork of Lake Fork, 8 miles above Forks, Utah, 1904.
    Uinta River near Whiterocks, Utah, 1899–1904; 1907–1910.

Colorado River tributaries—Continued.
- Duchesne River tributaries—Continued.
  - Uinta River at Fort Duchesne, Utah, 1899–1904; 1906–1910.
  - Uinta River at Ouray School, Utah, 1899–1904.
    - Whiterocks River near Whiterocks, Utah, 1899–1904; 1907–1910.
- North Fork of White River (head of White River) near Buford, Colo., 1903–1906; 1910–1913.
- White River at Meeker, Colo., 1901–1906; 1910–1913.
- White River at White River City, Colo., 1895.
- White River at Rangely, Colo., 1904–5.
- White River near Dragon, Utah, 1906.
- White River near Ouray, Utah, 1904.
  - Marvine Creek near Buford, Colo., 1903–1906.
  - South Fork of White River near Buford, Colo., 1903–1906; 1910–
- Price River near Helper, Utah, 1894–1895; 1904–
- Price River at Woodside, Utah, 1909–1911.
- San Rafael River near Green River, Utah, 1909–
  - Cottonwood Creek near Orangeville, Utah, 1909–
  - Ferron Creek (upper station) near Ferron, Utah, 1911–1914.
  - Ferron Creek near Ferron, Utah, 1909–1911; 1915–
  - Ferron Creek near Castledale, Utah, 1911–1914.
  - Huntington Creek near Huntington, Utah, 1909–
  - Huntington Creek (lower) near Castledale, Utah, 1911–
- North Fork of Grand River (head of Grand River) near Grand Lake, Colo., 1904–
- Grand River near Granby, Colo., 1908–1911.
- Grand River at Sulphur Springs, Colo., 1904–
- Grand River near Kremmling, Colo., 1904–
- Grand River near Wolcott, Colo., 1906–1908.
- Grand River at Shoshone, Colo., 1897.
- Grand River at Glenwood Springs, Colo., 1899–
- Grand River near Palisades, Colo., 1902–
- Grand River near Grand Junction, Colo., 1894–1900.
- Grand River near Fruita, Colo., 1911–
- Grand River near Cisco, Utah, 1914–
- Grand River near Moab, Utah, 1913–14.
  - North inlet to Grand Lake at Grand Lake, Colo., 1905–1912.
  - Grand Lake outlet at Grand Lake, Colo., 1904–1913.
  - South Fork of Grand River, near Lehman, Colo., 1907–8.
  - Fraser River near Arrow, Colo., 1910–
  - Fraser River at upper station near Fraser, Colo., 1908–1911.
  - Fraser River at lower station near Fraser, Colo., 1907–1909.
  - Fraser River at Granby (Coulter), Colo., 1904–1909.
    - Big Jim Creek near Fraser, Colo., 1907–1909.
      - Little Jim Creek near Fraser, Colo., 1907–1909.
    - Vasquez Creek at upper station near Fraser, Colo., 1908–9.
    - Vasquez Creek at lower station near Fraser, Colo., 1907–1909.
    - Elk Creek near Fraser, Colo., 1907–1909.
    - St. Louis Creek at upper station near Fraser, Colo., 1908–9.
    - St. Louis Creek at lower station near Fraser, Colo., 1908–9.
    - North Ranch Creek at upper station near Rollins Pass, Colo., 1908–9.
    - North Ranch Creek at lower station near Rollins Pass, Colo., 1907–1909.
      - Middle Ranch Creek at upper station near Arrow, Colo., 1908–9.
      - Middle Ranch Creek at lower station near Arrow, Colo., 1907–1909.
        - South Ranch Creek at upper station near Arrow, Colo., 1908–9.
        - South Ranch Creek at lower station near Arrow, Colo., 1907–1909.

Colorado River tributaries—Continued.
- Grand River tributaries—Continued.
  - Williams Fork near Scholl, Colo., 1910–
  - Williams Fork near Sulphur Springs, Colo., 1904–
  - Troublesome Creek at Troublesome, Colo., 1904–5.
  - Muddy Creek at Kremmling, Colo., 1904–5.
  - Blue River at Dillon, Colo., 1910–
  - Blue River near Kremmling, Colo., 1904–1908.
    - Tenmile Creek near Kokomo, Colo., 1904.
    - Tenmile Creek near Uneva Lake, Colo., 1903.
    - Tenmile Creek at Dillon, Colo., 1910–
    - Snake River at Dillon, Colo., 1910–
  - Eagle River at Red Cliff, Colo., 1911–
  - Eagle River above Brush Creek, at Eagle, Colo., 1911–
  - Eagle River below Brush Creek, at Eagle, Colo., 1905–1907.
  - Eagle River at Gypsum, Colo., 1907–1909.
    - Turkey Creek at Red Cliff, Colo., 1913–
    - Homestake Creek at Red Cliff, Colo., 1911–
    - Gore Creek near Minturn, Colo., 1911–1914.
    - Beaver Creek at Avon, Colo., 1911–1914.
    - Brush Creek at Eagle, Colo., 1911–1913.
    - No Name Creek near Glenwood Springs, Colo., 1911–1914.
    - Glenwood Light & Power Co.'s flume near Glenwood Springs, Colo., 1911–1914.
  - Roaring Fork at Aspen, Colo., 1911–
  - Roaring Fork below Aspen, Colo., 1913–14.
  - Roaring Fork near Emma, Colo., 1908–9.
  - Roaring Fork at Glenwood Springs, Colo., 1906–
    - Hunter Creek at Aspen, Colo., 1911–1913.
    - Castle Creek near Aspen, Colo., 1911–
    - Maroon Creek at upper station, near Aspen, Colo., 1911–
    - Maroon Creek at lower station, near Aspen, Colo., 1914–
    - Snow Mass Creek at Snow Mass, Colo., 1911–1913.
    - Fryingpan Creek at Norrie, Colo., 1911–
    - Fryingpan Creek at Thomasville, Colo., 1911–
    - Fryingpan Creek at Basalt, Colo., 1908–9.
      - North Fork of Fryingpan Creek near Norrie, Colo., 1911–
    - Crystal River at Marble, Colo., 1910–
    - Crystal River near Carbondale (Sewell), Colo., 1908–9.
  - West Fork of Elk Creek (head of Elk Creek), near Newcastle, Colo., 1911.
    - Middle Fork of Elk Creek near Newcastle, Colo., 1911–1914.
    - East Fork of Elk Creek near Newcastle, Colo., 1911–
  - West Divide Creek (head of Divide Creek) at Hostutler's ranch, near Raven, Colo., 1909.
  - West Divide Creek at Beard's ranch, near Raven, Colo., 1910–11.
  - West Divide Creek at Raven, Colo., 1909–1911.
  - West Mamm Creek near Rifle, Colo., 1909–10.
  - Taylor River (head of Gunnison River) near Almont, Colo., 1905.
  - Taylor River at Almont, Colo., 1910–
  - Gunnison River near Gunnison, Colo., 1910–1915.
  - Gunnison River near Iola, Colo., 1900–1903.
  - Gunnison River near Cimarron, Colo., 1903–1905.
  - Gunnison River at River Portal, Colo., 1905–1911.

Colorado River tributaries—Continued.
Grand River tributaries—Continued.
Gunnison River near Cory, Colo., 1903–1905.
Gunnison River at Roubideau, Colo., 1897.
Gunnison River at Whitewater, Colo., 1895; 1897; 1901–1906.
Gunnison River near Grand Junction, Colo., 1894–95; 1897–1899.
East River at Almont, Colo., 1905; 1910–
Cement Creek near Crested Butte, Colo., 1910–1913.
Tomichi Creek near Gunnison, Colo., 1910.
Quartz Creek near Pitkin, Colo., 1910–1913.
Cimarron Creek at Cimarron, Colo., 1903–1905.
North Fork of Gunnison River near Hotchkiss, Colo., 1903–1906.
Sapinero Creek at Sapinero, Colo., 1911–1914.
Uncompahgre River near Colona, Colo., 1903–1906.
Uncompahgre River at Ouray, Colo., 1908; 1911–
Uncompahgre River below Ouray, Colo., 1913–
Uncompahgre River near Fort Crawford, Colo., 1910–11.
Uncompahgre River at Fort Crawford, Colo., 1895–1899; 1908–1910.
Uncompahgre River at Montrose, Colo., 1900; 1903–
Uncompahgre River near Delta, Colo., 1903–
Canon Creek at Ouray, Colo., 1911–
Dolores River at Rico., Colo., 1914–15.
Rico Mining Co. Tailrace at Rico, Colo., 1914–15.
Dolores River at Dolores, Colo., 1895–1903; 1910–1912.
San Miguel River near Fall Creek, Colo., 1895–1899; 1910.
San Miguel River at Placerville, Colo., 1910–1912.
Mill Creek near Moab, Utah, 1914–
Fremont River near Thurber, Utah, 1909–1912.
Muddy Creek near Emery, Utah, 1909–1914.
Muddy Creek (lower station) near Emery, Utah, 1911–1914.
Ivie Creek near Emery, Utah, 1911–12.
Escalante Creek (head of Escalante River) near Escalante, Utah, 1909–1913.
San Juan River at Pagosa Springs, Colo., 1911–1914.
San Juan River at Arboles, Colo., 1895–1899; 1910–1915.
San Juan River at Turley, N. Mex., 1907–8.
San Juan River at Blanco, N. Mex., 1908–1910.
San Juan River near Bloomfield, N. Mex., 1909–1911.
San Juan River at Farmington, N. Mex., 1904–1906; 1912–1915.
San Juan River near Shiprock, N. Mex., 1911.
San Juan River near Bluff, Utah, 1914–
Navajo River at Chromo, Colo., 1911–12.
Navajo River at Edith, Colo., 1912–
Piedra River at Piedra, Colo., 1911–12.
Piedra River at Arboles, Colo., 1895–1899; 1910–1915.
Los Pinos River at Ignacio, Colo., 1899–1903; 1910–1915.
Animas River at Silverton, Colo., 1903.
Animas River at Tacoma, Colo., 1908–9; 1911.
Animas River above Lightner Creek, at Durango, Colo., 1895–1905.
Animas River below Lightner Creek, at Durango, Colo., 1910–1915.
Animas River at Aztec, N. Mex., 1904; 1907–1915.
Animas River at Farmington, N. Mex., 1912–1915.
Animas River near Farmington, N. Mex., 1904–5.
Hermosa Creek near Hermosa, Colo., 1911–1914.
Florida River near Durango., Colo., 1899; 1901–1903; 1910–1912.

Colorado River tributaries—Continued.
San Juan River tributaries—Continued.
La Plata River at Hesperus, Colo., 1904–1906; 1910.
La Plata River at La Plata, N. Mex., 1905–1914.
Mancos River at Mancos, Colo., 1898–1901.
West Mancos River near Mancos, Colo., 1910–11.
Montezuma Creek at Monticello, Utah, 1914–
South Fork of Montezuma Creek near Monticello, Utah, 1914–
Spring Creek near Monticello, Utah, 1914–
Verdure Creek near Verdure, Utah, 1914–

Canals in San Juan River basin.

Baker ditch at Monticello, Utah, 1915–
Christensen ditch at Monticello, Utah, 1915–
Davenport & Campbell canal near Monticello, Utah, 1914–
Gordon canal near Monticello, Utah, 1914–15.
Green ditch near Monticello, Utah, 1914–
Pioneer canal near Monticello, Utah, 1914–
North ditch near Monticello, Utah, 1914–15.
Middle ditch near Monticello, Utah, 1914–15.
South ditch near Monticello, Utah, 1914–15.
Wood High Line canal near Monticello, Utah, 1914–15.
San Juan Irrigation Co. canal near Grayson, Utah, 1914–
White Mesa canal near Grayson, Utah, 1914–
L. C. ditch near Grayson, Utah, 1914.

Little Colorado River at St. Johns, Ariz., 1906–1909.
Little Colorado River at Woodruff, Ariz., 1905–1908.
Little Colorado River at Holbrook, Ariz., 1905–1909.
Silver Creek at Snowflake, Ariz., 1906–1908.
Silver Creek at Canyon station, Ariz., 1906.
Woodruff ditch at Woodruff, Ariz., 1906.
Chevelon Fork near Winslow, Ariz., 1905–1908.
Clear Creek near Winslow, Ariz., 1906–1909.
Virgin River at Virgin, Utah, 1909–
Zion Creek near Springdale, Utah, 1913–14.
Ash Creek at Toquerville, Utah, 1915–
Leeds Creek near Leeds, Utah, 1915–
Santa Clara Creek near Central, Utah, 1909–
Santa Clara Creek at Santa Clara, Utah, 1915–
Santa Clara Creek near St. George, Utah, 1909–
Muddy River at Home ranch near Moapa, Nev., 1913–
Muddy River above Indian reservation near Moapa, Nev., 1914–
Muddy River at pumping plant near Moapa, Nev., 1914–
Muddy River near Moapa and Logan, Nev., 1904–1906; 1909–10; 1913–14.
Muddy River near St. Thomas, Nev., 1913–

Canals in Virgin River basin.

Central canal at Central, Utah, 1915–
Santa Clara north canal near Santa Clara, Utah, 1915–
Santa Clara south canal near Santa Clara, Utah, 1915–
Santa Clara town canal near Santa Clara, Utah, 1915–

Williams River near Swansea, Ariz., 1910–
Gila River near Cliff, N. Mex., 1904–1907.

Colorado River tributaries—Continued.
- Gila River near Silver City, N. Mex., 1912–1914.
- Gila River near Gila, N. Mex., 1914.
- Gila River near Redrock, N. Mex., 1908–1914.
- Gila River near Duncan, Ariz., 1914–
- Gila River near Guthrie, Ariz., 1910–
- Gila River near Solomonville, Ariz., 1914–
- Gila River at San Carlos, Ariz., 1899–1905; 1910–11; 1914–
- Gila River near Kelvin, Ariz., 1911–
- Gila River near Florence, Ariz., 1914.
- Gila River near Buttes, Ariz., 1889–90; 1895–1899.
- Gila River at Sentinel, Ariz., 1912–
- Gila River at Dome (Gila City), Ariz., 1903–1906.
- Gila River at mouth near Yuma, Ariz., 1903.
  - San Francisco River at Alma, N. Mex., 1904–1907; 1909–
  - San Francisco River at dam above Clifton, Ariz., 1910–
    - Whitewater Creek near Mogollon, N. Mex., 1909–
  - San Carlos River (staff gage) at San Carlos, Ariz., 1910–11.
  - San Carlos River (water-stage recorder) at San Carlos, Ariz., 1914–
  - San Pedro River near Lewis Springs, Ariz., 1910–11.
  - San Pedro River at Charleston, Ariz., 1904–1906.
  - San Pedro River near Fairbank, Ariz., 1911–12.
  - San Pedro River at Fairbank, Ariz., 1912–
  - San Pedro River near Dudleyville, Ariz., 1890.
  - Queens Creek at Whitlows, Ariz., 1896.
  - Santa Cruz River near Nogales, Ariz., 1907; 1909–
  - Santa Cruz River and ditches at Tucson, Ariz., 1905–
    - Rillito Creek near Tucson, Ariz., 1911–
  - Salt River at Roosevelt, Ariz., 1901–1907; 1910–
  - Salt River below mouth of Cherry Creek near Roosevelt, Ariz., 1906.
  - Salt River 50 miles above Phoenix, Ariz., 1890.
  - Salt River at Arizona Dam, Ariz., 1888–1891.
  - Salt River at McDowell, Ariz., 1897–1910.
    - Black River near Fort Apache, Ariz., 1912–
    - White River at Fort Apache, Ariz., 1912–
      - East Fork of White River at Fort Apache, Ariz., 1912–
    - Tonto Creek at Roosevelt, Ariz., 1901–1904.
    - Verde River near Camp Verde, Ariz., 1911–
    - Verde River at Camp Verde, Ariz., 1912–
    - Verde River at McDowell, Ariz., 1889, 1897–1899, 1901–
      - Beaver Creek at Camp Verde, Ariz., 1912–
  - Agua Fria River near Glendale, Ariz., 1910–
  - Hassayampa River at Walnut Grove, Ariz., 1912–
  - Hassayampa River at Wickenburg, Ariz., 1910–1912.

Canals in Colorado River basin below Virgin River.

- Imperial canal (main) near Calexico, Cal., 1904–5.
- Boundary canal near Calexico, Cal., 1905.
- Wisteria canal near Calexico, Cal., 1905.
- Imperial canal 10 miles below Yuma, Ariz., 1903–1905.
- Holt canal at Calexico, Cal., 1904–5.
- Hemlock canal at Calexico, Cal., 1904–5.
- Alamo channel near Calexico, Cal., 1904.
- Alamitos canal near Calexico, Cal., 1904–5.

PUBLICATIONS.

Investigation of water resources by the United States Geological Survey has consisted not only of measurements of the volume of flow of streams and studies of the conditions affecting that flow, but it has comprised also investigation of such closely allied subjects as irrigation, water storage, water powers, underground waters, and quality of waters. Most of the results of these investigations have been published in the series of water-supply papers, but some have appeared in the monographs, bulletins, professional papers, and annual reports.

The results of stream-flow measurements in the Colorado River basin have been published in the reports listed below.

Annual reports: 11, pt. 2; 12, pt. 2; 13, pt. 3; 14, pt. 2; 16, pt. 2; 18, pt. 4; 19, pt. 4; 20, pt. 4; 21, pt. 4; 22, pt. 4.
Bulletins: 131, 140.
Water-supply papers: 11, 16, 28, 37, 38, 50, 66, 75, 85, 100, 133, 175, 177, 211, 249, 269, 289, 309, 329, 359, 389.[1]

The following pages contain an annotated list of the publications (other than stream-measurement reports) of the Geological Survey relating to the water resources of the Colorado River basin, as well as brief references to reports published by State and other organizations.

PUBLICATIONS OF UNITED STATES GEOLOGICAL SURVEY

WATER-SUPPLY PAPERS.

Water-supply papers are distributed free by the Geological Survey as long as its stock lasts. An asterisk (*) indicates that this stock has been exhausted. Many of the papers marked in this way may, however, be purchased (at price noted) from the SUPERINTENDENT OF DOCUMENTS, WASHINGTON, D. C. Omission of the price indicates that the report is not obtainable from Government sources. Water-supply papers are of octavo size.

*2. Irrigation near Phoenix, Ariz., by A. P. Davis. 1897. 98 pp., 31 pls. 15c.

Describes physiographic features, temperature, rainfall, stream-flow, soils, and projected irrigation works in Gila River basin; discusses briefly possible use of underground water for irrigation and gives data concerning wells in Pinal and Maricopa counties. Chiefly of historic interest, as indicated by the date of publication.

*33. Storage of water on Gila River, Arizona, by J. B. Lippincott. 1900. 98 pp., 33 pls. 15c.

Describes conditions existing in 1898–99, available water supply, silt, and reservoir sites (Buttes, Riverside, San Carlos, and Queen Creek); contains section on cement, and treats of irrigable land, distribution canals, and organization of irrigation. Interest chiefly historic.

*43. Conveyance of water in irrigation canals, flumes, and pipes, by Samuel Fortier. 1901. 86 pp., 15 pls. 15c.

Describes various types of canals for irrigation.

57. Preliminary list of deep borings in the United States, Part I (Alabama–Montana), by N. H. Darton. 1902. 60 pp. (See No. 149.) 5c.

61. Preliminary list of deep borings in the United States, Part II (Nebraska–Wyoming), by N. H. Darton. 1902. 67 pp. 5c.

Nos. 57 and 61 contain information as to depth, diameter, yield, and head of water in borings more than 400 feet deep; under head "Remarks" give information concerning temperature, quality of water, purposes of boring, etc. See also No. 149.

[1] In preparation, May 1, 1916.

*73. Water storage on Salt River, Arizona, by A. P. Davis. 1902. 54 pp., 25 pls. 20c.

Discusses Verde and Salt River basins and McDowell and Salt River reservoirs.

74. Water resources of the State of Colorado, by A. L. Fellows. 1902. 151 pp., 14 pls. 25c.

Discusses drainage and irrigation; gives records of stream flow.

93. Proceedings of first conference of engineers of Reclamation Service, with accompanying papers, compiled by F. H. Newell, chief engineer. 1904. 361 pp. 25c. Contains:

Investigations in Arizona, by A. P. Davis. Describes the proposed storage reservoir on Salt River at the mouth of Tonto Creek.

Salt River Valley Water Users' Association, by B. A. Fowler. Contains Judge Kibbey's address presenting a plan for the organization of the owners of lands to be irrigated.

Topographic work in the Grand Canyon of the Gunnison, by I. W. McConnell. Discusses the proposed diversion of water from Gunnison River into Uncompahgre Valley.

Colorado River, by J. R. Lippincott.

Colorado River reclamation projects, by E. T. Perkins. Describes the site of the Yuma dam and summarizes the advantages of the Yuma site.

104. The underground waters of Gila Valley, Arizona, by W. T. Lee. 1904. 71 pp., 5 pls. 10c.

Presents information concerning the topographic features and surficial geology of the area between The Buttes, 12 miles east of Florence and the junction of Gila and Salt rivers, treats of the source, amount, quality, and methods of securing the underflow.

136. Underground waters of Salt River valley, Arizona, by W. T. Lee. 1905. 196 pp., 23 pls. 25c.

Describes the physiography and geology of the Mesa and Phoenix region, gives many well records, and discusses the amount and chemical character of the underground waters, duty of water, and cost of pumping.

147. Destructive floods in United States in 1904, by E. C. Murphy and others. 15c. Contains:

La Plata River flood, Colorado, from report of Theo. Tobish. Describes floods on the headwaters of the Big Sandy (tributary to the Colorado through Williams River), on Sacramento Wash, and on La Plata River (tributary to the Colorado through San Juan River).

149. Preliminary list of deep borings in the United States, second edition with additions, by N. H. Darton. 1905. 175 pp. 10c.

Gives by States location, depth, diameter, yield, height of water, and other valuable information concerning wells 400 feet or more in depth; includes all wells listed in Water-Supply Papers 57 and 61; mentions also principal publications relating to deep borings.

*162. Destructive floods in the United States in 1905, with a discussion of flood discharge and frequency and an index to flood literature, by E. C. Murphy and others. 1906. 105 pp., 4 pls. 15c.

Contains accounts of floods on Colorado, Green, Grand, Gunnison, San Juan, Little Colorado, Gila, San Francisco, Verde, San Pedro, and Salt rivers, and of the flow of the Colorado into Salton Sink; gives index to literature on floods on American streams.

274. Some stream waters of the western United States, with chapters on sediment carried by the Rio Grande and the industrial application of water analyses, by Herman Stabler. 1911. 188 pp. 15c.

Describes collection of samples, plan of analytical work, and methods of analyses; discusses soap-consuming power of waters, water softening, boiler waters, and water for irrigation; gives results of analyses of waters of Colorado, Green, Grand, Gunnison, Animas, Little Colorado, Gila, San Francisco, Salt, and Verde rivers.

320. Geology and water resources of the Sulphur Spring Valley, Arizona, by O. E. Meinzer and F. C. Kelton, with a section on agriculture, by R. H. Forbes. 1913. 231 pp., 15 pls. 45c.

Describes the physiography and drainage of the region, geologic formations, and geologic history; discusses the seasonal and geographic distribution of rainfall, the occurrence and level of ground waters, the flowing and nonflowing wells, the quality of ground waters, the effect of alkali on plant life and on waters for irrigation, the relation of zones of vegetation to water supply and geographic controls, and the plants used for pumping water; treats also of the early history of agriculture and agricultural methods.

365. Ground water in southeastern Nevada, by Everett Carpenter. 1915. 86 pp., 5 pls.

Describes an area in Clark, Lincoln, White Pine, and Nye counties drained in part by streams tributary to Colorado River and in part by streams discharging into the Great Basin. Discusses stream, lake, and wind topography, vegetation, crops, and industrial development, rainfall, currents of water in bedrock and unconsolidated sediments, source and permanence of artesian waters, and character and distribution of springs; also the quality of waters for domestic use and for irrigation, and gives analyses. Details of water-supply papers by areas in Las Vegas and Virgin river basins and the Great Basin. Gives information in regard to watering places on routes of travel.

375. Contributions to the hydrology of the United States, 1915. Contains:

(*b*) Ground water in Paradise Valley, Ariz., by O. E. Meinzer and A. J. Ellis, pp. 51–75, pls. 3–5. Describes an area north of Phoenix, in Maricopa County, between Phoenix Mountains on the west and McDowell Mountains on the east, terminated on the north by a rocky upland but on the south opening into the Salt River Valley. Discusses briefly physiography and drainage, soil and vegetation, climate, occurrence, source, and disposal of ground water, artesian prospects, quality of water, wells, and irrigation.

ANNUAL REPORTS.

Each of the papers contained in the annual reports was also issued in separate form.

Annual reports are distributed free by the Geological Survey as long as its stock lasts. An asterisk (*) indicates that this stock has been exhausted. Many of the papers so marked, however, may be purchased from the SUPERINTENDENT OF DOCUMENTS, WASHINGTON, D. C.

*Ninth Annual Report of the United States Geological Survey, 1887–88, J. W. Powell, Director. 1889. xiii, 717 pp., 88 pls. $2. Contains:

*On the geology and physiography of a portion of northwestern Colorado and adjacent parts of Utah and Wyoming, by C. A. White, pp. 677–712, Pl. LXXXVIII. Describes the canyons of Green, Yampa, Snake, and White rivers.

*Tenth Annual Report of the United States Geological Survey, 1888–89, J. W. Powell, Director. 1890. 2 parts. *Pt. II. Irrigation, viii, 123 pp. 35c.

Makes a preliminary report on the organization and prosecution of the survey of the arid lands for purposes of irrigation; includes an account of the methods of topographic and hydraulic work, the segregation work on reservoir sites and irrigable lands, field and office methods, and brief descriptions of the topography of some of the river basins.

Eleventh Annual Report of the United States Geological Survey, 1889–90, J. W. Powell, Director. 1891. 2 parts. Pt. II. Irrigation. pp. xiv, 395, 30 plates and maps. $1.25. Contains:

*Hydrography, pp. 1–110. Discusses scope of work, methods of stream measurement rainfall and evaporation, and describes the more important streams.

*Engineering, pp. 111–200. Defines the scope of the work and gives an account of the surveys in the Sun River basin and in the Arkansas, Rio Grande, California, Lahontan, Utah, and Snake River divisions.

*The arid lands, pp. 201–289. Includes statement of the director to the House Committee on Irrigation, extracts from the constitutions of States relating to irrigation, and a report on artesian irrigation on the Great Plains, including a discussion of the general considerations affecting artesian water supply, the economic limit to the utilization of artesian water for irrigation, irrigation by artesian wells in various countries, and the geologic conditions and statistics of artesian wells on the Great Plains.

*Topography, pp. 291–343. Comprises reports of the topographic surveys in California, Nevada, Colorado, Idaho, Montana, and New Mexico, and a report on reservoir sites.

*Irrigation literature, pp. 345–388. Gives a list of books and pamphlets on irrigation and allied subjects, mainly contained in the library of the United States Geological Survey.

*Twelfth Annual Report of the United States Geological Survey, 1890–91, J. W. Powell, Director. 1891. 2 parts. Pt. II, Irrigation, xviii, 576 pp., 93 pls. $2. Contains:

*Hydrography of the arid regions, by F. H. Newell, pp. 213–361, Pls. LVIII–CVI. Discusses the available water supply of the arid regions, the duty of water, flood waters, relation of rainfall to river flow; classifies the drainage basins; and describes the rivers of the Missouri, Arkansas, Rio Grande, Colorado, Sacramento, and San Joaquin basins, and the principal streams of the Great Basin in Nevada and Utah and the Snake River drainage.

*Sixteenth Annual Report of the United States Geological Survey, 1894–95, Charles D. Walcott, Director. 1896. (Pts. II, III, and IV, 1895.) 4 parts. *Pt. II, Papers of an economic character, pp. xix, 598, 43 pls. $1.25. Contains:

*The public lands and their water supply, by F. H. Newell, pp. 457–533, Pls. XXXV–XXXIX. Describes general character of the public lands, the lands disposed of (railroad, grant and swamp lands, and private miscellaneous entries), lands reserved (Indian, forest, and military reservations), the vacant lands, and the rate of disposal of vacant lands; discusses the streams, wells, and reservoirs as sources of water supply; gives details for each State.

Eighteenth Annual Report of the United States Geological Survey, 1896–97, Charles D. Walcott, Director. 1897. (Pts. II and III, 1898.) 5 parts in 6 vols. *Pt. IV, Hydrography, pp. x, 756, 102 pls. $1.75. Contains:

*Reservoirs for irrigation, by J. D. Schuyler, pp. 617–740, Pls. XLVII–CII. Describes the Agua Fria dam, Arizona, and reservoir projects on Rio Verde, Salt River, Queen Creek, Hassayampa River, and Little Colorado River, Arizona, and in the Tonto basin; gives tables of reservoir capacities and areas.

Twentieth Annual Report of the United States Geological Survey, 1898–99, Charles D. Walcott, Director. 1899. (Parts II, III, IV, V, and VII, 1900.) 7 parts in 8 vols. and separate case for maps with Pt. V. *Pt. V, Forest reserves, pp. xix, 498, 159 plates, 8 maps in separate case. $2.80. Contains:

*White River Plateau timber land reserve, by G. B. Sudworth, pp. 117–179, Pls. XLVII–LVIII; Battlement Mesa forest reserve, by G. B. Sudworth, pp. 181–243, Pls. LIX–LXXV. Describes briefly the streams and lakes in the reserves.

BULLETINS.

An asterisk (*) indicates that the Geological Survey's stock of the paper is exhausted. Many of the papers so marked may be purchased from the SUPERINTENDENT OF DOCUMENTS, WASHINGTON, D. C. Bulletins are of octavo size.

*298. Record of deep-well drilling for 1905, by M. L. Fuller and Samuel Sanford. 1906. 299 pp. 25c.

Gives an account of progress in the collection of well records and samples; contains tabulated records of wells in Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming; and detailed record of well near Phoenix, Maricopa County, Ariz. The well of which a detailed section is given was selected because it affords valuable stratigraphic information.

*350. Geology of the Rangely oil district, Rio Blanco County, Colorado, with a section on the water supply of the Raven Park district, by H. S. Gale, 1908. 60 pp., 4 pls. 20c.

Discusses White River and its tributaries as sources of water supply and the possibility of obtaining artesian flows; treats of the quality of the water of White River and gives analyses.

GEOLOGIC FOLIOS.

Under the plan adopted for the preparation of a geologic map of the United States the entire area is divided into small quadrangles, bounded by certain meridians and parallels, and these quadrangles, which number several thousand, are separately surveyed and mapped.[1] The unit of survey is also the unit of publication, and the maps and description of each quadrangle are issued in the form of a folio. When all the folios are completed they will constitute a Geologic Atlas of the United States.

[1] Index maps showing areas in the Colorado River basin covered by topographic maps and by geologic folios will be mailed on receipt of request addressed to the Director U. S. Geological Survey, Washington, D. C.

A folio is designated by the name of the principal town or of a prominent natural feature within the quadrangle. Each folio includes maps showing the topography, geology, underground structure, and mineral deposits of the area mapped and several pages of descriptive text. The text explains the maps and describes the topographic and geologic features of the country and its mineral products. The topographic map shows roads, railroads, waterways, and, by contour lines, the shapes of the hills and valleys and the height above sea level of all points in the quadrangle. The areal-geology map shows the distribution of the various rocks at the surface. The structural-geology map shows the relations of the rocks to one another underground. The economic-geology map indicates the location of mineral deposits that are commercially valuable. The artesian-water map shows the depth to underground-water horizons. Economic-geology and artesian-water maps are included in folios if the conditions in the areas mapped warrant their publication. The folios are of special interest to students of geography and geology and are valuable as guides in the development and utilization of mineral resources.

The folios numbered from 1 to 163, inclusive, are published in only one form (18 by 22 inches), called the library edition. Some of the folios that bear numbers higher than 163 are published also in an octavo edition (6 by 9 inches). Owing to a fire in the Geological Survey building May 18, 1913, the stock of geologic folios was more or less damaged by fire and water, but 80 or 90 per cent of the folios are usable. They will be sold at the uniform price of 5 cents each, with no reduction for wholesale orders. This rate applies to folios in stock from 1 to 184, inclusive (except reprints), also to the library edition of folio 186. The library edition of folios 185, 187, and higher numbers sells for 25 cents a copy, except that some folios which contain an unusually large amount of matter sell at higher prices. The octavo edition of folio 185 and higher numbers sells for 50 cents a copy, except folio 193, which sells for 75 cents a copy. A discount of 40 per cent is allowed on an order for geologic folios amounting to $5 at the retail price—that is, 20 of the 25-cent folios (or their equivalent in higher, priced folios) will be sold for $3. The discount is allowed on an order for folios alone, either of one kind or in any assortment, or for folios together with typographic maps, but no discount is allowed on the damaged folios sold at 5 cents each.

All the folios contain descriptions of the drainage of the quadrangles. The folios in the following list contain also brief discussions of the underground waters in connection with the economic resources of the areas and more or less information concerning the utilization of the water resources.

An asterisk (*) indicates that the Geological Survey's stock of the folio is exhausted.

*111. Globe, Arizona.

Describes the physiographic divisions of Arizona and the topography, climate, and vegetation of the Globe quadrangle; gives a brief account of the water resources.

*120. Silverton, Colorado.

Describes an area in the San Juan Mountains including a portion of the Continental Divide.

*129. Clifton, Arizona.

Describes the streams and springs of the area; gives analyses of spring water from San Francisco River.

*130. Rico, Colorado.

Describes the Rico Mountains and Dolores River valley; includes a brief paragraph on water resources.

*153. Ouray, Colorado.

Describes the river waters used for irrigation, the underground waters, and the thermal springs; gives analyses of water from Hot Spring at Ouray.

171. Engineer Mountain, Colorado. 5c.

Describes the topography and geology of the Engineer Mountain quadrangle, in southwestern Colorado, about 60 miles east of the Utah boundary and 34 miles north of New Mexico; discusses the drainage, which passes to the Gulf of California through Colorado River; gives a brief paragraph on the water resources.

MISCELLANEOUS REPORTS.

Other Federal bureaus and State and other organizations have from time to time published reports relating to water resources of various sections of the country. Notable among those pertaining to the Colorado River basin are the reports of the State engineers of Colorado, Nevada, New Mexico, and Wyoming, and the annual reports of the United States Reclamation Service. The following reports deserve special mention:

Canyons of the Colorado, by J. W. Powell, 1895. A popular, revised, and enlarged edition of his original journal of exploration which appeared as part of a report entitled "Exploration of the Colorado River of the West and its tributaries, explored in 1869, 1870, 1871, and 1872 under the direction of the Secretary of the Smithsonian Institution," published by the Smithsonian Institution in 1875.

A canyon voyage; the narrative of the second Powell expedition down the Green-Colorado River from Wyoming and the explorations on land in the year 1871–72, by Frederick S. Dellenbaugh, artist and assistant topographer of the expedition, 1908.

Preliminary examination of reservoir sites in Wyoming and Colorado; letter from the Secretary of War transmitting a letter from the Chief of Engineers, together with a report of Captain Chittenden: 55th Cong., 2d sess., House Doc. 141, 1898.

Irrigation pumping in Nevada, etc., by Charles Norcross: Nevada Bureau of Industry, Agriculture, and Irrigation Bull. 8, 1913.

Report on irrigation investigations in Utah under the direction of Elwood Mead: U. S. Dept. Agr. Office Exper. Sta. Bull. 124, 1903.

Irrigation in Utah, Utah Irrigation Commission, 1894.

Irrigation and agricultural practice in Arizona, by R. H. Forbes: Arizona Univ. Agr. Exper. Sta. Bull. 63, 1911.

Ground-water supply and irrigation in Rillito Valley, Arizona: Arizona Univ. Agr. Exper. Sta. Bull. 64.

The lower Colorado River and the Salton Basin, by C. E. Grunsky: Am. Soc. Civil Eng. Trans., vol. 59, pp. 1–51; discussion, pp. 52–62, December, 1907.

Irrigation and river control in the Colorado River delta, by H. T. Cory: Am. Soc. Civil Eng. Trans., vol. 76, pp. 1204–1453; discussion, pp. 1454–1571, December, 1913.

GREEN RIVER BASIN.

THE MAIN STREAM.

Green River and its tributaries [1] drain an area comprising a large part of western Wyoming, northwestern Colorado, and eastern Utah, bounded on the north and east by the Wind River Mountains and the ranges forming the Continental Divide, on the south and east by the White River Plateau and the Roan or Book Cliffs, and on the north and west by the Gros Ventre and Wyoming mountains and the great Wasatch Range. The area is roughly triangular in shape, its greatest length, north and south, being about 370 miles, and its greatest width, east and west, 240 miles. The total area is approximately 44,400 square miles.

[1] The geology of this basin is described in U. S. Geol. and Geog. Survey Terr. Eleventh Ann. Rept., pp. 509–646, 1877. Information in regard to the hydrography is contained in the first four annual reports of the Reclamation Service and in reports of the U. S. Geological Survey.

The river heads on the western slope of the Wind River Mountains in western Wyoming, its ultimate source being a number of small lakes fed by glaciers and the immense snow deposits always to be found on Fremont and neighboring peaks. For perhaps 25 miles the river flows northwestward through the mountains; it then turns abruptly and runs in a general southerly direction across western Wyoming into Utah, receiving in its upper course in Wyoming numerous tributaries that head in the Wind River, Gros Ventre, and Wyoming ranges of mountains, some of them extending so far back into the abrupt, ragged canyons that they dovetail with streams flowing in the opposite direction. The most important of these tributaries are East Fork River, Big Sandy Creek, Labarge Creek, Fontanelle Creek, and Blacks Fork, the last named being the largest and most important, its average annual run-off being approximately 400,000 acre-feet.

Between Green River, Wyo., and the Wyoming-Utah boundary the Green passes through an open canyon for approximately 70 miles. Just south of the boundary there is an open valley, comprising several square miles, in which Henrys Fork enters from the west. Immediately below the mouth of Henrys Fork the river enters Flaming Gorge and Horseshoe Canyon. (Pls. III, *A* and *B*, and IV, *B*.)

Beyond Horseshoe Canyon, which is 4 miles long, the course of the river is eastward through Kingfisher and Red canyons and Browns Park into Colorado, thence southward in Colorado for a distance of 35 miles, passing through Ladore (Pl. IV, *A*) and Whirlpool canyons. Just above Whirlpool Canyon it is joined from the east by Yampa River, a large tributary, whose average annual run-off is more than a million acre-feet.

Turning back into Utah the Green flows southwesterly through Island Park and Split Mountain Canyon into an open valley in the vicinity of Jensen and Ouray, where it is joined by the Duchesne from the west and White River from the east. The mean annual run-off of Duchesne River is approximately 700,000 acre-feet and that of White River 500,000 acre-feet.

A few miles below the mouth of Duchesne and White rivers the Green passes into a 120-mile canyon, the upper section of which is known as Desolation Canyon (Pl. V, *A*) and the lower as Gray Canyon (Pl. V, *B*). Near the lower end of Gray Canyon it is joined by Price

River, which enters from the west. The average annual run-off of Price River is approximately 180,000 acre-feet.

About 7 miles below the mouth of Price River the Green passes out of Gray Canyon into the Green River or Gunnison Valley, in which the town of Green River, Utah, is situated. Twenty-five miles below Green River, Utah, the San Rafael, the last large tributary of Green River, enters from the west. The average annual run-off of the San Rafael is about 230,000 acre-feet. From the mouth of the San Rafael to the junction of Green and Grand rivers the Green flows through a box canyon, the walls of which in many places rise almost vertically from the water's edge to a height ranging from 700 to 1,000 feet. Below the San Rafael, in Labyrinth and Stillwater canyons, the course of the Green is very tortuous. The distance by straight line from the mouth of the San Rafael to the junction of the Green and Grand is 43 miles; the distance by river is 95 miles. At a point 51 miles below Green River, Utah, the river turns abruptly to the east, forming a loop (Pl. VI, *A*); the distance around the loop is 7 miles; the distance from water's edge to water's edge at the narrow point is but 800 feet. The fall in the river in the 7-mile section around the loop is 6 feet. Labyrinth Canyon (Pl. VI, *B*) and Stillwater Canyon, which extend from the mouth of San Rafael to the mouth of Green River, are almost inaccessible except by boat.

The length of the Green, measured roughly along its course, is approximately 700 miles. Altitudes within the basin range from 14,000 feet in the high mountains to about 3,900 feet at the junction with Grand River.

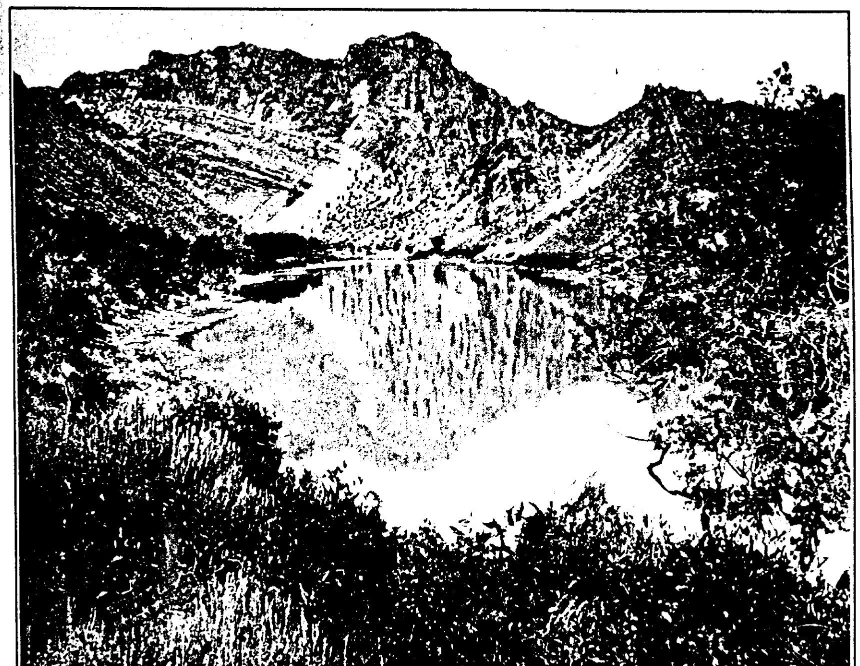
Except for the timber in the high mountains at the headwaters in Wyoming, extensive forests are lacking in the upper part of the basin. The timbered land includes probably 1,500 square miles, the average stand being about 4,000 feet board measure per acre. In Utah, above the mouth of the Duchesne, about 600 square miles is timbered, the average being nearly 3,000 feet board measure per acre; and in the basins of the White and the Yampa in Colorado timber and woodland comprise nearly 2,000 square miles.

The basin as a whole includes considerably more than 5,000 square miles of timbered land in addition to important woodland areas. The principal species of mountain timber are the Engelmann spruce and lodgepole pine.

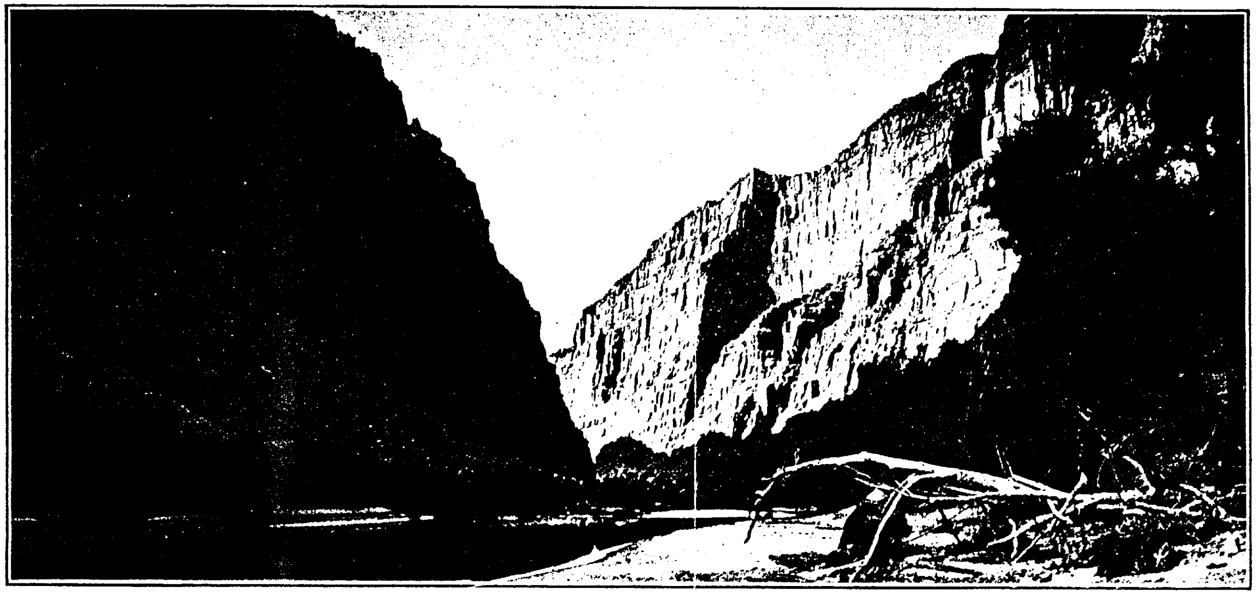
Over the plains section of the basin, which includes considerably more than half of it, the average annual precipitation seems to be less than 10 inches annually; over much of the remainder the average rainfall is between 10 and 15 inches, and in only a small area in the high mountains does the precipitation exceed 20 inches annually.

Throughout the basin winters are severe, and most of the streams are ice-covered for several months. In the high mountains snow is usually abundant, but on the plains the winters are frequently open.

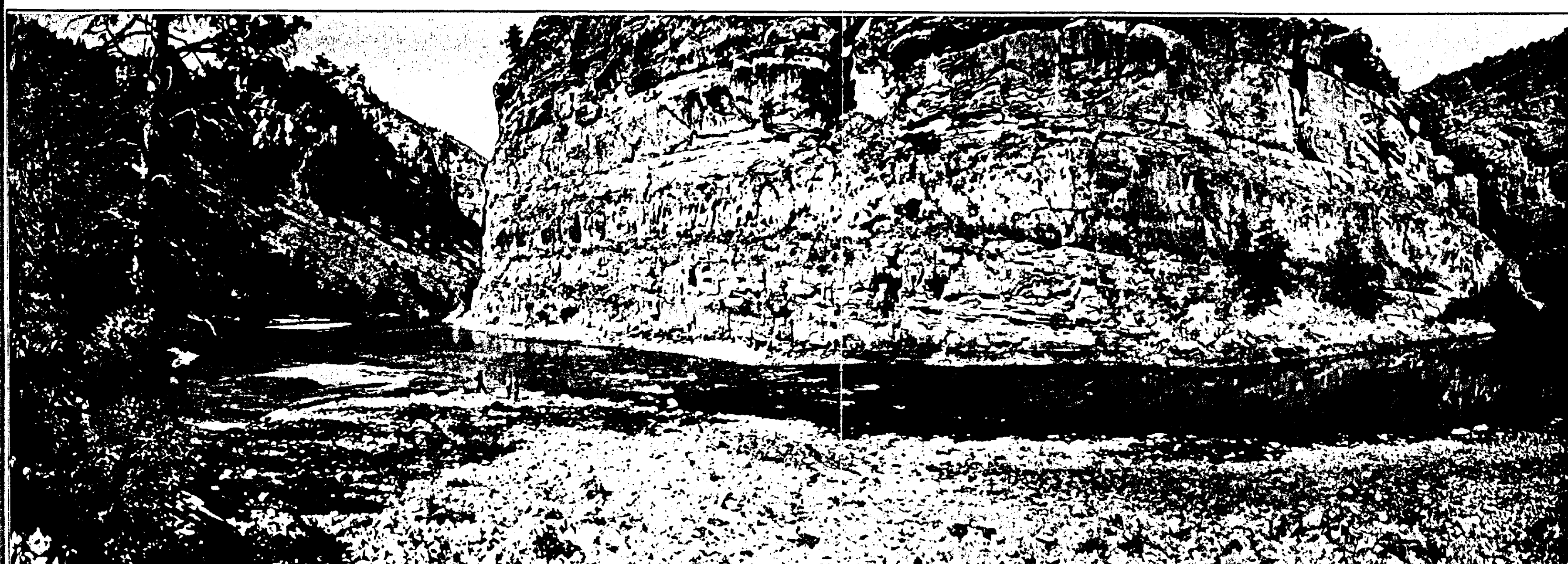
A. FIRST RAPID BELOW GREEN RIVER, WYO., AT EAST END OF HORSESHOE CANYON.



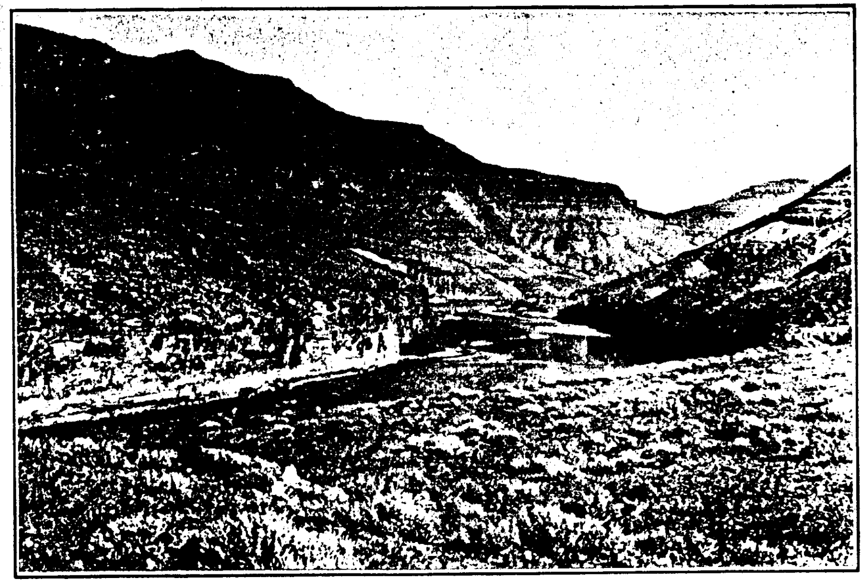
B. FLAMING GORGE, GREEN RIVER, UTAH.



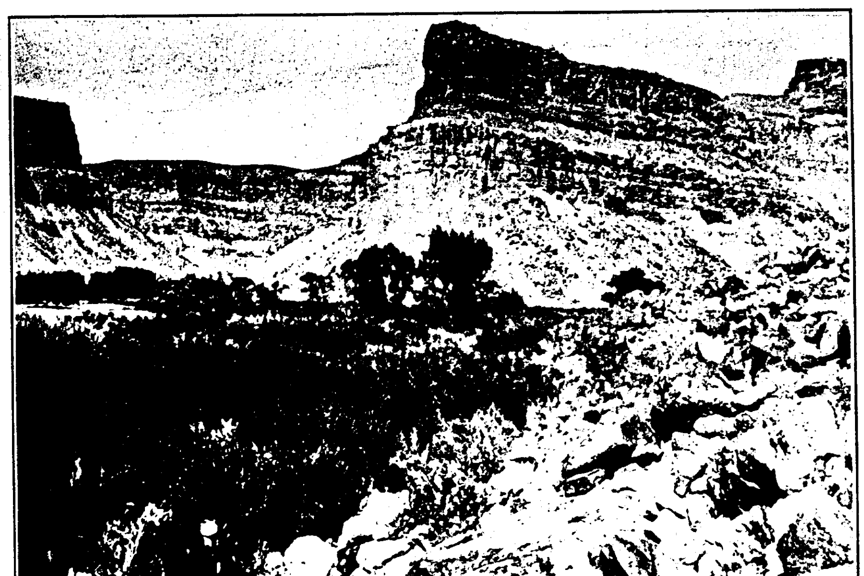
A. LADORE CANYON, GREEN RIVER, COLO.



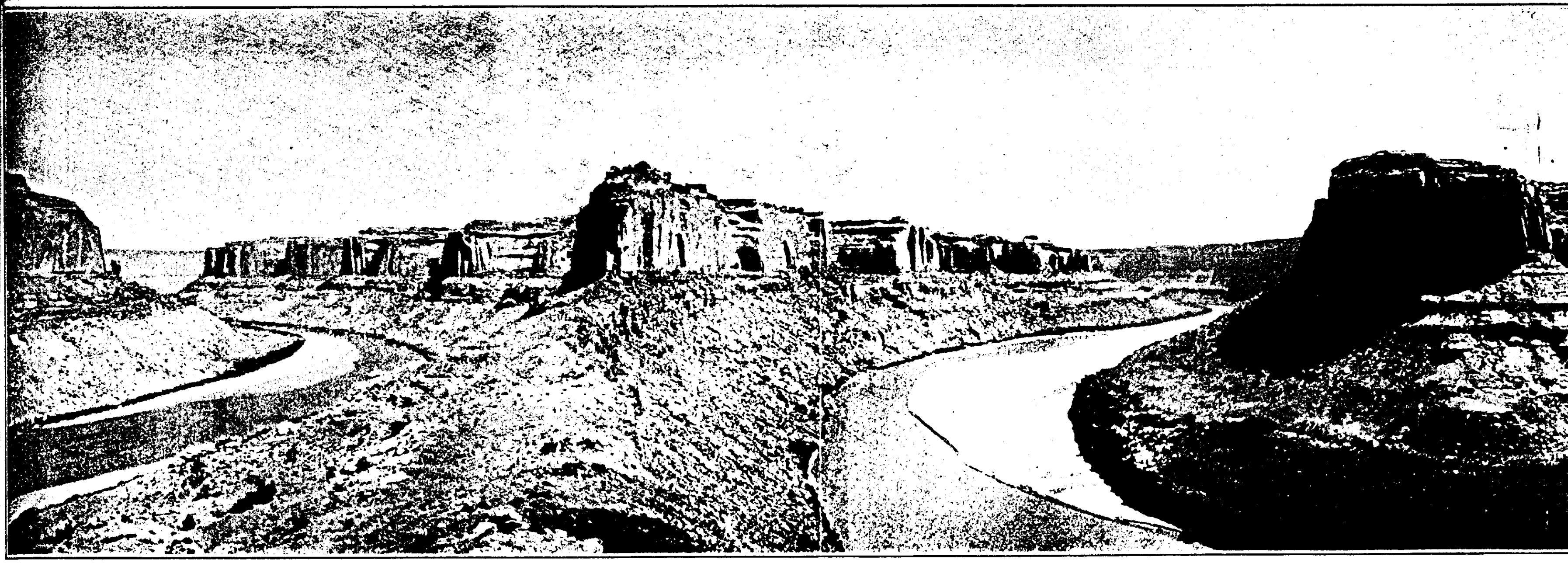
B. HORSESHOE CANYON, GREEN RIVER, UTAH.



A. DESOLATION CANYON AT MOUTH OF COAL CREEK, GREEN RIVER, UTAH.

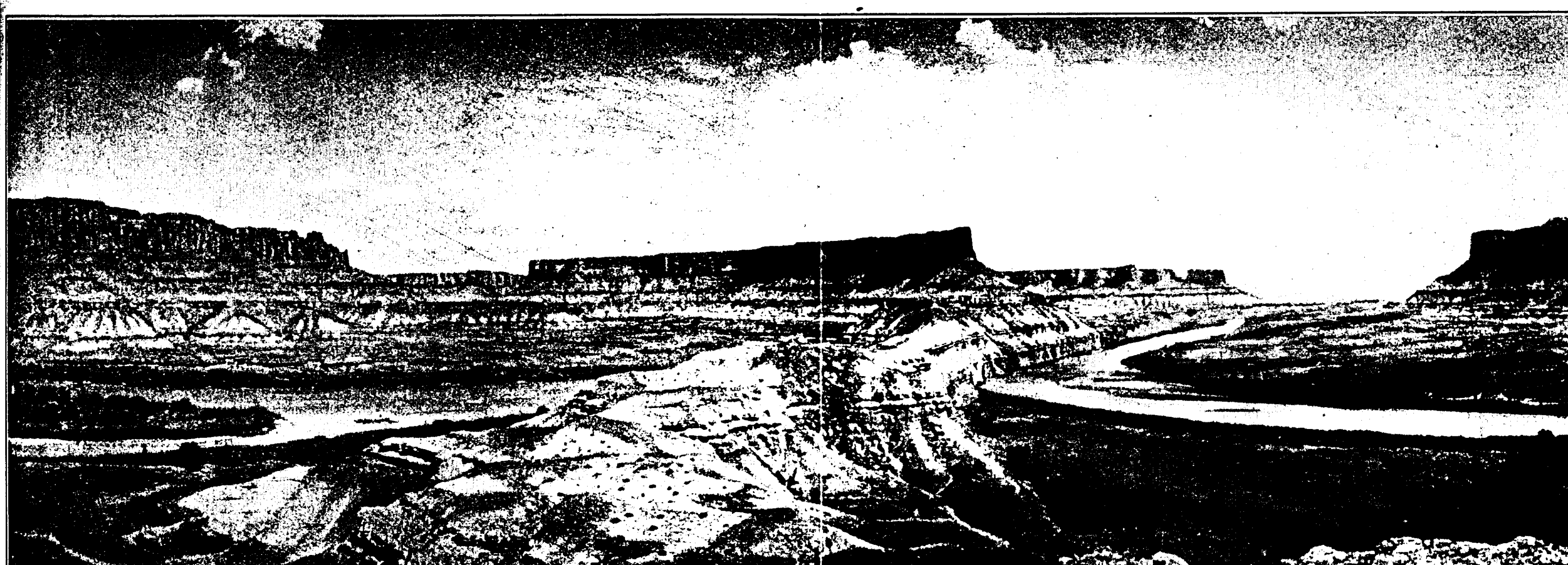


B. GRAY CANYON AT MOUTH OF PRICE RIVER, GREEN RIVER, UTAH.



A. THE LOOP ON GREEN RIVER 51 MILES BELOW GREEN RIVER, UTAH.

Distance around the loop, 7 miles; across the neck, 800 feet. Fall in 7-mile section of the river, 6 feet.



B. LABYRINTH CANYON AT FORT BOTTOMS, 77 MILES BELOW GREEN RIVER, UTAH.

PRINCIPAL TRIBUTARIES.

Blacks Fork.—Blacks Fork with its numerous tributaries drains the extreme southwestern part of Wyoming. Hams Fork and Little Muddy and Muddy creeks, which enter it from the north, rise in the Sublette Range and Bear River divide respectively, whereas the sources of Blacks Fork proper and Smiths Fork, its only important tributary from the south, are in the Uinta Mountains in Utah.

Henrys Fork.—Henrys Fork rises on the northern slope of the Uinta Mountains and flows northward into Wyoming; returning to Utah, it joins Green River about one-half mile above Flaming Gorge. The total drainage area is 644 square miles. Altitudes in this basin range from 5,900 feet to more than 13,000 feet. No records are available to show the run-off from Henrys Fork basin. It is known, however, that the run-off per square mile is comparatively high.

Yampa River.[1]—Yampa River rises in the southeastern part of Routt County, Colo., flows northward to Steamboat Springs and thence westward to its junction with Green River just east of the Colorado-Utah boundary. Throughout almost its entire course it occupies a succession of open valleys alternating with deep, narrow canyons, the longest and deepest of the canyons being that through which it enters the Green.

The drainage basin, which comprises 7,600 square miles, of which 1,870 square miles is in Wyoming, lies for the most part within the boundaries of Routt and Moffat counties, Colo. Its eastern limit is formed by the Park Mountains, and the melting of the snows on their high peaks is the source of numerous small streams whose waters augment the volume of the river and form its chief perennial supply. West of the mountains the basin is largely the eroded and dissected Yampa Plateau, whose wide terraces, abrupt cliffs, and deep-cut gulches and arroyos are the striking features of the region. The general elevation of the basin exceeds 6,000 feet.

Elk River, Fortification Creek, Elk Head Creek, Williams Fork, and Little Snake River are the most important tributaries of the Yampa. The upper basins of these streams are within the forested region, but along their lower courses are many cultivated areas. Little Snake River, the principal tributary, rises on the northern slope of the Elk Head Mountains and flows northwestward into Wyoming, and thence southwestward into Colorado; it enters the Yampa in sec. 19, T. 6 N., R. 98 W. The run-off from this tributary is comparatively small.

Ashley Creek.—Ashley Creek rises on the southern slope of the Uinta Mountains in Uinta County, Utah, flows southeastward, and joins Green River about 3 miles below Jensen.

[1] Decision of the United States Geographic Board: "Yampa; river, northwestern Colorado; not Bear."

Duchesne River.—Duchesne River, one of the most important tributaries of the Green, rises in the Wasatch and Uinta mountains, flows eastward, and joins the Green at Ouray, Utah. Its drainage area comprises approximately 4,000 square miles. Its principal tributaries are Strawberry River, Rock Creek, and Uinta River. The average annual run-off from the Duchesne and its tributaries is approximately 700,000 acre-feet.

White River.—White River rises in Trappers Lake, which lies at an elevation of 9,500 feet above sea level in a small mountain basin of the White River Plateau in eastern Garfield County, Colo.; thence it flows westward to its confluence with Green River in west-central Uinta County, Utah. Throughout its course it occupies a narrow, mountainous valley, in which parks and canyons alternate, entering the longest and deepest of the canyons, in which it continues to its mouth, about 8 miles east of the Colorado-Utah State line. White River drains an area of 4,620 square miles.

Topographically the basin is an arid, broken, and much eroded plateau, a continuation of the Grand River Mesa south of Grand River. The headwater region is greatest in area and is called the White River Plateau; below this and to the south is the Roan (or Book Cliffs) Plateau. Fragmentary plateaus also occur along the northern side of the river.

Numerous small streams, among which are Marvine Creek and South Fork, join the White in the upper, mountainous part of the basin. Douglas, Piceance, and Evacuation creeks, draining the Book Cliffs Plateau, enter White River from the south. In the spring these creeks carry considerable water, derived mainly from melting snow, but in the summer they are nearly dry.

The mean annual precipitation recorded at Meeker is 15.9 inches; farther west and at lower elevation it is undoubtedly much less. The average annual run-off from the basin of the White is approximately 500,000 acre-feet.

Minnie Maud Creek.—Immediately south of the Duchesne River basin is an area drained by Minnie Maud Creek, a small tributary of the Green. This creek flows through a comparatively narrow valley and information regarding it is meager.

Price River.—Price River, a rather important tributary of the Green, has its source in the Wasatch Mountains, flows southeasterly and joins the Green in Gray Canyon at a point 20 miles above the town of Green River, Utah. The elevation of the basin ranges from 4,200 feet to more than 10,000 feet. The total drainage area is approximately 1,860 square miles. The average annual run-off from the Price basin is approximately 180,000 acre-feet.

San Rafael River.—San Rafael River is formed at a point about 10 miles below Castledale, Utah, by the junction of Ferron, Cottonwood, and Huntington creeks, streams whose sources lie in the Wasatch Mountains. The general course of the San Rafael is southeastward to its confluence with the Green at a point 24 miles below the town of Green River, Utah. The drainage area comprises approximately 2,080 square miles. Altitudes within the basin range from 4,020 feet to more than 10,000 feet above sea level. The average annual run-off from the San Rafael basin is about 230,000 acre-feet.

DISCHARGE RECORDS.

GREEN RIVER AT GREEN RIVER, WYO.

Location.—About 40 feet below the bridge of Union Pacific Railroad at Green River, Wyo.

Records presented.—May 1, 1895, to March 31, 1900; October 1, 1900, to October 31, 1906. No estimates made November 1, 1899, to September 30, 1900.

Drainage area.—7,450 square miles.

Gage.—Staff fastened to heavy submerged cribbing on east bank of river near the pump house.

Channel.—During low water stream is confined in a single channel on the left. At medium stages water flows in two channels and under the approaches of the bridge. At times of flood there are four channels, interrupted to some extent by open cribs driven into the bed of the stream, which is sandy and somewhat shifting.

Discharge measurements.—Made from iron highway bridge about one-half mile below railway bridge.

Winter flow.—Affected by ice.

Diversions.—Water is diverted for the irrigation of about 190,000 acres above the gaging station.

Accuracy.—Estimates of discharge only fair.

Monthly discharge of Green River at Green River, Wyo., for the years ending Sept. 30, 1895–1906.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1895.				
May	6,200	2,340	3,970	244,000
June	6,920	3,600	4,550	271,000
July	7,050	2,530	4,120	253,000
August	2,740	1,000	1,700	105,000
September	980	482	638	38,000
The period				911,000
1895–96.				
October	608	400	472	29,000
November	361		a 300	17,900
December			a 300	18,400
January			a 300	18,400
February			a 300	17,300
March			a 350	21,500
April			a 1,020	60,700
May	6,980	1,220	2,140	132,000
June	15,500	7,540	11,800	702,000
July	6,380	2,430	4,200	258,000
August	2,500	979	1,470	90,400
September	1,040	750	869	51,700
The year	15,500		1,960	1,420,000

a Estimated.

Monthly discharge of Green River at Green River, Wyo., for the years ending Sept. 30, 1895–1906—Continued.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1896–97.				
October			a 740	45,500
November			a 600	35,700
December			a 500	30,700
January			a 450	27,700
February			a 400	22,200
March			a 400	24,600
April	3,200	1,200	1,960	117,000
May	17,900	2,720	9,770	601,000
June	14,400	4,400	7,550	449,000
July	4,400	1,760	2,790	172,000
August	2,500	640	1,600	98,400
September	640	400	465	27,700
The year	17,900		2,270	1,650,000
1897–98.				
October	1,760	500	1,010	62,100
November			a 760	45,200
December			a 550	33,800
January			a 500	30,700
February			a 400	22,200
March			a 450	27,700
April	5,520	800	2,660	158,000
May	7,680	2,320	4,060	250,000
June	15,100	4,200	9,060	539,000
July	9,120	2,160	4,620	284,000
August	2,080	720	1,420	87,300
September	1,200	260	646	38,400
The year	15,100		2,180	1,580,000
1898–99.				
October	400	300	347	21,300
November	1,280	160	400	23,800
December			a 300	18,400
January			a 300	18,400
February			a 400	22,200
March			a 450	27,700
April	2,390	990	1,600	95,200
May	5,690	1,530	3,270	201,000
June	21,400	5,480	12,500	744,000
July	20,700	8,880	14,500	892,000
August	8,650	2,460	5,170	318,000
September	2,460	1,700	2,060	123,000
The year	21,400		3,440	2,500,000
1899.				
October	1,990	1,640	1,820	112,000
1900–1901.				
October			a 600	36,900
November			a 600	35,700
December			a 500	30,700
January			a 500	30,700
February			a 400	22,200
March			a 500	30,700
April	2,880	500	1,320	78,600
May	12,400	1,780	6,750	415,000
June	10,200	3,400	5,420	323,000
July	4,200	1,840	2,750	169,000
August	2,460	905	1,410	86,700
September	905	500	632	37,600
The year	12,400		1,780	1,300,000
1901–2.				
October			a 500	30,700
November			a 450	26,800
December			a 400	24,600
January			a 300	18,400
February			a 300	16,700
March			a 300	18,400
April	1,380	285	844	50,200
May	7,920	845	2,260	139,000
June	10,800	4,380	7,100	422,000

a Estimated.

Monthly discharge of Green River at Green River, Wyo., for the years ending Sept. 30, 1895–1906—Continued.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1901–2.				
July	4,550	1,720	2,670	164,000
August	2,260	950	1,390	85,500
September	950	380	656	39,000
The year			1,430	1,040,000
1902–3.				
October	380	285	329	20,200
November			a 300	17,900
December			a 300	18,400
January			a 300	18,400
February			a 250	13,900
March			a 600	36,900
April	1,740	582	1,200	71,400
May	2,650	1,300	1,840	113,000
June	13,000	2,020	9,570	569,000
July	8,010	2,400	3,990	245,000
August	2,160	1,110	1,460	89,800
September	3,320	792	1,550	92,200
The year	13,000		1,810	1,310,000
1903–4.				
October	1,160	845	1,010	62,100
November			a 800	47,600
December			a 600	36,900
January			a 500	30,700
February			a 700	40,300
March			a 900	55,300
April	3,660	1,160	1,960	117,000
May	13,100	2,690	6,130	377,000
June	12,200	7,160	10,200	607,000
July	8,010	3,470	5,260	323,000
August	3,540	1,220	2,040	125,000
September	1,400	620	890	53,000
The year	13,100		2,580	1,870,000
1904–5.				
October	838	597	698	42,900
November			a 550	32,700
December			a 500	30,700
January			a 400	24,600
February			a 400	22,200
March			a 550	33,800
April	1,260	600	883	52,500
May	3,600	820	1,580	97,200
June	8,540	3,320	5,950	354,000
July	5,590	1,820	3,460	213,000
August	1,740	860	1,120	68,900
September	964	420	639	38,000
The year	8,540		1,390	1,010,000
1905–6.				
October	600	420	486	29,900
November			a 400	23,800
December			a 300	18,400
January			a 300	18,400
February			a 300	16,700
March			a 500	30,700
April	3,360	893	2,040	121,000
May	8,700	2,060	5,030	309,000
June	12,200	4,510	6,830	406,000
July	6,210	2,740	4,860	299,000
August	4,060	1,390	2,240	138,000
September	1,990	790	1,260	75,000
The year	12,200		2,050	1,490,000
1906.				
October	790	560	660	40,600

a Estimated.

NOTE.—No measurements in 1903; records questionable.

GREEN RIVER NEAR BRIDGEPORT, UTAH.

Location.—In sec. 3, T. 1 N., R. 25 E., at the ferry of the Jarvis or Park Live Stock Co., 3 miles south of the town of Bridgeport.

Records presented.—October 1, 1911, to September 30, 1914.[a]

Drainage area.—15,700 square miles.

Gage.—Staff, consisting of two vertical sections and one inclined section.

Channel.—Gravel and sand; may shift at high stages.

Discharge measurements.—Made from the ferryboat or car on ferry cable.

Winter flow.—Discharge relation affected by ice.

Diversions.—Water for the irrigation of about 285,000 acres is diverted above the gaging station.

Regulation.—None.

Accuracy.—Records good for all stages except for winter periods.

Monthly discharge of Green River near Bridgeport, Utah, for the years ending Sept. 30, 1912–1914.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1911–12.					
October	1,020	....	b 940	57,800	C.
November	950	....	b 822	48,900	B.
December	....	....	b 580	35,700	C.
January	....	....	b 550	33,800	D.
February	....	....	b 590	33,900	D.
March	....	....	b 774	47,600	D.
April	1,900	1,200	1,630	97,000	C.
May	6,640	1,660	4,020	247,000	A.
June	16,900	6,640	11,900	708,000	A.
July	13,200	4,820	7,700	473,000	A.
August	4,820	2,000	3,390	208,000	A.
September	2,340	1,270	1,540	91,600	B.
The year	16,900	....	2,870	2,080,000	
1912–13.					
October	1,710	1,190	1,330	81,800	A.
November	....	....	b 1,100	65,500	D.
December	....	....	b 700	43,000	D.
January	....	....	b 850	52,300	D.
February	....	....	b 800	44,400	D.
March	....	....	b 1,800	111,000	D.
April	6,800	....	b 5,070	302,000	B.
May	10,900	3,750	6,330	389,000	A.
June	14,000	8,080	10,900	649,000	A.
July	12,000	4,030	6,720	413,000	A.
August	4,600	....	b 2,720	167,000	B.
September	....	....	b 1,850	110,000	B.
The year	14,000	....	3,350	2,430,000	
1913–14.					
October	2,220	1,270	1,860	114,000	B.
November	1,530	....	b 1,120	66,600	B.
December	....	....	b 750	46,100	D.
January	....	....	b 780	48,000	D.
February	....	....	b 1,020	56,600	D.
March	3,750	....	b 1,970	121,000	C.
April	6,800	3,100	5,130	305,000	A.
May	14,400	4,750	8,870	545,000	A.
June	16,700	9,480	11,800	702,000	A.
July	9,300	2,840	5,980	368,000	A.
August	4,350	1,160	2,480	152,000	B.
September	1,160	790	903	53,700	A.
The year	16,700	....	3,560	2,580,000	

a On Sept. 29, 1914, the station was moved about 5 miles upstream to Bridgeport post office and a water-stage recorder installed.

b Estimated.

GREEN RIVER AT JENSEN, UTAH.

Location.—About 300 feet below Billings Ferry at Jensen and about 15 miles from Vernal, 1½ miles below mouth of Brush Creek, and 3 miles above mouth of Ashley Creek.

Records presented.—November 7, 1903, to September 30, 1906. No estimates made December 25, 1904, to March 12, 1906.

Drainage area.—26,600 square miles.

Gage.—Vertical staff.

Channel.—Bed of stream sandy and shifting.

Discharge measurements.—Before August 8, 1903, made from ferryboat; after that date from cable and car.

Winter flow.—Affected by ice.

Diversions.—Water is diverted for the irrigation of about 328,000 acres above the gaging station.

Monthly discharge of Green River at Jensen, Utah, for the years ending Sept. 30, 1904–1906.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1903–4.				
November 7–30	1,560	852	1,290	61,400
December	2,830	1,390	1,730	106,000
January	....	....	a 1,800	111,000
February	4,990	....	a 2,000	115,000
March	6,290	2,270	3,550	218,000
April	12,200	2,820	7,580	451,000
May	32,100	12,400	20,400	1,250,000
June	26,200	13,700	23,000	1,370,000
July	13,200	5,400	9,480	583,000
August	4,850	2,240	3,100	191,000
September	2,350	670	1,210	72,000
The period	....	....	....	4,530,000
1904.				
October	1,800	670	1,040	64,000
November	1,080	586	745	44,300
December 1–24	980	236	639	31,700
1906.				
March 13–31	16,200	1,990	7,340	277,000
April	14,700	3,970	8,070	480,000
May	29,600	8,850	19,400	1,190,000
June	30,200	9,670	20,400	1,210,000
July	12,300	5,160	9,230	568,000
August	5,870	2,520	3,850	237,000
September	4,420	2,240	3,080	183,000
The period	....	....	....	4,140,000

a Estimated.

GREEN RIVER AT LITTLE VALLEY,[1] NEAR GREEN RIVER, UTAH.

Location.—Prior to December 31, 1911, in sec. 15, T. 21 S., R. 16 E., at highway bridge 200 feet upstream from railroad bridge at Green River; beginning January 1, 1912, 4 miles downstream in sec. 5, T. 22 S., R. 16 E., at Little Valley Ferry.

Records presented.—October 21, 1894, to September 30, 1897; February 16, 1905, to December 31, 1911, at Green River; January 1, 1912, to September 30, 1914, at Little Valley. The flow is practically the same at the two points.

Drainage area.—41,000 square miles, at lower station.

[1] Also known as "at Blake" and "at Elgin."

Gage.—Chain gage at upper location; staff and automatic gage at lower location.

Channel.—Shifting.

Discharge measurements.—Made from bridge or ferry at Green River and from car on ferry cable at Little Valley.

Winter flow.—Discharge relation affected by ice.

Diversions.—Water for the irrigation of approximately 464,000 acres is diverted above the gaging station.

Accuracy.—Records fair.

Monthly discharge of Green River at Little Valley, near Green River, Utah, for the years ending Sept. 30, 1895–1897, 1905–1914.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1894–95.					
October 21–31	3,250	3,100	3,170	69,200	
November	3,250	2,440	2,930	174,000	
December	2,440	1,700	2,240	138,000	
January	2,440	2,010	2,170	133,000	
February	2,320	2,010	2,140	119,000	
March	6,470	2,320	3,780	232,000	
April	16,700	4,720	8,280	493,000	
May	26,300	13,900	21,400	1,320,000	
June	21,000	10,600	14,600	869,000	
July	15,000	4,740	9,430	580,000	
August	4,860	2,150	3,340	205,000	
September	2,790	1,450	1,770	105,000	
The period	....	....	....	4,440,000	
1895–96.					
October	2,620	1,650	2,020	124,000	
November	1,880	900	1,590	94,600	
December	1,450	950	1,300	79,900	
January	1,500	1,160	1,330	81,800	
February	1,550	1,200	1,390	80,000	
March	4,540	1,450	2,460	151,000	
April	13,100	2,960	4,930	293,000	
May	29,800	7,330	13,500	830,000	
June	43,500	12,300	27,400	1,630,000	
July	11,300	5,140	6,720	413,000	
August	5,650	1,870	3,240	199,000	
September	9,430	1,740	3,060	182,000	
The year	43,500	900	5,730	4,160,000	
1896–97.					
October	2,990	1,740	2,110	130,000	
November	2,160	1,390	1,720	102,000	
December	....	....	[a] 1,300	79,900	
January	....	....	[a] 1,000	61,500	
February	....	....	[a] 1,200	66,600	
March	....	....	[a] 2,000	123,000	
April	13,100	3,550	6,430	383,000	
May	67,300	15,700	43,500	2,670,000	
June	55,200	11,400	26,600	1,580,000	
July	10,500	3,900	6,320	389,000	
August	4,110	2,150	3,260	200,000	
September	9,450	1,880	3,230	192,000	
The year	67,300	....	8,260	5,980,000	
1905.					
March	3,840	1,760	2,990	184,000	B.
April	6,360	2,720	4,070	242,000	B.
May	24,200	6,360	12,900	793,000	B.
June	33,900	14,000	24,300	1,450,000	B.
July	13,400	4,180	7,640	470,000	B.
August	3,840	1,870	2,730	168,000	B.
September	6,030	1,870	2,510	149,000	B.
The period	....	....	....	3,460,000	

[a] Estimated.

Monthly discharge of Green River at Little Valley, near Green River, Utah, for the years ending Sept. 30, 1895–1897, 1905–1914—Continued.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1905–6.					
October	6,190	1,870	2,480	152,000	B.
November	2,560	1,820	2,050	122,000	B.
December	1,870	....	1,320	81,200	C.
January	....	....	1,400	86,100	D.
February	....	....	1,620	90,000	C.
March	21,800	1,870	6,110	376,000	B.
April	16,900	5,400	9,580	570,000	A.
May	36,500	12,400	24,800	1,520,000	B.
June	42,100	24,500	31,300	1,860,000	B.
July	15,700	8,040	13,400	824,000	A.
August	8,260	4,430	6,170	379,000	A.
September	7,440	3,720	5,080	302,000	A.
The year	42,100	....	8,780	6,360,000	
1906–7.					
October	3,720	2,560	3,020	186,000	A.
November	5,870	1,760	3,260	194,000	A.
December	3,280	1,700	2,430	149,000	B.
January	2,900	1,820	2,440	150,000	B.
February	7,840	2,560	4,910	273,000	A.
March	13,400	3,720	6,760	416,000	A.
April	24,900	6,030	14,000	833,000	A.
May	42,900	13,100	24,700	1,520,000	B.
June	48,100	29,800	38,800	2,310,000	B.
July	42,900	19,000	31,600	1,940,000	B.
August	19,300	7,100	11,200	689,000	A.
September	7,940	3,220	4,820	287,000	A.
The year	48,100	1,700	12,300	8,950,000	
1907–8.					
October	5,260	3,000	3,670	226,000	A.
November	3,000	1,890	2,560	152,000	B.
December	1,890	1,240	1,470	90,400	C.
January	....	....	1,300	79,900	C.
February	....	....	1,530	88,000	C.
March	5,940	1,740	3,570	220,000	A.
April	12,800	3,450	6,590	392,000	A.
May	14,600	8,160	11,600	713,000	A.
June	25,000	11,400	18,100	1,080,000	A.
July	14,400	4,820	10,300	633,000	A.
August	8,890	4,820	6,810	419,000	A.
September	5,300	1,900	3,380	201,000	B.
The year	25,000	....	5,910	4,290,000	
1908–9.					
October	6,120	2,700	3,580	220,000	B.
November	3,220	830	2,160	129,000	C.
December	1,460	750	801	49,300	C.
January	3,510	930	1,980	122,000	B.
February	2,580	1,330	1,720	95,500	B.
March	33,000	1,460	8,120	499,000	B.
April	16,200	4,820	9,290	553,000	A.
May	32,700	11,000	22,400	1,380,000	A.
June	62,200	32,700	46,300	2,760,000	C.
July	42,600	12,800	25,200	1,550,000	B.
August	14,100	8,000	10,300	633,000	A.
September	18,000	5,170	9,960	593,000	A.
The year	62,200	750	11,800	8,580,000	
1909–10.					
October	4,820	3,220	3,930	242,000	A.
November	3,510	2,470	2,980	177,000	A.
December	4,820	....	1,290	79,300	C.
January	....	....	1,000	61,500	D.
February	7,500	1,200	2,500	139,000	D.
March	22,400	2,700	11,400	701,000	C.
April	24,800	7,560	12,500	744,000	A.
May	28,800	13,000	21,200	1,300,000	B.
June	21,300	6,310	13,700	815,000	C.
July	6,500	1,640	3,230	199,000	B.
August	4,650	1,100	2,160	133,000	B.
September	6,500	1,100	2,040	121,000	B.
The year	28,800	....	6,490	4,710,000	

Monthly discharge of Green River at Little Valley, near Green River, Utah, for the years ending Sept. 30, 1895–1897, 1905–1914—Continued.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1910–11.					
October	5,940	1,300	3,280	202,000	B.
November	3,450	2,000	2,270	135,000	B.
December	2,000	770	1,520	93,500	B.
January	4,380	....	2,330	143,000	D.
February	8,640	1,630	3,440	191,000	B.
March	13,500	1,500	6,280	386,000	B.
April	7,440	4,050	5,480	326,000	B.
May	16,100	7,770	11,700	719,000	B.
June	27,600	11,300	19,400	1,150,000	A.
July	16,400	4,950	8,460	520,000	B.
August	4,480	2,130	2,930	180,000	B.
September	4,390	1,520	1,970	117,000	B.
The year	27,600	....	5,760	4,160,000	
1911–12.					
October	6,120	2,440	3,800	234,000	B.
November	2,640	1,740	2,240	133,000	B.
December	1,910	1,450	1,640	101,000	B.
January	2,280	1,430	1,720	106,000	B.
February	2,070	1,480	1,800	104,000	B.
March	6,050	1,530	3,690	227,000	A.
April	9,850	4,870	6,550	390,000	A.
May	30,600	5,330	16,100	990,000	A.
June	54,600	22,600	37,600	2,240,000	A.
July	28,800	9,500	16,300	1,000,000	A.
August	10,900	3,860	6,860	422,000	A.
September	4,440	2,810	3,620	215,000	B.
The year	54,600	....	8,490	6,160,000	
1912–13.					
October	7,790	2,810	3,660	225,000	B.
November	4,240	2,210	3,510	209,000	A.
December	1,810	1,290	1,520	93,500	B.
January	2,400	....	2,300	141,000	C.
February	2,400	....	2,230	124,000	C.
March	6,040	....	4,160	256,000	C.
April	19,100	7,800	12,800	762,000	C.
May	24,500	9,100	16,500	1,010,000	B.
June	26,700	12,800	19,400	1,150,000	A.
July	18,200	8,760	14,700	904,000	A.
August	8,100	2,240	4,330	266,000	A.
September	8,760	2,240	3,830	228,000	A.
The year	26,700	....	7,410	5,370,000	
1913–14.					
October	4,540	2,880	3,560	219,000	B.
November	3,770	2,720	3,250	193,000	C.
December	2,720	....	1,680	103,000	C.
January	....	....	1,950	120,000	C.
February	7,200	....	2,640	147,000	C.
March	12,800	3,300	6,430	395,000	B.
April	19,600	6,300	12,600	750,000	A.
May	45,900	15,600	28,500	1,750,000	A.
June	50,800	24,000	35,700	2,120,000	A.
July	23,000	6,600	13,600	836,000	A.
August	6,300	3,040	4,620	284,000	A.
September	3,580	2,320	2,620	156,000	B.
The year	50,800	....	9,780	7,080,000	

NOTE.—Station moved 4 miles downstream Jan. 1, 1912.

BLACKS FORK AT GRANGER, WYO.

Location.—About one-fourth mile below Granger, below the mouth of Hams Fork.

Records presented.—April 28, 1897, to September 30, 1900. April 18, 1896, to April 27, 1897, a station was maintained three miles above Granger at Union Pacific Railroad bridge, above Hams Fork.

Gage.—Wire gage suspended from horizontal timber fastened to two upright posts set in the bank of the river.

Channel.—Shifting.

Discharge measurements.—Made from cable and car.

Winter flow.—Affected by ice.

Diversions.—Water is diverted for the irrigation of about 55,000 acres above the gaging station.

Accuracy.—Records can not be considered better than fair.

Monthly discharge of Blacks Fork above Hams Fork, near Granger, Wyo., for the year ending Sept. 30, 1896.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
April 18–30	470	230	388	10,000
May	4,160	380	1,130	69,500
June	5,020	440	1,760	105,000
July	410	190	278	17,100
August	620	40	174	10,700
September	620	60	131	7,800
The period	....	....	....	220,000

Monthly discharge of Blacks Fork at Granger, Wyo., for the years ending Sept. 30, 1897–1900.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1896–97.				
October	....	....	a 120	7,380
November	....	....	a 100	5,950
December	....	....	a 90	5,530
January	....	....	a 70	4,300
February	....	....	a 50	2,780
March	....	....	a 200	12,300
April	....	....	a 700	41,700
May	5,830	1,400	3,750	231,000
June	3,370	495	1,310	78,000
July	570	145	315	19,400
August	210	90	146	8,980
September	245	65	131	7,800
The year	....	....	582	425,000
1897–98.				
October	....	....	a 400	24,600
November	....	....	a 200	11,900
December	....	....	a 180	11,100
January	....	....	a 100	6,150
February	....	....	a 80	4,440
March	....	....	a 500	30,700
April	2,260	990	1,670	99,400
May	2,590	1,180	1,700	105,000
June	2,520	990	1,730	103,000
July	822	145	405	24,900
August	245	0	108	6,640
September	....	....	0	0
The year	2,590	....	589	428,000
1898–99.				
October	210	0	127	7,810
November	....	....	a 80	4,760
December	....	....	a 70	4,300
January	....	....	a 60	3,690
February	....	....	a 50	2,780

a Estimated.

Monthly discharge of Blacks Fork at Granger, Wyo., for the years ending Sept. 30, 1897–1900—Continued.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1898–99.				
March	....	....	a 400	24,600
April	2,090	520	987	58,700
May	3,870	640	2,260	139,000
June	6,780	2,950	4,740	282,000
July	3,710	455	1,630	100,000
August	510	110	287	17,600
September	145	15	62.2	3,700
The year	6,780	....	896	649,000
1899–1900.				
October	145	15	90	5,530
November	....	....	a 100	5,950
December	....	....	a 80	4,920
January	....	....	a 70	4,300
February	....	....	a 70	3,890
March	....	....	a 450	27,700
April	860	372	576	34,300
May	2,650	770	1,650	101,000
June	2,270	135	910	54,100
July	110	19	44.1	2,710
August	27	0	10.6	652
September	....	....	1.0	60
The year	2,650	....	338	245,000

a Estimated.

NOTE.—Records October, 1896, to April, 1897, estimated from record of Blacks Fork above Hams Fork.

YAMPA RIVER AT CRAIG, COLO.

Location.—One mile south of Craig, on steel bridge on road to Hamilton, a short distance below the mouth of Fortification Creek, the nearest tributary.

Records presented.—April 1 to September 4, 1902; May 1, 1904, to October 31, 1906; April 1, 1910, to November 30, 1913. Station discontinued during the winter months.

Drainage area.—1,730 square miles.

Gage.—Vertical staff.

Channel.—Slightly shifting.

Discharge measurements.—Made from highway bridge.

Diversions.—There are court decrees for diversions of about 1,260 second-feet from Yampa River and its tributaries above this station, exclusive of a conditional decree for 587 second-feet from the North Fork of Elk Head Creek.

Cooperation.—Since 1910 station has been maintained and records have been furnished complete for publication by the State engineer.

Monthly discharge of Yampa River at Craig, Colo., for 1902, 1904–1906, 1910–1913.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1902.				
April	4,200	370	1,800	107,000
May	8,730	3,320	6,720	413,000
June	8,520	825	3,970	236,000
July	1,080	198	479	29,500
August	165	90	115	7,070
The period	....	....	....	793,000

Monthly discharge of Yampa River at Craig, Colo., for 1902, 1904–1906, 1910–1913—Con.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1904.				
May	7,550	3,480	5,280	325,000
June	5,820	1,960	4,010	239,000
July	1,820	310	731	45,000
August	375	238	299	18,400
September	291	163	201	12,000
October	291	163	230	14,100
The period	....	....	....	654,000
1905.				
April	3,380	510	1,580	94,000
May	8,000	1,920	4,180	257,000
June	9,000	2,420	5,710	340,000
July	2,360	370	1,000	61,600
August	570	100	333	20,500
September	230	100	124	7,380
October	230	125	163	10,000
The period	....	....	....	790,000
1906.				
April	4,460	808	2,100	125,000
May	9,680	2,550	6,180	380,000
June	8,800	2,480	5,620	334,000
July	2,700	450	1,470	90,400
August	535	215	359	22,100
September	425	200	283	16,800
October	350	265	285	17,500
The period	....	....	....	986,000
1910.				
April	5,650	1,740	3,080	183,000
May	5,650	2,830	4,130	254,000
June	5,870	662	2,490	148,000
July	662	72	237	14,600
August	292	95	167	10,300
September	360	95	233	13,800
October	465	145	281	17,300
November	325	260	288	17,100
The period	....	....	....	658,000
1911.				
April	4,360	885	1,800	107,000
May	8,320	2,350	4,470	275,000
June	7,350	1,940	4,370	260,000
July	1,940	425	973	59,800
August	425	172	254	15,600
September	230	95	154	9,160
October	1,810	260	551	33,900
November	325	230	261	15,500
The period	....	....	....	776,000
1912.				
April	3,340	1,260	2,220	132,000
May	9,700	2,670	6,150	378,000
June	10,300	3,490	7,080	421,000
July	5,450	1,620	2,820	173,000
August	1,880	615	998	61,400
September	932	615	680	40,400
October	790	615	738	45,400
November	790	615	715	42,600
The period	....	....	....	1,290,000
1913.				
April	4,150	1,030	2,660	158,000
May	6,640	2,780	4,490	276,000
June	5,580	1,030	2,440	145,000
July	1,080	325	568	34,900
August	390	50	208	12,800
September	292	145	211	12,600
October	390	260	325	20,000
November	390	325	364	21,700
The period	....	....	....	681,000

YAMPA RIVER NEAR MAYBELL, COLO.

Location.—At the Thornburg bridge, 9 miles below Maybell. The nearest tributary is Deception Creek, which enters the river about 2 miles above.

Records presented.—April 17, 1904, to October 31, 1905; June 12, 1910, to November 30, 1912.

Drainage area.—3,670 square miles (State engineer's report).

Gage.—Vertical staff.

Channel.—Practically permanent.

Discharge measurements.—Made from car and cable.

Winter flow.—Ice causes backwater at the gage and the records are discontinued during the winter months.

Diversions.—There are court decrees for diversions of 115 second-feet from Yampa River between this station and Craig. Below Maybell there are decrees for diversions of 37 second-feet from Yampa River.

Cooperation.—Since 1910 station has been maintained and records have been furnished complete for publication by the State engineer.

Monthly discharge of Yampa River near Maybell, Colo., for 1904–5, 1910–1912.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1904.				
April 17–30	5,570	2,700	3,930	109,000
May	7,730	3,650	5,230	322,000
June	6,610	2,240	4,560	271,000
July	2,110	340	942	57,900
August	450	250	360	22,100
September	428	195	271	16,100
October	405	195	301	18,500
The period				817,000
1905.				
April	3,660	655	1,820	109,000
May	9,320	2,920	5,580	343,000
June	10,800	2,700	6,770	403,000
July	2,020	450	968	59,500
August	880	145	303	18,600
September	250	130	185	11,000
October	290	145	188	11,600
The period				956,000
1910.				
June 12–30	4,340	985	2,000	75,400
July	985	151	450	27,700
August	253	105	141	8,670
September	214	116	153	9,100
October	468	126	216	13,300
November	340	165	216	12,900
The period				147,000
1911.				
June 5–30	5,860	2,400	4,430	228,000
July	2,940	345	1,440	89,600
August	345	125	216	13,300
September	590	150	266	15,800
October	2,360	278	1,310	80,400
November	560	255	384	22,800
The period				450,000
1912.				
April	6,940	1,750	2,720	162,000
May	13,000	4,720	8,150	501,000
June	13,600	5,370	8,920	531,000
July	5,820	545	2,590	159,000
August	2,320	440	1,020	63,000
September	1,500	390	790	47,000
October	1,550	345	910	55,900
November	1,600	390	894	53,200
The period				1,570,000

WILLIAMS FORK AT HAMILTON, COLO.

Location.—Near Hamilton, at highway bridge, on the road from Meeker to Craig. Morapos Creek, the nearest tributary, enters some distance below the station.

Records presented.—May 1, 1904, to October 31, 1906; April 15, 1910, to November 30, 1913.

Drainage area.—378 square miles (Forest Service atlas).

Gage.—Chain gage.

Channel.—Shifting.

Discharge measurements.—Made from highway bridge.

Diversions.—There are court decrees for diversions of 40 second-feet from Williams Fork above the station and 7 second-feet below. There are also decrees for diversions of 87 second-feet from tributaries entering above.

Cooperation.—Since 1910 station maintained and records furnished complete for publication by the State engineer.

Monthly discharge of Williams Fork at Hamilton, Colo., for 1904–1906, 1910–1913.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1904.				
May	1,370	685	1,000	61,700
June	970	345	667	39,700
July	330	75	166	10,200
August	148	59	87	5,350
September	148	21	60	3,570
October	95	39	61	3,750
The period				124,000
1905.				
April	336	70	135	8,030
May	1,680	255	737	45,300
June	1,550	231	745	44,300
July	212	58	115	7,070
August	126	23	46.6	2,860
September	62	23	36.6	2,180
October	102	30	43.6	2,680
The period				112,000
1906.				
April	634	89	218	13,000
May	2,580	260	1,340	82,400
June	1,730	514	1,120	66,600
July	480	75	230	14,100
August	126	54	78.4	4,820
September	158	35	74.0	4,400
October	75	28	53.2	3,270
The period				189,000
1910.				
April 15–30	1,320	272	696	22,100
May	1,580	570	840	51,600
June	1,220	196	576	34,300
July	176	57	101	6,210
August	130	42	55.0	3,380
September	112	35	61.9	3,680
October	104	50	63.9	3,930
November	64	50	58.1	3,460
The period				129,000
1911.				
March 12–31	143	74	103	4,070
April	470	82	172	10,200
May	1,230	125	737	45,300
June	1,050	215	593	35,300
July	238	58	121	7,440
August	58	30	44	2,690
September	58	36	47	2,810
October	272	19	80	4,910
November 1–11	43	43	43	938
The period				114,000

Monthly discharge of Williams Fork at Hamilton, Colo., for 1904–1906, 1910–1913—Con.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1912.				
April	249	116	152	9,050
May	2,060	226	901	55,400
June	1,770	562	1,090	65,000
July	745	215	377	23,200
August	272	74	138	8,510
September	100	58	78	4,630
October	91	74	79	4,890
November	108	74	80	4,770
The period				175,000
1913.				
April	985	185	472	28,100
May	1,150	415	751	46,200
June	678	155	327	19,500
July	320	65	123	7,560
August	95	50	70.8	4,350
September	235	50	98.0	5,830
October	125	45	80.4	4,940
November	50	30	38.0	2,260
The period				119,000

LITTLE SNAKE RIVER NEAR DIXON, WYO.

Location.—In sec. 6, T. 12 N., R. 90 W., 1 mile west of Dixon. Nearest tributaries are Cottonwood Creek, which enters a short distance east of Dixon, and Beaver Creek, which enters a mile or less downstream.

Records presented.—June 1, 1910, to November 30, 1913.

Drainage area.—1,294 square miles (State engineer's report).

Gage.—Chain gage.

Channel.—Slightly shifting during high water.

Cooperation.—Station maintained and records furnished complete for publication by the State engineer of Colorado.

Monthly discharge of Little Snake River near Dixon, Wyo., for 1910–1913.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1910.				
June	1,900	77	663	39,500
July	149	11	34.3	2,110
August	47	9	16.3	1,000
September	69	17	38.4	2,280
October	149	35	78.9	4,850
November	95	54	77.3	4,600
December			77.1	4,740
The period				59,100
1911.				
March	488	140	219	13,400
April	2,110	320	830	49,400
May	3,000	1,230	2,150	132,000
June	2,690	400	1,520	90,400
July	360	15	117	7,200
August	22	5	12	758
September	75	10	23	1,350
October	760	65	198	12,200
November	160	75	117	6,980
The period				314,000

Monthly discharge of Little Snake River near Dixon, Wyo., 1910–1913—Continued.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1912.				
April	991	193	526	31,300
May	6,140	778	3,240	200,000
June	5,480	1,210	2,910	173,000
July	1,120	122	401	24,600
August	272	20	76	4,680
September	122	20	77	4,560
October	420	82	158	9,700
November	223	100	152	9,220
The period				457,000
1913.				
April	2,320	363	1,350	80,300
May	2,600	1,370	1,880	116,000
June	1,580	163	611	36,400
July	135	11	50.7	3,120
August	20	8	12.3	756
September	49	11	36.6	2,180
October	135	34	88.5	5,440
November	135	82	103	6,130
The period				250,000

DUCHESNE RIVER AT MYTON, UTAH.

Location.—In secs. 24–25, T. 3 S., R. 2 W., Uinta special base and meridian, at the highway bridge at Myton, 3 miles below the mouth of Lake Fork Creek, and 15 miles above the mouth of Uinta River.

Records presented.—October 1, 1899, to July 10, 1906; April 10, 1907, to November 30, 1910; August 1, 1911, to September 30, 1914.

Drainage area.—2,750 square miles.

Gage.—Chain gage attached to upstream side of bridge.

Channel.—Cobblestones; fairly permanent.

Discharge measurements.—Made from highway bridge.

Winter flow.—The stream is frozen entirely across in the vicinity of the gage during the greater part of the winter.

Diversions.—A large part of the low-water flow of the Duchesne and its tributaries is diverted and used for irrigation above the station.

Regulation.—None.

Accuracy.—Records fair except during winter months.

Monthly discharge of Duchesne River at Myton, Utah, for the years ending Sept. 30, 1900–1906, 1907–1914.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1899–1900.					
October			[a] 403	24,800	
November			[a] 398	23,700	
December			[a] 347	21,300	
January			[a] 370	22,800	
February			[a] 370	20,500	
March	700	315	394	24,200	
April	860	350	467	27,800	
May	5,880	630	2,330	143,000	
June	4,440	600	1,700	101,000	
July	570	275	377	23,200	
August	350	235	271	16,700	
September	450	245	296	17,600	
The year	5,880		644	467,000	

[a] Estimated.

Monthly discharge of Duchesne River at Myton, Utah, for the years ending Sept. 30, 1900–1906, 1907–1914—Continued.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1900–1901.					
October	330	300	313	19,200	
November	330	288	305	18,100	
December			a 342	21,000	
January			a 280	17,200	
February			a 280	15,600	
March		278	a 289	17,800	
April	1,190	247	498	29,600	
May	6,680	1,190	3,170	195,000	
June	2,860	870	1,480	88,100	
July	910	408	597	36,700	
August	950	313	453	27,900	
September	408	262	307	18,300	
The year	6,680		693	504,000	
1901–2.					
October	439	278	322	19,800	
November	355	278	316	18,800	
December			a 300	18,400	
January			a 280	17,200	
February			a 280	15,600	
March			a 291	17,900	
April	1,360	304	656	39,000	
May	5,820	820	1,970	121,000	
June	4,900	892	2,240	133,000	
July	892	292	555	34,100	
August	410	240	273	16,800	
September	374	184	258	15,400	
The year	5,820		645	467,000	
1902–3.					
October	320	280	297	18,300	
November	332	312	322	19,200	
December			a 300	18,400	
April 5–30	900	320	456	23,500	
May	2,300	665	1,330	81,800	
June	4,750	1,580	3,260	194,000	
July	1,460	570	912	56,100	
August	535	296	375	23,100	
September	500	275	329	19,600	
1903–4.					
October	605	319	383	23,600	
November	431	296	353	21,000	
December 1–5	465	344	415	4,120	
March 10–31	406	308	335	14,600	
April	1,230	323	691	41,100	
May	6,080	1,100	2,860	176,000	
June	4,880	1,890	3,450	205,000	
July	1,830	615	1,030	63,300	
August	2,080	423	623	38,300	
September	581	269	369	22,000	
1904–5.					
October	484	355	401	24,700	
November	411	313	346	20,600	
March 13–31	355	274	313	11,800	
April	840	274	448	26,700	
May	2,260	643	1,220	75,000	
June	5,150	1,300	3,100	184,000	
July 1–22	2,150	484	902	39,400	
September 24–30	920	219	455	6,320	
1905–6.					
October	484	313	355	21,800	
November 1–28	366	313	319	17,700	
April	1,770	423	893	53,100	
May	4,970	1,440	3,320	204,000	
June	7,320	2,800	4,520	269,000	
July 1–10	3,850	2,720	3,140	62,300	

a Estimated.

Monthly discharge of Duchesne River at Myton, Utah, for the years ending Sept. 30, 1900–1906, 1907–1914—Continued.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1907.					
April 10–30	2,650	794	2,060	85,800	A.
May	6,000	1,900	3,290	202,000	A.
June	7,610	3,400	5,390	321,000	A.
July	9,560	2,470	5,680	349,000	A.
August	2,440	1,120	1,560	95,900	A.
September	1,400	670	874	52,000	A.
The period				1,110,000	
1907–8.					
October	792	670	693	42,600	A.
November	670	525	564	33,600	B.
December 1–15	595	525	551	16,400	B.
March 18–31	620	430	490	13,600	A.
April	1,550	430	813	48,400	B.
May	1,490	815	1,160	71,300	B.
June	4,670	845	2,400	143,000	B.
July	2,000	668	1,230	75,600	A.
August	2,440	480	869	53,400	A.
September	850	422	539	32,100	A.
1908–9.					
October	770	602	682	41,900	A.
November	668	450	522	31,100	A.
December			a 527	32,400	D.
April	1,480	562	841	50,000	A.
May	4,430	1,080	2,850	175,000	A.
June 1–6	8,080	3,500	5,740	68,300	B.
July 10–31	3,270	2,100	2,410	105,000	D.
August	1,960	1,200	1,490	91,600	C.
September	3,270	928	1,520	90,400	C.
1909–10.					
October	980	775	866	53,200	C.
November	775	605	731	43,500	C.
December			a 637	39,200	D.
March 12–31	2,240	875	1,140	45,200	C.
April	4,540	980	2,110	126,000	D.
May	5,440	2,700	3,690	227,000	D.
June	4,840	875	1,970	117,000	D.
July	1,090	385	588	36,200	B.
August	685	285	384	23,600	A.
September	1,150	285	501	29,800	B.
1910–11.					
October	935	425	533	32,800	B.
November	480	455	458	27,300	B.
August	382	193	246	15,100	B.
September	770	193	255	15,200	B.
1911–12.					
October	605	345	423	26,000	A.
November	444	262	360	21,400	A.
December	402	247	343	21,100	B.
January			a 300	18,400	D.
February			a 280	16,100	D.
March	474		a 354	21,800	C.
April	550	362	423	25,200	A.
May	4,020	404	1,470	90,400	B.
June	6,320	2,700	4,150	247,000	A.
July	2,960	536	1,090	67,000	A.
August	598	184	313	19,200	A.
September	464	222	299	17,800	A.
The year	6,320		817	591,000	
1912–13.					
October	899	292	489	30,100	A.
November	586	358	456	27,100	B.
December			a 338	20,800	C.
January			a 280	17,200	D.
February			a 300	16,700	D.
March	1,300		a 408	25,100	C.
April	1,110	428	662	39,400	A.
May	3,880	767	2,020	124,000	A.
June	4,160	732	1,660	98,800	A.

a Estimated.

Monthly discharge of Duchesne River at Myton, Utah, for the years ending Sept. 30, 1900–1906, 1907–1914—Continued.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1912–13.					
July	1,790	336	745	45,800	A.
August	404	184	253	15,600	A.
September	1,530	328	657	39,100	A.
The year	4,160	....	689	500,000	
1913–14.					
October	732	418	525	32,300	A.
November	598	328	445	26,500	B.
December	....	....	*a* 321	19,700	B.
January	....	....	*a* 396	24,300	C.
February	....	....	*a* 380	21,100	C.
March	732	....	*a* 492	30,300	B.
April	1,410	480	947	56,400	A.
May	5,940	1,030	3,340	205,000	B.
June	6,240	1,660	3,780	225,000	B.
July	1,660	532	1,030	63,300	B.
August	710	244	397	24,400	A.
September	336	244	292	17,400	A.
The year	6,240	....	1,030	746,000	

a Estimated.

UINTA RIVER AT FORT DUCHESNE, UTAH.

Location.—At wooden highway bridge on road to Vernal, one-fourth mile from Fort Duchesne.

Records presented.—October 1, 1899, to November 30, 1904; April 9, 1907, to November 30, 1910.

Drainage area.—672 square miles.

Gage.—1899 to 1904, vertical staff; 1907 to 1910, chain attached to bridge April 9, 1907; datum of chain gage entirely different from that of the staff gages previously used.

Channel.—Bed of stream rocky, but at times a section at the station is filled in with sediment brought down during floods from Deep Creek.

Discharge measurements.—At high stages made from the bridge; at ordinary stages by wading below bridge.

Winter flow.—Affected by ice.

Diversions.—Water diverted for irrigation by numerous ditches on the Uinta and Whiterocks rivers above the station. Comparatively small amount diverted for irrigation below station.

Accuracy.—Results somewhat impaired by eddies around the crib piers and by deposits of sediment brought down by Deep Creek.

Monthly discharge of Uinta River at Fort Duchesne, Utah, for the years ending Sept. 30, 1900–1905, 1907–1911.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1899–1900.					
October	....	....	*a* 83	5,010	
November	....	....	*a* 111	6,600	
December	....	....	*a* 114	7,010	
January	....	....	*a* 125	7,690	
February	....	....	*a* 125	6,940	
March	193	85	123	7,560	
April	128	85	99	5,890	
May	2,340	95	924	56,800	
June	1,270	140	431	25,600	
July	140	25	67	4,120	
August	62	20	36	2,210	
September	125	25	62	3,690	
The year	2,340	....	192	139,000	

a Estimated.

Monthly discharge of Uinta River at Fort Duchesne, Utah, for the years ending Sept. 30, 1900–1905, 1907–1911—Continued.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1900–1901.					
October	110	70	98	6,030	
November	140	90	105	6,250	
December	140	55	90	5,530	
January	....	....	*a* 135	8,300	
February	....	....	*a* 135	7,500	
March	295	77	132	8,120	
April	184	87	117	6,960	
May	4,520	218	1,190	73,000	
June	485	184	261	15,500	
July	201	97	140	8,610	
August	2,120	87	168	10,300	
September	184	97	121	7,200	
The year	4,520	....	224	163,000	
1901–2.					
October	184	97	116	7,130	
November	137	109	117	6,960	
December	....	....	*a* 130	7,990	
January	....	....	*a* 125	7,690	
February	....	....	*a* 130	7,220	
March	180	56	118	7,250	
April	160	70	98	5,860	
May	2,000	92	662	40,700	
June	1,640	280	622	37,000	
July	308	54	158	9,730	
August	60	24	43	2,680	
September	232	30	54	3,220	
The year	2,000	....	198	143,000	
1902–3.					
October	92	66	79	4,850	
November	153	60	102	6,050	
December	105	56	85	5,200	
April	259	94	125	7,440	
May	1,330	108	461	28,300	
June	2,730	561	1,440	85,700	
July	524	159	343	21,100	
August	159	70	102	6,272	
September	259	70	121	7,200	
1903–4.					
October	205	123	149	9,160	
November	205	108	133	7,910	
December 1–12	123	43	73	1,740	
March	130	46	89.3	5,490	
April	170	67	99.0	5,890	
May	1,980	161	966	59,400	
June	918	304	627	37,300	
July	304	148	207	12,700	
August	219	93	149	9,160	
September	181	107	137	8,150	
1904.					
October	215	145	182	11,200	
November	184	136	168	10,000	
1907.					
April 9–30	535	168	361	15,800	B.
May	1,870	180	635	39,000	B.
June	3,040	810	1,860	111,000	B.
July	3,510	903	1,860	114,000	B.
August	945	240	487	29,900	B.
September	370	190	253	15,100	B.
The period	....	....	....	325,000	

a Estimated.

Monthly discharge of Uinta River at Fort Duchesne, Utah, for the years ending Sept. 30, 1900–1905, 1907–1911—Continued.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1907–8.					
October	240	170	188	11,600	B.
November	148	120	139	8,270	B.
December 1–15	115	100	102	3,030	D.
March 14–31	174	103	134	4,940	
April	220	103	152	4,940	B.
May	635	153	342	9,040	B.
June	2,360	213	857	21,000	A.
July	435	91	242	51,000	B.
August	392	117	243	14,900	B.
September	563	118	216	14,900	B.
1908–9.					
October	358	238	293	18,000	A.
November	276	192	228	13,600	B.
December			[a] 191	11,700	D.
January			[a] 151	9,280	C.
February			[a] 125	6,940	C.
March			[a] 149	9,160	C.
April	255	160	187	11,100	B.
May	582	175	319	19,600	B.
June	4,470	412	1,940	115,000	C.
July	1,090	192	430	26,400	C.
August	614	175	272	16,700	B.
September	1,540	282	740	44,000	B.
The year	4,470		419	301,000	
1909–10.					
October	310	210	246	15,100	B.
November	255	175	201	12,000	B.
December			[a] 168	10,300	D.
January			[a] 151	9,280	D.
February			[a] 149	8,280	D.
March	225	147	195	12,000	D.
April	818	147	295	17,600	C.
May	1,290	307	541	33,300	C.
June	527	36	143	8,510	B.
July	94	1	25.0	1,540	B.
August	147	19	41.9	2,580	B.
September	216	19	93.8	5,580	B.
The year	1,290	1	187	136,000	
1910.					
October	241	79	144	8,850	B.
November	147	94	126	7,500	B.

[a] Estimated.

UINTA RIVER AT OURAY SCHOOL, UTAH.

Location.—At the highway bridge 5 miles below station at Fort Duchesne.

Records presented.—November 1, 1899, to December 9, 1904.

Drainage area.—967 square miles.

Gage.—Original gage a vertical board fastened to east side of south crib of the bridge; new gage rod, with zero 1 foot below the datum of old gage, installed April 20, 1904.

Channel.—Rocky; filled in with sediment during part of year.

Discharge measurements.—At high stages made from bridge; at ordinary stages by wading about 200 feet below.

Winter flow.—Discharge relation affected by ice.

Accuracy.—Estimates only fair.

Monthly discharge of Uinta River at Ouray School, Utah, for 1899–1904.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1899.				
November			[a] 124	7,380
December			[a] 113	6,950
1900.				
January			[a] 100	6,150
February			[a] 100	5,550
March	179	56	97	5,960
April	232	64	88	5,240
May	1,500	92	689	42,400
June	1,120	179	451	26,800
July	156	28	65	4,000
August	40	19	32	1,970
September	242	37	89	5,300
October	156	113	122	7,500
November	200	64	128	7,620
The period				118,000
1901.				
January			[a] 120	7,380
February			[a] 120	6,660
March		92	116	7,130
April	151	92	116	6,900
May	3,450	215	1,140	69,900
June	598	181	309	18,400
July	192	58	114	7,010
August	953	52	164	10,100
September	192	100	121	7,200
October	181	108	123	7,560
November	142	116	126	7,500
December			[a] 115	7,070
The year	3,450		223	163,000
1902.				
January			[a] 110	6,760
February			[a] 110	6,110
March			[a] 100	6,150
April	146	76	92	5,460
May	2,650	84	740	45,500
June	2,120	246	651	39,000
July	327	47	132	8,150
August	65	30	40	2,470
September	470	34	72	4,280
October	94	78	89	5,460
November	154	57	97	5,780
December	104	57	83	5,130
The year	2,650		193	140,000
1903.				
April	248	80	115	6,840
May	1,400	88	447	27,500
June	2,750	490	1,500	89,100
July	710	150	313	19,200
August	132	58	78	4,800
September	202	58	114	6,780
October	328	114	144	8,850
November	180	80	124	7,380
December 1–12	170	72	117	2,780
The period				173,000
1904.				
March 15–31	105	64	70.5	2,380
April	164	62	83.2	4,950
May	2,510	137	972	59,800
June	964	270	577	34,300
July	298	100	174	10,700
August	270	58	141	8,670
September	204	89	120	7,140
October	148	126	140	8,610
November	126	77	94.7	5,640
The period				142,000

[a] Estimated.

WHITE RIVER AT MEEKER, COLO.

Location.—In sec. 23, T. 1 N., R. 94 W., at Van Cleave's ranch, one-half mile southeast of Meeker. Nearest tributary above is Curtis Creek; nearest below is Sulphur Creek.

Records presented.—April 1, 1902, to October 31, 1906; May 7, 1910, to November 14, 1913. Station discontinued during winter months.

Drainage area.—634 square miles.

Gage.—Automatic recording gage.

Channel.—Practically permanent.

Discharge measurements.—Made from highway bridge.

Diversions.—There are court decrees for diversions of 186 second-feet from White River above the station and 59 second-feet from tributaries entering above. Below there are decrees for diversions of 198 second-feet from White River.

Cooperation.—Records since 1910 published as furnished by the State engineer, who maintains the station.

Monthly discharge of White River at Meeker, Colo., for 1902–1906, 1910–1913.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1902.				
April	800	315	442	26,300
May	2,320	890	1,630	100,000
June	1,730	415	906	53,900
July	565	250	398	24,500
August	315	250	282	17,300
September	395	280	329	19,600
October	395	315	324	19,900
The period				262,000
1903.				
April	710	375	468	27,800
May	2,240	620	1,200	73,800
June	2,400	1,290	1,980	118,000
July	1,180	440	678	41,700
August	440	315	373	22,900
September	710	395	490	29,200
October	565	440	493	30,300
The period				344,000
1904.				
April	1,570	335	745	44,300
May	2,510	1,000	1,760	108,000
June	2,190	878	1,570	93,400
July	842	395	559	34,400
August	515	375	413	25,400
September	530	375	409	24,300
October	465	375	404	24,800
The period				355,000
1905.				
April	712	370	443	26,400
May	2,800	640	1,490	91,600
June	3,370	1,090	2,440	145,000
July	1,020	407	572	35,200
August	520	357	405	24,900
September	435	357	382	22,700
October	400	357	376	23,100
The period				369,000
1906.				
April	1,120	410	628	37,400
May	3,390	718	2,100	129,000
June	3,710	1,460	2,530	151,000
July	1,400	510	836	51,400
August	500	288	371	22,800
September	470	258	345	20,500
October	331	243	292	18,000
The period				430,000

Monthly discharge of White River at Meeker, Colo., for 1902–1906, 1910–1913—Continued.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1910.				
May 7–31	2,580	1,000	1,270	63,100
June	2,580	611	1,660	98,800
July	611	308	435	26,700
August	414	288	354	21,800
September	458	338	357	21,200
October	374	338	351	21,600
November	355	292	335	19,900
December 1–9	374	292	339	6,050
The period				279,000
1911.				
January	505	275	338	20,800
February	470	275	337	18,700
March	545	275	371	22,800
April	1,170	350	594	35,300
May	2,360	770	1,460	89,800
June	3,030	628	1,840	109,000
July	820	325	515	31,700
August	375	275	318	19,600
September	405	260	311	18,500
October	870	375	449	27,600
November	545	375	428	25,500
The period				419,000
1912.				
February 20–29	375	325	352	6,990
March	630	325	437	26,800
April	545	325	401	23,800
May	4,200	435	1,840	113,000
June	4,650	1,500	2,950	176,000
July	2,540	630	1,220	75,000
August	630	375	464	28,500
September	405	295	329	19,600
October	505	295	348	21,400
November	435	245	316	18,800
The period				510,000
1913.				
April 13–30	960	445	637	22,700
May	2,080	670	1,150	70,700
June	1,830	762	1,140	67,800
July	700	420	576	35,400
August	395	300	351	21,600
September	445	345	390	23,200
October	395	250	342	21,000
November 1–14	295	250	264	7,330
The period				270,000

PRICE RIVER NEAR HELPER, UTAH.

Location.—In sec. 25 or 26, T. 13 S., R. 9 E., at settlement known locally as Spring Glenn, 2½ miles south of Helper; about 2 miles above the diversion dam of the Price River Irrigation Co., and 300 feet west of the main line of the Denver & Rio Grande Railroad, 4 miles below mouth of White Creek.

Records presented.—February 20, 1904, to September 30, 1914.

Drainage area.—530 square miles.

Gage.—Vertical staff on left bank.

Channel.—Shifting during sudden floods.

Discharge measurements.—Made from cable and car.

Winter flow.—Relation of gage height to discharge is affected by ice during the winter.

Diversions.—Records indicate the amount of water available for the Price River Irrigation Co. and for the canals for the town of Price, which divert a few miles below the station. No important diversions above the station.

Regulation.—The Price River Irrigation Co. has a reservoir with a capacity of about 24,000 acre-feet (ultimately to be increased to 30,000 acre-feet) on Gooseberry Fork of Price River about 40 miles above the station. Stored water is turned out of this reservoir during the irrigation season and passes the gaging station on its way to the canal below.

Accuracy.—Record fair.

Monthly discharge of Price River near Helper, Utah, for the years ending Sept. 30, 1904–1914.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1904.					
February 20-29	70	16	38	754	
March	70	27	44	2,700	
April	288	63	162	9,640	
May 1-24	433	30	335	16,000	
June 11-30	259	97	183	7,260	
July	100	44	57.6	3,540	
August	63	27	38.7	2,380	
September	63	9	38.1	2,270	
1904-5.					
October	63	20	29.5	1,810	
November	35	14	21.2	1,260	
December	63	9	17.8	1,090	
January	30	18	21.1	1,300	
February	60	24	36.3	2,020	
March	69	37	49.8	3,060	
April	305	6	71.5	4,250	
May	678	150	379	23,300	
June	563	44	254	15,100	
July	44	18	25.8	1,590	
August	44	9	18.8	1,160	
September	1,740	9	87.8	5,220	
The year	1,740	9	84.2	61,200	
1905-6.					
October	44	18	26.3	1,620	
November	30	9	20.5	1,220	
December	18	4	12.0	738	
January	18	4	7.1	437	
February	30	9	16.5	916	
March	182	4	38.6	2,370	
April	563	60	290	17,300	
May	1,530	305	949	58,400	
June	740	150	446	26,500	
July	1,220	78	191	11,700	
August	354	44	113	6,950	
September	60	30	42.0	2,500	
The year	1,530	4	179	131,000	
1906-7.					
October	30	30	30.0	1,840	
November	60	18	27.5	1,640	
December	30	18	19.5	1,200	
January	60	18	23.8	1,460	D.
February	60	18	40.6	2,250	C.
March	150	18	72.0	4,430	C.
April 1-11	455	122	244	5,320	B.
June 23-30	736	468	554	8,790	B.
July	468	140	242	14,900	C.
August	680	54	141	8,670	A.
September	114	54	67.6	4,020	C.
1907-8.					
October	54	54	54.0	3,320	C.
November	54	42	46.0	2,740	C.
December	54	42	44.3	2,720	C.
January	50	35	40.3	2,480	C.
February	68	35	40.7	2,340	C.
March	910	35	248	15,200	B.
April	418	50	268	15,900	B.
May	326	204	256	15,700	B.
June	242	89	169	10,100	B.
July	242	23	50.9	3,130	A.
August	570	7	56.8	3,490	B.
September	50	7	17.5	1,040	D.
The year	910	7	108	78,200	

Monthly discharge of Price River near Helper, Utah, for the years ending Sept. 30, 1904–1914—Continued.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1908-9.					
October	68	23	33.6	2,070	C.
November	50	23	37.8	2,250	C.
December	35	14	29.2	1,800	C.
January	....	....	a 14.0	861	D.
February	....	8	a 13.0	722	D.
March	120	24	59.1	3,630	A.
April	729	95	364	21,700	A.
May	1,460	455	1,030	63,300	B.
June	1,660	357	925	55,000	B.
July	311	95	167	10,300	A.
August	357	72	146	8,980	A.
September	1,090	72	142	8,450	A.
The year	1,660	....	247	179,000	
1909-10.					
October	95	53	71.6	4,400	B.
November	53	53	53.0	3,150	B.
December	53	24	47.7	2,930	C.
January	519	24	155	9,530	C.
February	53	24	40.5	2,250	C.
March	1,470	24	318	19,600	C.
April	1,470	370	794	47,200	B.
May	1,350	307	801	49,300	A.
June	307	53	136	8,090	A.
July	95	37	43.5	2,670	A.
August	228	14	33.8	2,080	A.
September	607	24	62.7	3,730	A.
The year	1,470	24	213	155,000	
1910-11.					
October	252	37	67.7	4,160	A.
November	53	24	38.8	2,310	A.
December	125	24	47.6	2,930	B.
January	210	20	42.5	2,610	C.
February	137	40	56.9	3,160	B.
March	534	40	202	12,400	A.
April	384	170	225	13,400	A.
May	810	318	558	34,300	A.
June	420	82	236	14,000	A.
July	234	59	81.6	5,020	A.
August	59	25	36.7	2,260	A.
September	1,350	25	128	7,620	A.
The year	1,350	20	143	104,000	
1911-12.					
October	170	82	89.5	5,500	A.
November	82	40	73.1	4,350	B.
December	107	40	64.2	3,950	B.
January	....	....	a 25	1,540	C.
February	....	....	a 30	1,730	C.
March	....	....	a 35	2,150	C.
April	320	42	121	7,200	B.
May	896	99	451	27,700	B.
June	990	138	444	26,400	A.
July	153	77	120	7,380	A.
August	123	39	64.5	3,970	A.
September	176	36	49.9	2,970	A.
The year	990	....	131	94,800	
1912-13.					
October	990	29	72.7	4,470	A.
November	42	18	29.5	1,760	A.
December	29	18	27.4	1,680	B.
January	24	9	17.2	1,060	B.
February	24	9	18.2	1,010	B.
March	943	16	72.8	4,480	B.
April	2,020	176	500	29,800	B.
May	650	348	480	29,500	B.
June	548	110	238	14,200	B.
July	2,100	68	193	11,900	B.
August	191	24	65.0	4,000	A.
September	1,140	29	88.3	5,250	B.
The year	2,020	9	150	109,000	

a Estimated.

Monthly discharge of Price River at Helper, Utah, for the years ending Sept. 30, 1904–1914—Continued.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1913–14.					
October	55	39	46.8	2,880	A.
November	71	16	48.0	2,860	B.
December	41	21	29.1	1,790	B.
January	41	23	31.9	1,960	B.
February	57	30	40.0	2,220	B.
March	295	29	127	7,810	A.
April	704	170	471	28,000	B.
May	1,680	477	1,160	71,300	A.
June	896	150	465	27,700	B.
July	571	126	208	12,800	C.
August	285	79	117	7,190	B.
September	63	45	50.6	3,010	B.
The year	1,680	16	234	170,000	

SAN RAFAEL RIVER NEAR GREEN RIVER, UTAH.

Location.—In sec. 27, T. 22 S., R. 16 E., at the county bridge near the J. C. Morris ranch on the main road from Green River to Hankesville, about 16 miles southwest of Green River.

Records presented.—May 5, 1909, to September 30, 1914.

Drainage area.—1,690 square miles.

Gage.—Vertical staff attached to downstream side of right crib abutment of bridge.

Channel.—Shifting; frequent discharge measurements are necessary.

Discharge measurements.—Made by wading at low water and from cable at high stages.

Winter flow.—Affected by ice.

Diversions.—Water is diverted above the station for irrigation in Castle Valley. A small amount of water is diverted below the station.

Accuracy.—Fair, except for periods during which the observer was unable to read gage because of excessive deposits of silt.

Monthly discharge of San Rafael River near Green River, Utah, for the years ending Sept. 30, 1909–1914.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1909.					
May 5–31	1,660	221	721	38,600	B.
June	3,610	1,090	2,450	146,000	B.
July	1,310	200	523	32,200	C.
August	3,730	180	745	45,800	C.
September	4,720	150	655	39,000	C.
The period	....	....	....	302,000	
1909–10.					
October	140	110	128	7,870	C.
November	360	130	162	9,640	C.
March	2,330	320	729	44,800	C.
April	1,880	310	748	44,500	B.
May	2,100	690	1,200	73,800	B.
June	900	57	307	18,300	C.
July	492	8	110	6,760	B.
August	390	0	44.3	2,720	B.
September	3,040	0	235	14,000	C.

Monthly discharge of San Rafael River near Green River, Utah, for the years ending Sept. 30, 1909–1914—Continued.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1910–11.					
October	2,250	46	222	13,600	C.
November	310	36	98.8	5,880	B.
December	150	68	101	6,210	B.
January	1,550	102	224	13,800	B.
February	649	137	196	10,900	A.
March	261	108	164	10,100	A.
April	272	119	163	9,700	A.
May	835	128	492	30,300	B.
June	939	214	608	36,200	B.
July	238	54	98.8	6,080	B.
August	614	50	88.0	5,410	B.
September	2,070	50	152	9,040	B.
The year	2,250	....	217	157,000	
1911–12.					
October	2,580	59	356	21,900	B.
November	....	....	[a] 64.1	3,810	C.
December	....	....	[a] 60.0	3,690	C.
January	....	....	[a] 50	3,070	D.
February	....	....	[a] 70	4,030	D.
March	....	....	[a] 100	6,150	D.
April	178	61	95.7	5,690	A.
May	2,270	56	406	25,000	A.
June	3,510	600	1,570	93,400	A.
July	645	20	223	13,700	A.
August	532	....	[a] 74.7	4,590	C.
September	....	....	[a] 59.7	3,550	D.
The year	3,510	....	261	189,000	
1912–13.					
October	2,890	....	[a] 384	23,600	D.
November	1,680	40	199	11,800	C.
December	....	....	[a] 46.6	2,870	C.
January	....	....	[a] 40.0	2,460	D.
February	....	....	[a] 50.0	2,780	D.
March	205	88	136	8,360	B.
April	1,060	80	338	20,100	A.
May	1,980	500	1,080	66,400	B.
June	1,490	54	464	27,600	B.
July	460	39	136	8,360	B.
August	580	2	52.8	3,250	B.
September	2,560	8	237	14,100	B.
The year	2,560	2	264	192,000	
1913–14.					
October	228	43	72.5	4,460	B.
November	645	46	125	7,440	B.
December	120	....	[a] 65.1	4,000	C.
January	....	....	[a] 55	3,380	C.
February	....	....	[a] 65	3,610	C.
March	....	....	[a] 90	5,530	D.
April	702	82	251	14,900	B.
May	3,140	114	1,630	100,000	B.
June	3,580	145	1,650	98,200	B.
July	1,300	95	294	18,100	B.
August	255	18	45.1	2,770	C.
September	95	16	25.2	1,500	C.
The year	3,580	....	364	264,000	

[a] Estimated.

GRAND RIVER BASIN.

THE MAIN STREAM.

Grand River and its tributaries drain an area comprising approximately 25,900 square miles, of which 22,290 are in Colorado and the rest in eastern Utah. On the east and southeast the basin is bounded by the high ranges of the Continental Divide, which separate it from the basins of Platte and Arkansas rivers; on the north it is limited by the White River and Book Cliffs Plateau, and on the west by the canyon district of the Colorado.

Grand River rises among the high peaks of the Rocky Mountains in north-central Colorado and flows southwestward to its junction with Green River, traversing approximately 423 miles. Its tributaries include Fraser, Blue, Eagle, Williams and Roaring forks, Gunnison and Dolores rivers, all of which enter from the south.

In most respects the Grand is a typical mountain stream, flowing throughout its course in a succession of long, narrow, fertile valleys alternating with deep canyons, whose precipitous or even perpendicular walls in places attain a height of 3,000 feet above the water's edge. The headwater region, comprising approximately 50 per cent of the basin, is extremely rugged, including elevations ranging from 7,000 to 14,000 feet above sea level. Stream channels are numerous, and gradients are steep, the fall ranging from 20 to 150 feet to the mile. The intermediate or middle part of the basin—that part immediately east and west of the Colorado State line—is dry, broken, and much eroded.

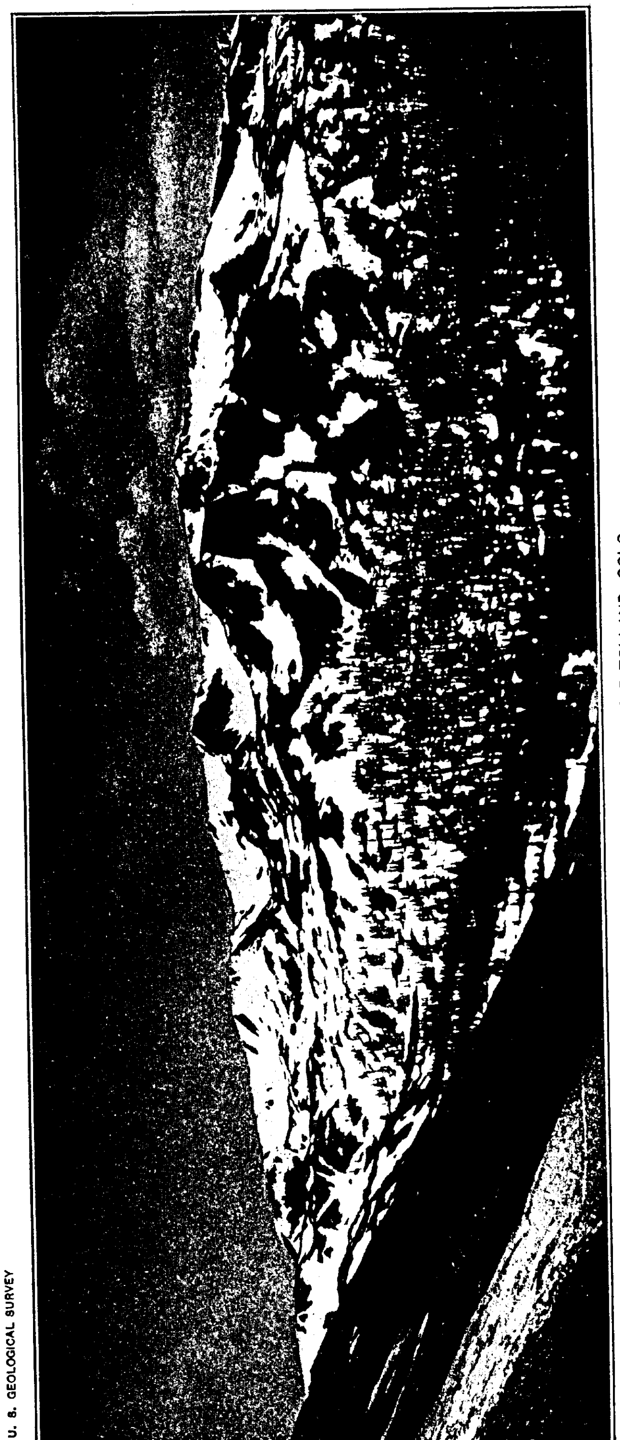
The rocks of the basin include all varieties, from the granites and igneous masses on the crest of the Continental Divide to the younger and less resistant sedimentary rocks of the plateau region. The soils of the upper basin, though shallow, generally contain considerable organic matter; those of the intermediate basin are largely decomposed and disintegrated sedimentary rocks which grade imperceptibly from one to the other. In the lower basin vegetation is scant and soil erosion consequently large.

The precipitation ranges from 5 to 10 inches in the lower basin, 10 to 20 inches in the intermediate region, and 20 to 30 inches in the headwater region. By far the greater part of the precipitation is in the form of snow. (See Pls. VII and VIII.)

The forests of the mountainous part of the basin, except in a few localities, are good—equal to any in Colorado—consisting of spruce, quaking asps, cedars, and piñon. The intermediate basin is fairly well forested with quaking asp, cedar, and piñon. The lower basin supports only scattered pines, cedars, and piñons, the prevailing vegetation being sagebrush, chico, and cactus pads.

The greater part of the timbered area in the Grand River basin above the Gunnison is included in the Arapahoe and Holy Cross national forests. These reserves in the drainage basin of the Grand include about 1,400 square miles of merchantable timber land, 900 square miles of woodland, and about 800 square miles of burned area.

SNOW AND ICE ON COLORADO MOUNTAIN STREAMS.



CONTINENTAL DIVIDE NEAR TOLLAND, COLO.

At two points along Grand River—Hot Sulphur Springs and Glenwood Springs, Colo.—hot-water springs containing hydrogen sulphide increase the temperature of the river water, but probably all these springs together add less than 20 second-feet to the flow of the river.

Natural storage within the basin is restricted to a few high mountain lakes, of which Grand Lake is the largest. There are, however, reservoir sites along the Grand and its tributaries, of which the Kremmling reservoir site is by far the best. (See pp. 210–211.) A standard gage railroad now runs through this site.

PRINCIPAL TRIBUTARIES.

Roaring Fork.—Roaring Fork, which enters the Grand at Glenwood Springs, drains a large area lying chiefly in Pitkin County and reaching to the Continental Divide. It is one of the largest tributaries of the Grand. Fryingpan Creek and Crystal River are its most important branches.

Gunnison River.—Gunnison River is formed in Gunnison County, Colo., by the union of East and Taylor rivers, two streams whose origin is among the snow-covered peaks and on the slopes of the Continental Divide in the northeastern part of the county. They flow through narrow mountain valleys and unite about 12 miles above Gunnison. From the junction of these rivers the Gunnison flows west and southwest to its union with Grand River at Grand Junction, in the central part of Mesa County, Colo.

The upper course of the river lies through a broad, mountainous valley, but near the mouth of Lake Fork the valley becomes narrower and the river enters Black Canyon of the Gunnison, through which it winds in a tortuous course for 56 miles between granite walls that rise precipitously 3,000 feet above the water's edge. A short distance below the mouth of North Fork the canyon walls break abruptly, and the valley is broad and fertile. Below Delta the river enters another narrow canyon whose walls average 800 feet in height, and this canyon continues irregularly to Grand Junction. A few tracts of narrow bottom land lie between the channel and the canyon walls.

The chief tributaries of the Gunnison are Ohio, Tomichi, Lake Fork, and Cimarron creeks, and Smith, North Fork, and Uncompahgre rivers, North Fork being the largest.

North Fork rises in the Huntsman Hills, 20 miles south of Glenwood Springs, flows in a general southerly and southwesterly course, and unites with the Gunnison about 8 miles west of Hotchkiss. The drainage area is highly mountainous, except for a small part below Paonia, extreme points reaching an altitude of 13,000 feet. All the tillable lands of the North Fork and its tributaries have been brought under cultivation, and irrigation is practiced to such an extent that the entire flow is needed for existing systems.

Uncompahgre River, the principal tributary of the Gunnison from the south, rises among the snowy peaks of the highly serrated Uncompahgre Mountains and flows a little west of north to its junction with the Gunnison at Delta. The basin embraces a mountainous plateau and valley 1,130 square miles in area, and oblong in shape, the width increasing slightly at the lower end. The mountain area occupies only a small part of the basin but contributes the perennial waters. The plateau area is greatest in extent and borders the valley on both sides, the larger Uncompahgre Plateau lying to the southwest. Uncompahgre Valley proper begins at a point near Eldredge siding, on the Denver & Rio Grande Railroad, and comprises about 140,000 acres of irrigable land.

Ohio, Tomichi, Lake Fork, and Cimarron creeks, from which water for this land is chiefly obtained, are perennial streams, but almost their entire volume is diverted for irrigation during the growing season, so that very little water reaches the Gunnison except at times of heavy storms or during spring floods. The meager records of precipitation indicate a range from 9 inches in the plateau region to about 25 inches in the mountains.

The run-off of the Gunnison drainage basin is protected to a large extent by four forest reserves, comprising a total area of about 5,700 square miles, of which approximately 3,800 square miles is in the basin. About 65 per cent of this area is in standing timber, the remainder being classed as sagebrush, barren, and burned.

Dolores River.—The Dolores rises in the La Plata and San Miguel mountains, whose highest peak, Mount Wilson, exceeds 14,000 feet in elevation. After flowing southwesterly about 50 miles, the river turns to the west and enters Grand River about 15 miles west of the Colorado-Utah line. For the greater part of its course the river flows through deep canyons, but in the vicinity of Dolores the valley broadens, and for about 40 miles is half a mile to a mile wide. Much of this area is cultivated. In Paradox Valley also considerable land is cultivated, chiefly from small tributaries running into the main stream. By far the greater part of the Dolores water is used for irrigation in the San Juan drainage basin, to which it is diverted by means of a tunnel and a great cut into the Montezuma Valley.

San Miguel River, the most important tributary of the Dolores, which drains an area immediately west of the headwaters of the Uncompahgre, rises in San Miguel County, Colo., and enters the Dolores about 12 miles east of the Colorado-Utah line at an elevation of about 5,000 feet. In general the stream and its tributaries flow northeasterly. Considerable land along the San Miguel is irrigated.

The mean annual run-off of Dolores River above the mouth of the San Miguel is about 300,000 acre-feet, and the San Miguel furnishes at least half as much. Probably 600 square miles of the Dolores River basin is covered with merchantable timber and as much more is woodland. The total area of this basin is about 4,500 square miles.

DISCHARGE RECORDS.

GRAND RIVER NEAR KREMMLING, COLO.

Location.—In sec. 23, T. 1 N., R. 81 W., at the entrance to Gore Canyon, 3 miles southwest of Kremmling. Nearest tributary, Blue River, enters a mile below Kremmling.

Records presented.—July 24, 1904, to September 30, 1914.

Drainage area.—2,380 square miles.

Gage.—Automatic recording gage, except during the winter months, when a staff gage is read. Automatic gage was installed in 1910; prior to that time staff gage and chain gage were used.

Channel.—Somewhat shifting; the bed scours at high stages and silts during low.

Winter flow.—Although the river is frozen entirely across at the station, there is little, if any, backwater, as shown by discharge measurements made during the winter. Rapids below the station remain open and thus prevent backwater except for short periods when ice jams on the rapids.

Kremmling reservoir site.—The station is at the site of the proposed Kremmling reservoir of the United States Reclamation Service. With a 230-foot dam at the mouth of Gore Canyon the capacity of the reservoir would be 2,200,000 acre-feet.

Diversions.—Above this station there are court decrees for diversions of several thousand second-feet from Grand River and its tributaries.

Accuracy.—Although the channel is somewhat shifting, sufficient discharge measurements have been made to form a basis for fairly reliable estimates of flow.

Cooperation.—Station maintained since 1910 by State engineer, who furnished records complete for publication.

Monthly discharge of Grand River near Kremmling, Colo., for the years ending Sept. 30, 1904–1914.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1904.					
July 24–31	2,010	1,590	1,760	28,200	
August	1,800	1,010	1,310	80,400	
September	1,820	662	893	53,100	
The period				172,000	
1904–5.					
October	790	530	646	39,700	
November 1–26	554	397	470	24,200	
January	402	287	314	19,300	
February	340	282	316	17,600	
March	550	332	390	24,000	
April	1,980	426	924	55,000	
May	6,430	1,660	3,520	217,000	
June	11,800	4,850	8,000	476,000	
July	4,340	1,340	2,050	126,000	
August	1,390	617	866	53,200	
September	800	436	532	31,700	

Monthly discharge of Grand River near Kremmling, Colo., for the years ending Sept. 30, 1904–1914—Continued.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1905-6.					
October	520	368	475	29,200	
November	532	272	419	24,900	
December	515	228	325	20,000	
April	3,020	725	1,440	85,700	
May	8,350	1,430	5,060	311,000	
June	11,600	4,440	7,080	421,000	
July	4,710	1,820	3,290	202,000	
August	1,990	960	1,400	86,100	
September	1,680	785	1,160	69,000	
1906-7.					
October	1,140	565	817	50,200	
November	755	405	546	32,500	
December	565	....	[a] 477	29,300	
February 18-28	438	325	384	8,380	B.
March	2,520	335	874	53,700	A.
April	3,010	734	1,690	101,000	A.
May	8,210	1,420	3,680	226,000	A.
June	11,700	4,040	9,170	546,000	A.
July	11,400	3,120	6,220	382,000	A.
August	2,810	1,140	1,700	105,000	B.
September	1,140	585	784	46,700	A.
1907-8.					
October	1,100	540	719	44,200	A.
November	590	220	407	24,200	B.
December	....	....	[a] 259	15,900	D.
January	....	....	[a] 304	18,700	D.
February	....	....	[a] 306	17,600	D.
March	740	....	[a] 419	25,800	C.
April	2,300	415	1,290	76,800	A.
May	3,650	1,170	2,390	147,000	A.
June	6,510	3,120	4,720	281,000	A.
July	3,150	1,170	2,010	124,000	A.
August	2,220	815	1,310	80,600	A.
September	755	465	597	35,500	A.
The year	6,510	....	1,230	891,000	
1908-9.					
October	540	415	488	30,000	B.
November	502	260	390	23,200	B.
December	....	....	[a] 303	18,600	D.
April	1,680	490	864	51,400	B.
May	6,860	978	4,040	248,000	A.
June	15,300	4,960	11,700	696,000	A.
July	11,500	2,020	5,270	324,000	A.
August	3,120	1,380	1,890	116,000	A.
September	2,280	908	1,410	83,900	A.
1909-10.					
October	908	528	739	45,400	A.
November	680	365	533	31,700	A.
December	515	302	437	27,000	B.
February	....	....	[a] 360	20,000	C.
March	1,480	....	[a] 905	55,600	B.
April	4,020	800	1,620	96,400	A.
May	7,280	2,440	3,600	221,000	A.
June	7,600	1,990	4,010	239,000	B.
July	2,420	710	1,270	78,100	A.
August	1,440	502	784	48,200	A.
September	960	478	706	42,000	A.
1910-11.					
October	578	465	513	31,500	A.
November	490	377	435	25,900	B.
January	650	330	426	26,200	B.
February	590	350	405	22,500	B.
March	635	380	525	32,300	B.
April	2,550	620	1,150	68,400	A.
May	6,550	1,800	4,440	273,000	A.
June	8,350	3,200	6,370	379,000	A.
July	5,850	1,480	2,930	180,000	A.
August	1,680	950	1,180	72,600	A.
September	965	695	804	47,800	A.

[a] Estimated.

Monthly discharge of Grand River near Kremmling, Colo., for the years ending Sept. 30, 1904–1914—Continued.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1911-12.					
October	1,340	578	863	53,100	A.
November	755	340	562	33,400	B.
December	502	....	[a] 393	24,200	B.
January	....	....	[a] 434	26,700	
February	....	....	[a] 425	24,500	
March	....	....	[a] 465	28,600	
April	1,240	718	894	53,200	
May	11,000	1,420	4,450	273,000	
July	11,300	4,220	6,040	372,000	
September	1,200	900	1,000	61,400	
1912-13.					
October	988	785	908	55,900	
November	880	672	734	43,700	
May 10-31	7,610	3,140	4,660	203,000	
June	7,730	3,020	4,610	274,000	
July	2,720	1,290	1,970	121,000	
August	1,250	812	949	58,400	
September	1,170	782	918	54,600	
1913-14.					
October	1,050	622	822	50,500	
November	752	461	653	38,900	
December	....	....	[a] 375	23,100	
January	487	313	374	23,000	
February	474	301	447	24,800	
March	875	461	545	33,500	
April	2,420	843	1,520	90,400	
May	13,700	2,100	7,320	450,000	
June	16,400	5,500	10,500	625,000	
July	5,290	2,370	3,450	212,000	
August	3,080	1,160	1,580	97,200	
September	1,190	707	871	51,800	
The year	16,400	....	2,370	1,720,000	

[a] Estimated.

GRAND RIVER AT GLENWOOD SPRINGS, COLO.

Location.—At Glenwood Springs, at the point where the discharge from the hot springs enters the river. No Name Creek enters Grand River about 2 miles above the station and Roaring Fork enters one-half mile below.

Records presented.—January 1, 1900, to September 30, 1914. No estimates made for 1899.

Drainage area.—1,520 square miles (measured on Nell's map of Colorado).

Gage.—Chain gage originally installed at the railroad bridge just above the Roaring Fork, but January 1, 1900, a staff gage was installed at the present location. Since 1902 a number of automatic gages referred to the staff gage datum have been used, the present one being a Friez gage.

Channel.—Slightly shifting.

Discharge measurements.—Made from a car and cable stretched beneath the State Street Bridge, which crosses the river one-third mile below the gage.

Winter flow.—Ice never forms at the station, as the hot water from the springs keeps the water above the freezing point.

Artificial control.—The Shoshone power plant of the Central Colorado Power Co., 6 miles above Glenwood Springs, has sufficient pondage to withhold the flow of the river for a portion of the day during low-water periods.

Diversions.—Between this station and the one near Kremmling there are court decrees for a diversion of 13 second-feet from Grand River and 1,508 second-feet from the intervening tributaries.

Accuracy.—Conditions are favorable for accurate results and the estimates are considered reliable.

Cooperation.—Station maintained in cooperation with the United States Forest Service and Central Colorado Power Co.

Monthly discharge of Grand River at Glenwood Springs, Colo., for the years ending Sept. 30, 1903–1914.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1900.					
January	970	810	890	54,700	
February	935	810	882	49,000	
March	1,460	902	1,190	73,000	
April	3,490	1,120	1,820	108,000	
May	22,900	3,240	12,000	736,000	
June	22,400	7,620	14,800	882,000	
July	7,270	1,520	3,120	192,000	
August	1,460	935	1,130	69,700	
September	870	755	800	47,600	
The period				2,210,000	
1900–1901.					
October	755	755	755	46,400	
November	935	727	807	48,000	
December	840	580	682	41,900	
January	810	550	688	42,300	
February	970	630	746	41,400	
March	970	727	837	51,500	
April	7,100	727	1,890	112,000	
May	22,900	6,420	13,800	849,000	
June	15,700	9,620	12,200	724,000	
July	10,800	2,090	4,830	297,000	
August	3,630	1,350	1,910	117,000	
September	1,460	840	1,040	62,200	
The year	22,900	550	3,350	2,430,000	
1901–2.					
October	970	870	917	56,400	
November	935	810	879	52,300	
December	935	630	788	48,500	
January	882	600	721	44,300	
February	845	600	775	43,000	
March	882	710	802	49,300	
April	2,770	742	1,420	84,400	
May	14,000	3,880	9,820	604,000	
June	12,100	2,770	7,320	435,000	
July 1–27			1,860	99,800	
The period				1,520,000	
1902–3.					
January	505	430	458	28,200	
February	605	455	544	30,200	
March	950	555	740	45,500	
April	3,850	894	1,680	100,000	
May	11,000	2,890	5,800	357,000	
June	17,900	8,260	12,800	762,000	
July	9,710	2,660	5,220	321,000	
August	2,520	1,210	1,610	99,200	
September	1,690	1,040	1,340	79,900	
The period				1,820,000	
1903–4.					
October	1,510	1,040	1,310	80,700	
November	1,040	595	857	51,000	
December	830	395	518	31,900	
January	760	455	539	33,100	
February	950	455	605	34,800	
March	1,240	760	911	56,000	
April	4,320	774	2,290	136,000	
May	18,100	3,080	7,760	477,000	
June	14,600	6,760	10,500	625,000	
July	7,840	2,710	4,420	272,000	
August	3,080	1,770	2,270	140,000	
September	3,080	1,400	1,780	106,000	
The year	18,100	395	2,810	2,040,000	

Monthly discharge of Grand River at Glenwood Springs, Colo., for the years ending Sept. 30, 1900–1914—Continued.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1904–5.					
October	1,510	1,130	1,320	81,400	
November	1,160	642	854	50,800	
December	746	355	599	36,800	
January	812	670	753	46,300	
February	764	554	672	37,300	
March	1,060	746	906	55,700	
April	3,260	956	1,640	97,600	
May	13,000	3,140	6,680	410,000	
June	27,700	7,980	16,600	987,000	
July	7,650	2,470	3,610	222,000	
August	2,520	1,340	1,740	107,000	
September	1,700	1,130	1,360	80,700	
The year	27,700	355	3,060	2,210,000	
1905–6.					
October	1,240	1,070	1,140	70,200	
November	1,220	620	1,070	63,500	
December	770	530	685	42,100	
January	660	505	610	37,500	
February	760	630	685	38,000	
March	1,810	690	1,060	65,200	
April	5,790	1,370	2,780	165,000	
May	17,400	3,080	9,750	600,000	
June	27,600	7,580	13,900	827,000	
July	8,080	3,900	5,930	365,000	
August	4,250	1,900	2,770	170,000	
September	5,140	1,870	3,340	199,000	
The year	27,600	505	3,640	2,640,000	
1906–7.					
October	3,790	1,010	1,730	106,000	
November	1,420	642	1,100	65,500	
December	1,010	455	801	49,300	
January	760	520	674	41,400	B.
February	974	704	853	47,400	B.
March	3,500	795	1,550	95,300	A.
April	5,680	1,460	3,180	189,000	A.
May	16,500	2,820	6,820	419,000	A.
June	24,700	7,740	18,400	1,090,000	A.
July	22,000	6,250	11,400	701,000	A.
August	5,460	2,220	3,290	202,000	B.
September	2,340	1,180	1,670	99,400	B.
The year	24,700	455	4,290	3,110,000	
1907–8.					
October	1,850	1,230	1,400	86,100	B.
November	1,430	830	1,070	63,700	B.
December	1,130	580	839	51,600	C.
January	1,180	690	954	58,700	A.
February	910	580	745	42,900	A.
March	1,510	830	1,130	69,500	B.
April	3,690	910	2,230	133,000	B.
May	5,980	1,940	3,790	233,000	A.
June	11,100	4,980	7,880	469,000	A.
July	5,330	2,140	3,280	202,000	B.
August	2,980	1,440	2,080	128,000	C.
September	1,300	705	884	52,600	B.
The year	11,100	580	2,190	1,590,000	
1908–9.					
October	1,180	785	960	59,000	C.
November	1,180	575	885	52,700	B.
December	925	430	677	41,600	A.
January	1,070	525	771	47,400	A.
February	750	575	665	36,900	A.
March	1,070	602	861	52,900	A.
April	2,910	900	1,580	94,000	B.
May	10,200	2,010	5,830	358,000	B.
June	37,200	7,250	24,500	1,460,000	C.
July	18,100	3,140	8,470	521,000	B.
August	4,520	2,400	2,910	179,000	B.
September	3,660	1,800	2,480	148,000	B.
The year	37,200	430	4,220	3,050,000	

Monthly discharge of Grand River at Glenwood Springs, Colo., for the years ending Sept. 30, 1900–1914—Continued.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1909–10.					
October	1,750	1,140	1,460	89,800	B.
November	1,240	845	1,110	66,000	B.
December	1,090	520	772	47,500	C.
January	1,190	740	841	51,700	B.
February	810	580	730	40,500	B.
March	2,680	775	1,860	114,000	B.
April	7,660	1,630	3,190	190,000	B.
May	13,400	....	a 6,760	416,000	C.
June	....	....	a 7,690	458,000	D.
July	....	....	a 2,230	137,000	D.
August	....	....	a 1,330	81,800	D.
September	....	....	a 1,370	81,500	D.
The year	....	....	2,450	1,770,000	
1910–11.					
October	....	....	a 988	60,800	D.
November	....	....	a 903	53,700	D.
December	....	....	a 665	40,000	D.
January	1,360	510	701	43,100	B.
February	1,490	600	749	41,600	A.
March	1,360	660	942	57,900	A.
April	4,160	1,030	1,790	107,000	A.
May	11,600	3,030	7,910	486,000	A.
June	15,200	5,500	11,700	696,000	B.
July	9,150	2,700	5,020	309,000	A.
August	2,700	1,490	1,930	119,000	A.
September	1,490	1,030	1,280	76,200	A.
The year	15,200	....	2,880	2,090,000	
1911–12.					
October	2,540	940	1,440	88,500	A.
November	1,240	450	915	54,400	A.
December	860	470	653	40,200	B.
January	940	630	768	47,200	B.
February	940	575	754	43,400	B.
March	1,030	630	805	49,500	B.
April	1,930	860	1,410	83,900	B.
May	18,700	2,380	7,510	462,000	B.
June	29,700	9,580	19,100	1,140,000	B.
July	18,700	6,430	9,490	584,000	B.
August	6,980	1,780	3,240	199,000	B.
September	1,930	1,490	1,660	98,800	A.
The year	29,700	450	3,980	2,890,000	
1912–13.					
October	1,640	1,280	1,470	90,400	A.
November	1,510	428	904	53,800	A.
December	905	600	745	45,800	A.
January	....	....	b 760	46,700	A.
February	782	556	674	37,400	A.
March	1,370	426	705	43,300	A.
April	4,540	1,220	2,980	177,000	A.
May	11,500	4,550	7,020	432,000	A.
June	12,100	4,690	7,120	424,000	A.
July	4,660	2,220	3,220	198,000	A.
August	2,060	940	1,430	87,900	A.
September	1,730	1,030	1,390	82,700	A.
The year	12,100	426	2,370	1,720,000	
1913–14.					
October	1,820	1,050	1,410	86,700	A.
November	1,290	803	1,060	63,100	A.
December	857	529	682	41,900	A.
January	891	613	733	45,100	A.
February	802	672	754	41,900	A.
March	2,000	725	1,010	62,100	A.
April	3,770	1,340	2,600	155,000	A.
May	24,200	3,490	12,500	769,000	A.
June	29,700	9,220	18,700	1,110,000	A.
July	8,870	3,990	5,830	358,000	A.
August	4,570	2,010	2,710	167,000	A.
September	2,240	1,340	1,700	101,000	A.
The year	29,700	529	4,150	3,000,000	

a Estimated from discharge measurements and by comparison of records at adjacent stations.
b Estimated.

GRAND RIVER NEAR PALISADES, COLO.

Location.—About sec. 3, T. 11 S., R. 98 W., at the State bridge 2 miles above Palisades. Nearest important tributary, Plateau Creek, enters about 6 miles above the station.

Records presented.—April 1, 1902, to September 30, 1914.

Drainage area.—8,550 square miles.

Gage.—Chain gage; location and datum unchanged.

Channel.—Practically permanent.

Discharge measurements.—Made from bridge to which the gage is attached. Prior to 1906 measurements were made from the suspension bridge at Palisades, where conditions were less favorable for accurate determination of discharge.

Winter flow.—The river usually freezes over a portion of the year, but except for slush and ice and an occasional thin ice cover the effect on the discharge relation is slight.

Diversions.—There are court decrees for diversions of 420 second-feet from Grand River and 2,500 second-feet from intervening tributaries between Palisades and the Glenwood Springs station. The proposed high-line canal of the United States Reclamation Service will divert 700 second-feet 7 miles above the Palisades station. Below the station the Grand Valley Irrigation Co. has a diversion of 400 second-feet.

Accuracy.—Conditions are favorable for accurate results, and the estimates should be reliable.

Cooperation.—Since 1910 field data furnished by the United States Reclamation Service.

Monthly discharge of Grand River near Palisades, Colo., for the years ending Sept. 30, 1902–1914.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1902.					
April	3,230	1,080	1,700	101,000	
May	18,000	4,400	12,200	750,000	
June	14,500	3,420	8,650	515,000	
July	3,600	1,350	2,200	135,000	
August	1,460	1,030	1,210	74,400	
September	1,550	1,080	1,220	72,600	
1902–3.					
October	1,500	1,340	1,410	86,700	
April	5,150	1,380	2,320	138,000	
May	16,500	4,190	8,980	552,000	
June	25,100	13,000	19,600	1,170,000	
July	16,100	4,190	8,780	540,000	
August	3,800	1,700	2,220	136,000	
September	3,320	1,650	2,270	135,000	
1903–4.					
October	2,880	1,700	2,050	126,000	
April	7,640	1,320	3,910	232,000	
May	24,800	5,520	12,800	787,000	
June	20,400	11,400	16,500	981,000	
July	13,200	4,240	7,400	455,000	
August	4,460	2,390	3,240	199,000	
September	4,680	1,830	2,650	158,000	
1904–5.					
October	2,630	1,710	2,140	132,000	
April	6,000	1,500	2,640	157,000	
May	24,900	6,120	13,100	804,000	
June	35,900	13,500	24,400	1,450,000	
July	12,400	3,440	6,080	374,000	
August	4,600	1,720	2,530	155,000	
September	2,280	1,610	1,830	109,000	

Monthly discharge of Grand River near Palisades, Colo., for the years ending Sept. 30, 1902–1914—Continued.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1905–6.					
October	1,890	1,610	1,750	107,000	
April	10,200	1,950	4,730	281,000	
May	28,900	5,760	18,600	1,140,000	
June	37,000	12,000	23,500	1,400,000	
July	12,700	5,400	9,820	604,000	
August	5,640	2,350	3,800	234,000	
September	4,940	2,350	3,340	199,000	
1906–7.					
October	4,060	2,140	2,850	175,000	
February 15–28	1,600	1,350	1,460	40,500	B.
March	4,840	1,350	2,240	138,000	B.
April	9,340	2,200	5,250	312,000	A.
May	23,200	4,540	10,500	646,000	A.
June	30,200	13,400	24,800	1,480,000	A.
July	29,300	9,030	17,000	1,040,000	A.
August	8,310	3,380	4,890	301,000	A.
September	3,460	2,130	2,600	155,000	B.
1907–8.					
October	3,900	2,270	2,640	162,000	B.
November	2,270	1,450	1,820	108,000	B.
December	1,550	1,260	1,370	84,200	C.
January	....	....	*a* 1,300	79,900	C.
February	1,820	....	*a* 1,320	75,900	C.
March	2,000	1,350	1,630	100,000	B.
April	6,930	1,550	3,900	232,000	A.
May	10,600	3,640	6,720	413,000	A.
June	20,300	8,180	14,600	869,000	A.
July	9,810	3,210	5,670	349,000	A.
August	4,840	2,270	3,550	218,000	A.
September	2,270	1,550	1,760	105,000	B.
The year	20,300	....	3,860	2,800,000	
1908–9.					
October	3,210	1,550	1,890	116,000	B.
November	1,820	1,350	1,600	95,200	B.
December	1,760	1,170	1,320	81,200	B.
January	....	....	*a* 1,340	82,400	D.
February	....	....	*a* 1,200	66,600	D.
March	2,280	1,120	1,560	95,900	C.
April	5,680	1,420	2,690	160,000	C.
May	20,800	3,800	13,100	806,000	B.
June	43,000	14,600	33,300	1,980,000	B.
July	29,300	5,790	14,400	885,000	B.
August	7,290	3,990	5,190	319,000	B.
September	7,410	3,070	4,870	290,000	B.
The year	43,000	....	6,870	4,980,000	
1909–10.					
October	3,070	2,140	2,570	158,000	A.
November	2,570	2,010	2,080	124,000	B.
December	2,080	1,530	1,630	100,000	C.
March	4,810	2,280	3,470	213,000	
April	15,400	3,070	5,850	348,000	
May	22,500	9,650	13,100	806,000	
June	27,100	6,580	14,300	851,000	
July	6,810	2,010	3,710	228,000	
August	4,290	1,530	2,330	143,000	
September	2,900	1,530	2,240	133,000	
1910–11.					
October	2,570	1,530	1,830	113,000	
November	2,500	1,370	1,660	98,800	
December	1,530	1,050	1,260	77,500	
January	2,800	1,150	1,550	95,300	
February	3,440	1,030	1,470	81,600	
March	3,790	1,100	1,860	114,000	
April	6,770	1,370	3,050	181,000	
May	18,600	4,750	12,700	781,000	
June	24,800	10,400	19,900	1,180,000	
July	16,400	4,350	8,570	527,000	
August	4,350	1,960	2,640	162,000	
September	3,270	1,590	2,070	123,000	
The year	24,800	1,030	4,880	3,530,000	

a Estimated.

Monthly discharge of Grand River near Palisades, Colo., for the years ending Sept. 30, 1902–1914—Continued.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1911–12.					
October	9,770	1,960	3,420	210,000	
November	2,220	1,590	1,920	114,000	
March	4,050	1,320	1,760	108,000	
April	3,650	2,080	2,710	161,000	
May	33,600	4,260	15,600	959,000	
June	43,400	17,200	30,600	1,820,000	
July	28,900	11,200	17,200	1,060,000	
August	12,200	2,620	5,460	336,000	
September	3,280	2,080	2,450	146,000	
1912–13.					
October	3,460	2,210	2,520	155,000	
November	2,480	1,590	2,020	120,000	
March 6–31	2,700	1,370	1,960	101,000	
April	8,030	2,700	5,250	312,000	
May	20,800	8,180	13,300	818,000	
June	20,300	8,640	13,200	786,000	
July	7,880	2,780	4,930	303,000	
August	2,620	1,280	1,850	114,000	
September	3,780	1,280	2,250	134,000	
1913–14.					
October	2,780	1,640	2,120	130,000	
November	2,540	1,370	1,710	102,000	
December 1–19	1,760	1,150	1,380	52,000	
February	2,940	1,530	1,870	104,000	
March	2,700	1,320	1,870	115,000	
April	6,080	2,250	4,340	258,000	
May	38,800	5,720	20,800	1,280,000	
June	42,800	17,800	29,700	1,770,000	
July	17,400	6,880	10,800	664,000	
August	8,640	2,780	4,290	264,000	
September	3,580	2,120	2,530	151,000	

GRAND RIVER AT GRAND JUNCTION, COLO.

Location.—At wagon bridge, 300 feet from city waterworks pump house at Grand Junction, a short distance above the mouth of Gunnison River.

Records presented.—October 1, 1896, to September 30, 1899.

Drainage area.—8,640 square miles.

Gage.—Vertical staff fastened to stone pier of bridge; auxiliary wire gage in second channel.

Channel.—Water flows in two channels at medium and high stages, both somewhat shifting.

Discharge measurements.—Made from bridge.

Accuracy.—Estimates only fair, owing to the unstable conditions of channel.

Monthly discharge of Grand River at Grand Junction, Colo., for the years ending Sept. 30, 1897–1899.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1896–97.				
October	1,890	1,430	1,530	94,100
November	1,430	910	1,280	76,200
December	....	....	1,100	67,600
January	....	....	1,000	61,500
February	....	....	1,150	63,900
March	....	....	1,380	84,800
April	9,900	1,360	3,480	207,000
May	37,200	11,000	27,500	1,690,000
June	36,000	13,300	23,300	1,390,000
July	13,300	3,730	7,970	490,000
August	5,650	1,840	3,240	199,000
September	2,940	1,720	1,940	115,000
The year	37,200	....	6,260	4,540,000

Monthly discharge of Grand River at Grand Junction, Colo., for the years ending Sept. 30, 1897–1899—Continued.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1897–98.				
October	2,590	1,610	1,950	120,000
November	1,970	1,450	1,750	104,000
December	....	....	1,600	98,400
January	....	....	2,940	181,000
February	....	....	2,980	166,000
March	....	....	2,110	130,000
April	....	....	4,300	256,000
May	12,600	4,630	7,130	438,000
June	17,300	8,280	13,700	815,000
July	7,610	1,720	4,440	273,000
August	1,720	949	1,130	69,300
September	1,140	561	907	54,000
The year	17,300	....	3,740	2,700,000
1898–99.				
October	1,140	561	915	56,300
November	1,340	755	1,070	63,800
December	....	....	1,010	62,200
January	....	....	1,000	61,500
February	....	....	2,000	111,000
March	....	....	1,800	111,000
April	....	....	3,940	234,000
May	....	....	19,400	1,190,000
June	....	....	31,300	1,860,000
July	....	....	14,100	865,000
August	....	....	4,580	281,000
September	....	....	2,160	129,000
The year	....	....	6,940	5,020,000

GRAND RIVER NEAR FRUITA, COLO.

Location.—In sec. 20, T. 1 N., R. 2 W., at highway bridge 1½ miles south of Fruita. Nearest important tributary, Little Salt Wash, enters a mile below the station; Gunnison River enters at Grand Junction, about 12 miles above.

Records presented.—January 1, 1908, to September 30, 1914.

Drainage area.—16,800 square miles (Hayden's Atlas).

Gage.—Chain gage; datum was raised 0.05 foot May 3, 1911.

Channel.—Practically permanent.

Discharge measurements.—Made from the highway bridge.

Winter flow.—The river is frozen over during a portion of the year and readings are taken to water surface through a hole in the ice.

Diversions.—Between the Palisades station and Fruita nearly 500 second-feet are diverted during the irrigation season.

Maximum stage.—Since the establishment of the station the maximum stage has been 15 feet, which occurred June 9, 1909. The highest stage known was about 18.5 feet on July 4, 1884.

Accuracy.—Records as a whole reliable, but only fair for periods when the monthly mean discharge was estimated.

Cooperation.—Gage-height record furnished through the courtesy of the United States Weather Bureau.

Monthly discharge of Grand River near Fruita, Colo., for the years ending Sept. 30, 1908–1914.

Month.	Discharge in second-feet.			Run-off (in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1908.					
January	....	....	a 2,500	154,000	
February	....	....	a 2,600	150,000	
March	....	....	a 4,000	246,000	
April	13,300	4,560	8,130	484,000	B.
May	17,100	6,630	10,900	670,000	B.
June	27,300	13,600	20,100	1,200,000	B.
July	14,000	4,560	8,350	513,000	B.
August	....	....	a 2,800	172,000	
September	....	....	a 2,700	161,000	
The period	....	....	....	3,750,000	
1908–9.					
October	....	....	a 3,000	184,000	
November	....	....	a 2,800	167,000	
December	....	....	a 2,600	160,000	
January	....	....	a 2,500	154,000	
February	....	....	a 2,400	133,000	
March	....	....	a 5,500	338,000	
April	12,600	4,560	6,530	389,000	B.
May	34,100	6,630	23,200	1,430,000	B.
June	63,600	21,300	45,500	2,710,000	B.
July	37,700	8,800	19,100	1,170,000	A.
August	....	....	a 7,000	430,000	
September	....	....	a 5,500	327,000	
The year	63,600	....	10,500	7,590,000	
1909–10.					
October	....	....	a 3,600	221,000	
November	....	....	a 3,200	190,000	
December	....	....	a 2,900	178,000	
January	....	....	a 2,800	172,000	
February	....	....	a 2,700	150,000	
March	....	....	a 9,000	553,000	
April	26,600	4,560	10,800	643,000	A.
May	32,700	15,700	21,400	1,320,000	A.
June	34,100	9,060	19,300	1,150,000	A.
July	9,060	4,560	6,360	391,000	B.
August	....	....	a 3,000	184,000	
September	....	....	a 3,000	179,000	
The year	34,100	....	7,340	5,330,000	
1910–11.					
October	....	....	a 3,400	209,000	
November	....	....	a 2,900	173,000	
December	....	....	a 2,600	160,000	
January	....	....	a 2,600	160,000	
February	....	....	a 2,800	156,000	
March	....	....	a 5,000	307,000	
April	....	....	a 6,000	357,000	
May	31,000	14,200	22,500	1,380,000	A.
June	38,800	15,900	29,000	1,730,000	A.
July	23,900	8,160	14,000	861,000	A.
August	7,200	3,010	4,460	274,000	A.
September	8,160	2,630	3,400	202,000	A.
The year	38,800	....	8,220	5,970,000	
1911–12.					
October	13,800	4,660	6,980	429,000	A.
November	4,470	2,880	3,410	203,000	A.
December	....	....	a 2,700	166,000	C.
January	....	....	a 2,700	166,000	D.
February	....	....	a 2,600	150,000	C.
March	6,740	2,630	3,350	206,000	A.
April	8,410	3,770	5,660	337,000	A.
May	53,600	8,160	28,400	1,750,000	A.
June	58,100	25,100	42,800	2,550,000	A.
July	38,800	15,900	21,600	1,330,000	A.
August	16,400	3,610	7,510	462,000	A.
September	4,660	3,010	4,000	238,000	A.
The year	58,100	....	11,000	7,990,000	

a Estimated.

Monthly discharge of Grand River near Fruita, Colo., for the years ending Sept. 30, 1908–1913—Continued.

Month.	Discharge in second-feet.			Run-off (in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1912–13.					
October	4,850	3,770	4,340	267,000	A.
November	4,290	2,750	3,630	216,000	A.
December	....	....	a 3,000	184,000	C.
January	....	....	a 2,900	178,000	D.
February	....	....	a 2,700	150,000	C.
March	....	....	a 4,000	246,000	C.
April	16,600	5,050	10,400	619,000	A.
May	27,300	13,500	19,200	1,180,000	B.
June	26,800	11,900	17,800	1,060,000	B.
July	10,500	4,470	6,930	426,000	A.
August	4,110	2,100	2,660	164,000	A.
September	4,950	2,320	3,670	218,000	A.
The year	27,300	....	6,770	4,910,000	
1913–14.					
October	4,660	3,150	3,890	239,000	A.
November	3,860	2,690	3,200	190,000	A.
December	....	....	a 2,500	154,000	C.
January	....	....	a 3,050	188,000	D.
February	....	....	a 2,900	161,000	C.
March	4,290	2,880	3,400	209,000	A.
April	12,400	3,610	8,480	505,000	A.
May	53,600	11,000	33,500	2,060,000	A.
June	58,100	23,900	41,400	2,460,000	A.
July	22,700	10,400	15,700	965,000	A.
August	12,000	3,660	6,730	414,000	A.
September	6,020	3,360	3,960	236,000	A.
The year	58,100	....	10,700	7,780,000	

a Estimated.

GRAND RIVER NEAR MOAB, UTAH.

Location.—In sec. 26, T. 25 S., R. 21 E., at highway bridge 3 miles northwest of Moab, 33 miles from Thompson. Mill Creek enters about 2 miles below the station.

Records presented.—October 1, 1913, to September 30, 1914.

Drainage area.—Not measured.

Gage.—Chain gage attached to bridge. Auxiliary gage painted on bridge abutment.

Channel.—Gravel and sand; shifting.

Discharge measurements.—Made from bridge.

Accuracy.—Estimates of discharge may be considered good.

On November 10, 1914, the station was moved 23 miles upstream to the Dewey Ferry. No tributaries or diversions between the two points.

Monthly discharge of Grand River near Moab, Utah, for the year ending Sept. 30, 1914.

Month.	Discharge in second-feet.			Run-off (in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
October	4,700	3,640	4,050	249,000	B.
November	4,240	3,040	3,610	215,000	A.
December	3,190	1,560	2,310	142,000	B.
January	6,400	1,650	2,930	180,000	B.
February	8,350	1,950	2,730	152,000	B.
March	5,300	2,050	3,640	224,000	A.
April	14,100	4,400	9,810	584,000	B.
May	58,800	10,500	33,800	2,080,000	A.
June	65,600	28,600	47,200	2,810,000	B.
July	29,200	12,000	18,400	1,130,000	B.
August	13,800	4,660	8,120	499,000	B.
September	6,940	3,660	4,460	265,000	B.
The year	65,600	1,560	11,800	8,530,000	

ROARING FORK AT GLENWOOD SPRINGS, COLO.

Location.—On bridge 500 feet above the mouth of the river in Glenwood Springs. Nearest important tributary enters about 3 miles above the station.

Records presented.—April 6, 1906, to September 30, 1909; October 1, 1910, to September 30, 1914.

Drainage area.—1,450 square miles (Nell's map of Colorado, 1903).

Gage.—Chain gage; location and datum unchanged.

Channel.—Practically permanent but rough. Extremely high water in Grand River may cause backwater at the gage. Measurements made at stages as high as 5.7 feet on Roaring Fork and 9.2 feet on Grand River have shown no backwater effect.

Discharge measurements.—Made from highway bridge.

Winter flow.—Surface ice rarely forms entirely across the river, but slush and anchor ice frequently occur. Discharge measurements sometimes show backwater from ice.

Diversions.—There are court decrees for diversions of 196 second-feet from Roaring Fork above the station, and 795 second-feet from the various tributaries.

Accuracy.—Conditions are favorable for accurate results; estimates should be reliable.

Cooperation.—Since 1910 the station has been maintained in cooperation with the United States Forest Service.

Monthly discharge of Roaring Fork at Glenwood Springs, Colo., for the years ending Sept. 30, 1906–1909, 1911–1914.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1906.					
April 6–30	2,530	670	1,310	65,000	
May	6,940	1,280	4,290	264,000	
June	11,400	4,740	7,060	420,000	
July	6,060	2,220	4,000	246,000	
August	2,640	910	1,590	97,800	
September	1,870	784	1,150	68,400	
The period	....	....	....	1,160,000	
1906–7.					
October	1,340	700	943	58,000	
November	858	375	604	35,900	
December	520	225	421	25,900	
January	450	266	368	22,600	C.
February	450	290	367	20,400	B.
March	995	330	554	34,100	B.
April	2,640	670	1,490	88,700	B.
May	5,300	1,090	2,410	148,000	B.
June	8,040	2,750	6,270	373,000	A.
July	8,000	3,600	5,500	338,000	A.
August	3,120	1,240	1,980	122,000	A.
September	1,290	805	1,030	61,300	A.
The year	8,040	225	1,830	1,330,000	
1907–8.					
October	1,040	670	802	49,300	A.
November	670	375	504	30,000	A.
December	486	360	453	27,900	B.
January	510	400	433	26,600	A.
February	450	350	400	23,000	A.
March	650	400	509	30,700	A.
April	1,980	400	1,160	69,000	A.
May	3,190	1,190	1,870	115,000	A.
June	6,320	2,620	4,380	261,000	A.
July	3,510	1,190	2,170	133,000	A.
August	1,680	670	1,210	74,400	A.
September	625	455	534	31,800	A.
The year	6,320	350	1,200	872,000	

Monthly discharge of Roaring Fork at Glenwood Springs, Colo., for the years ending Sept. 30, 1906–1909, 1911–1914—Continued.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1908–9.					
October	625	455	530	32,600	A.
November	540	390	447	26,600	C.
December	555	375	455	28,000	B.
January	510	300	410	25,200	C.
February	400	300	362	20,100	C.
March	450	350	421	25,900	C.
April	1,500	450	782	46,500	A.
May	4,730	905	2,910	179,000	A.
June	11,300	2,820	8,350	497,000	B.
July	8,740	1,700	4,070	250,000	A.
August	2,000	1,220	1,480	91,000	A.
September	2,840	935	1,530	91,000	A.
The year	11,300	300	1,810	1,310,000	
1910–11.					
October	760	485	587	36,100	B.
November	655	380	494	29,400	B.
December	....	....	*a* 383	23,600	C.
January	680	270	403	24,800	C.
February	680	315	389	21,600	B.
March	790	365	514	31,600	B.
April	2,530	645	1,040	61,900	B.
May	5,430	1,500	3,820	235,000	C.
September 15–30	2,040	715	948	30,100	B.
1911–12.					
October	4,800	680	1,490	91,600	C.
November	1,120	365	653	38,900	B.
December	680	365	521	32,000	C.
January	535	370	445	27,400	C.
February	460	330	385	22,100	B.
March	535	370	423	26,000	B.
April	1,380	435	900	53,600	B.
May	9,840	1,750	4,040	248,000	B.
June	12,800	7,270	10,000	595,000	B.
July	5,840	3,650	5,000	307,000	B.
August	3,270	1,420	2,160	133,000	B.
September	1,370	785	983	58,500	B.
The year	12,800	330	2,250	1,630,000	
1912–13.					
October	900	750	812	49,900	B.
November	820	535	689	41,000	B.
December	620	410	542	33,300	B.
January	....	....	*a* 450	27,700	C.
February	....	....	*a* 420	23,300	C.
March	680	350	426	26,200	B.
April	2,530	535	1,120	66,600	B.
May	7,270	1,960	3,880	239,000	B.
June	6,300	3,280	4,640	276,000	C.
July	....	....	*a* 2,200	135,000	C.
August	990	620	773	47,500	B.
September	1,180	620	801	47,700	B.
The year	7,270	....	1,400	1,010,000	
1913–14.					
October	820	590	702	43,200	B.
November	650	560	614	36,500	B.
December	560	350	472	29,000	C.
May 5–31	12,300	3,040	7,650	410,000	B.
June	14,200	7,140	11,000	655,000	C.
July	9,070	2,620	6,230	383,000	B.
August	2,620	852	1,310	80,600	B.
September	990	638	791	47,100	B.

a Estimated.

GUNNISON RIVER AT WHITEWATER, COLO.

Location.—At steel highway bridge, one-half mile above railroad station at Whitewater.

Records presented.—April 1, 1902, to October 31, 1906. Station discontinued during winter months.

Drainage area.—7,870 square miles.

Gage.—Chain gage attached to bridge.

Channel.—Gravel and small bowlders; somewhat shifting.

Discharge measurements.—Made from bridge.

Winter flow.—Discharge relation affected by ice.

Accuracy.—Estimates of discharge fair.

Monthly discharge of Gunnison River at Whitewater, Colo., for 1902–1906.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1902.				
April	3,790	860	2,080	124,000
May	8,350	2,580	5,930	365,000
June	5,920	623	2,970	177,000
July	1,000	383	570	35,000
August	1,170	341	610	37,500
September	1,460	427	667	39,700
October	860	383	504	31,000
The period	....	....	....	809,000
1903.				
April	5,790	670	2,260	135,000
May	14,000	5,040	8,160	502,000
June	17,800	8,770	12,500	746,000
July	8,770	3,860	5,130	316,000
August	4,470	740	1,310	80,700
September	2,130	740	1,280	76,400
October	1,130	740	890	54,700
November	1,210	635	844	50,200
December	970	670	810	49,800
The period	....	....	....	2,010,000
1904.				
January	1,000	570	724	44,500
February	1,050	600	774	44,500
March	920	510	648	39,800
April	4,600	570	2,250	134,000
May	8,630	2,920	5,620	346,000
June	6,880	2,570	4,600	274,000
July	3,220	630	1,320	81,100
August	2,640	1,100	1,640	101,000
September	3,140	695	1,100	65,700
October	2,500	730	1,300	80,000
The period	....	....	....	1,210,000
1905.				
April	7,940	840	2,490	148,000
May	22,700	6,030	12,700	782,000
June	28,100	6,760	16,800	1,000,000
July	6,130	1,520	2,780	171,000
August	3,780	720	1,430	87,900
September	1,470	720	962	57,200
October	1,520	870	1,100	67,800
The period	....	....	....	2,310,000
1906.				
April	10,700	1,730	4,590	273,000
May	21,700	5,130	14,800	910,000
June	21,900	6,920	14,400	857,000
July	7,350	3,190	4,710	290,000
August	3,400	1,290	2,080	128,000
September	2,860	1,050	1,680	100,000
October	2,300	1,420	1,690	104,000
The period	....	....	....	2,660,000

GUNNISON RIVER NEAR GRAND JUNCTION, COLO.

Location.—At steel highway bridge, 1½ miles south of the town of Grand Junction, near the mouth of the river.

Records presented.—May 1, 1897, to September 30, 1899. Station discontinued during winter months.

Gage.—Vertical staff bolted to bridge pier.

Channel.—Rocks and filled with sand; somewhat shifting.

Discharge measurements.—Made from bridge.

Winter flow.—Discharge relation affected by ice.

Accuracy.—Discharge relation affected by backwater from Grand River; estimates only fair.

Monthly discharge of Gunnison River near Grand Junction, Colo., for 1897–1899.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1897.				
May	20,700	11,800	16,900	1,040,000
June	19,100	5,370	11,200	664,000
July	5,370	1,510	3,230	199,000
August	1,850	160	975	60,000
September	1,510	160	628	37,400
October	2,020	1,060	1,470	90,500
November	1,200	230	933	55,500
The period	....	....	....	2,150,000
1898.				
May	9,000	3,960	5,320	327,000
June	11,400	4,160	8,850	527,000
July	3,960	1,080	2,540	156,000
August	968	578	689	42,400
September	578	399	479	28,500
October	672	399	533	32,800
November	672	314	497	29,600
The period	....	....	....	1,140,000
1899.				
April	8,790	968	3,550	211,000
May	16,800	3,900	10,300	633,000
June	16,800	8,080	12,400	737,000
July	8,430	2,250	4,350	267,000
August	4,560	908	1,920	118,000
September	1,000	758	875	52,100
The period	....	....	....	2,020,000

DOLORES RIVER AT DOLORES, COLO.

Location.—One-fourth mile southwest of the railroad station at Dolores, in Montezuma County, Colo. Nearest tributary, Lost Canyon Creek, enters some distance above the station. During 1895 to 1903 at footbridge one-half mile above railroad station.

Records presented.—July 1, 1895, to October 31, 1903; August 27, 1910, to November 30, 1912.

Drainage area.—524 square miles (State engineer's report).

Gage.—Automatic recording gage. Vertical staff at old site.

Channel.—Practically permanent.

Discharge measurements.—Made from bridge.

Diversions.—No data.

Cooperation.—Since 1910 station has been maintained and records have been furnished complete for publication by the State engineer.

Monthly discharge of Dolores River at Dolores, Colo., for the years ending Sept. 30, 1895–1903, 1910–1913.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1895.				
July	490	127	270	16,600
August	548	97	248	15,200
September	177	68	99	5,890
1895–96.				
October	97	68	79	4,860
November	405	42	134	7,970
December	605	281	419	26,400
January	....	....	[a] 300	18,400
February	....	....	[a] 300	16,700
March	557	96	244	15,000
April	1,580	144	747	44,400
May	1,450	373	958	58,900
June	781	44	263	15,600
July	480	44	130	7,990
August	180	8	38	2,340
September	1,180	28	195	11,600
The year	1,580	....	317	230,000
1896–97.				
October	180	96	113	6,950
November	618	36	179	10,700
December	....	....	[a] 200	12,300
January	....	....	[a] 200	12,300
February	....	....	[a] 200	11,100
March	....	....	[a] 200	12,300
April	2,940	235	1,480	88,200
May	2,840	1,990	2,440	150,000
June	2,520	570	1,460	87,200
July	608	186	368	22,600
August	235	76	148	9,100
September	852	76	394	23,400
The year	2,940	....	615	446,000
1897–98.				
October	570	235	391	24,000
November	235	108	172	10,200
December	....	....	[a] 120	7,380
January	....	....	[a] 150	9,220
February	....	....	[a] 150	8,330
March	....	....	[a] 200	12,300
April	1,980	198	1,090	65,000
May	1,870	912	1,210	74,200
June	2,030	784	1,510	89,900
July	1,230	144	490	30,100
August	228	102	120	7,380
September	293	34	78	4,640
The year	2,030	....	473	343,000
1898–99.				
October	50	34	37	2,280
November	72	34	48	2,860
December	....	....	100	6,150
March 22–31	....	....	37	665
April	885	37	437	26,000
May	1,460	118	785	48,300
June	810	220	499	29,700
July	412	100	207	12,700
August	736	30	204	12,500
September	82	23	33	1,960
1899–1900.				
October	343	23	93	5,720
November	82	37	49	2,920
December	220	30	151	9,280
January	220	164	200	12,300
February	164	82	107	5,940
March	192	37	101	6,210
April	555	100	284	16,900
May	1,740	483	1,320	81,100
June	1,600	280	808	48,100
July	220	37	84	5,160
August	37	20	29	1,780
September	250	23	89	5,300
The year	1,740	20	276	201,000

[a] Estimated.

Monthly discharge of Dolores River at Dolores, Colo., for the years ending Sept. 30, 1895–1903, 1910–1913—Continued.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1900–1901.				
October	118	56	83	5,100
November	220	37	88	5,240
December	412	100	216	13,300
March	555	82	178	10,900
April	2,390	82	878	52,200
May	3,090	1,370	2,080	128,000
June	1,690	810	1,210	71,500
July	627	141	266	16,400
August	343	100	174	10,700
September	220	19	42	2,500
1901–2.				
October	37	19	26	1,600
April	1,160	51	497	29,600
May	1,320	484	857	52,700
June	811	106	342	20,400
July	106	28	56	3,440
August	341	20	92	5,660
September	237	28	62	3,690
1902–3.				
October	37	28	34	2,090
April	1,480	205	629	37,400
May	2,630	997	1,750	108,000
June	2,820	1,720	2,260	134,000
July	1,660	206	662	40,700
August	206	116	137	8,420
September	557	80	155	9,220
1903.				
October	116	43	71	4,370
1910.				
August 27–31	84	55	69.2	686
September	141	69	85.0	5,060
1910–11.				
October	291	69	113	6,960
November	112	62	89.4	5,320
December	102	84	85.1	5,230
January	80	60	70	4,320
February	113	65	73	4,050
March	692	67	245	15,100
April	2,060	548	1,080	64,300
May	2,860	1,390	2,160	133,000
June	2,220	895	1,620	96,300
July	1,840	605	1,040	64,100
August	695	180	339	20,800
September	1,040	82	191	11,400
The year	2,860	....	592	431,000
1911–12.				
October 1–2	2,090	1,510	1,800	7,150
November 12–30	250	165	206	7,740
December 1–12	200	88	130	2,090
January	85	75	81	4,980
February	80	70	73	4,230
March	340	80	188	11,600
April	855	260	451	26,800
May	3,790	1,100	2,560	158,000
June	2,490	915	1,680	99,900
July	1,260	390	685	42,200
August	740	70	272	16,800
September	740	70	115	6,860
1912.				
October	335	70	127	7,800
November	450	35	107	6,370

SAN MIGUEL RIVER AT FALL CREEK, COLO.

Location.—At wagon bridge at railroad station of Fall Creek. Fall Creek enters the river about 200 feet below the gage.

Records presented.—July 1, 1895, to September 30, 1899. Station discontinued during winter months.

Drainage area.—Not measured.

Gage.—Vertical staff fastened to north abutment of bridge.

Channel.—Fairly permanent.

Discharge measurements.—Made from bridge or by wading.

Accuracy.—Estimates fair.

Monthly discharge of San Miguel River at Fall Creek, Colo., for 1895–1899.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1895.				
July	675	219	347	21,300
August	312	145	230	14,100
September	168	61	100	5,950
October	101	42	64	3,940
November	180	....	[a] 30	1,780
December	....	....	[a] 10	615
The period	....	....	....	47,700
1896.				
April 12–30	531	147	281	10,600
May	2,400	310	770	47,300
June	684	135	349	20,800
July	320	93	157	9,650
August	113	49	65	4,000
September	1,070	62	176	10,500
October	135	49	82	5,040
November	147	22	57	3,390
The period	....	....	....	111,000
1897.				
January	....	....	[a] 60	3,690
February	....	....	[a] 60	3,330
March	....	....	[a] 60	3,690
April	433	52	213	12,700
May	962	369	626	38,500
June	997	504	774	46,100
July	621	243	375	23,100
August	288	122	183	11,300
September	304	132	215	12,800
October	273	122	184	11,300
November	132	62	96	5,710
December	....	....	[a] 75	4,610
The year	....	....	243	177,000
1898.				
April 11–30	447	196	272	10,800
May	545	196	296	18,200
June	1,340	571	813	48,400
July	760	109	380	23,400
August	183	109	133	8,180
September	121	66	89	5,300
October	66	30	50	3,070
November	66	22	40	2,380
The period	....	....	....	120,000
1899.				
April	299	25	134	7,970
May	934	126	414	25,500
June	995	249	538	32,000
July	387	176	238	14,600
August	387	105	195	12,000
September	138	64	101	6,000
The period	....	....	....	98,100

[a] Estimated.

SAN MIGUEL RIVER AT PLACERVILLE, COLO.

Location.—About sec. 34, T. 44 N., R. 11 W., about three-fourths of a mile below Placerville, Colo. Nearest tributary, Rio del Codo, enters at Placerville.

Records presented.—September 13, 1910, to November 30, 1912.

Drainage area.—504 square miles (State engineer's report).

Gage.—Vertical staff.

Channel.—Permanent.

Discharge measurements.—Made from the bridge during high water and by wading at ordinary stages.

Diversions.—No data.

Cooperation.—Station maintained and records furnished complete for publication by the State engineer.

Monthly discharge of San Miguel River at Placerville, Colo., for the years ending Sept. 30, 1910–1913.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1910.				
September 13–30	171	95	122	4,360
1910–11.				
October	245	95	121	7,440
November	111	65	94.8	5,640
December	88	58	72.3	4,450
January	127	60	78.8	4,850
February	91	54	64.4	3,580
March	148	60	81.1	4.990
April	438	118	245	14,600
May	706	306	557	34,200
June	910	600	742	44,200
July 1–13	1,290	514	742	19,100
August 9–31	460	184	314	14,300
September	571	124	177	10,500
1911–12.				
October	1,540	142	399	24,500
November	162	85	126	7,500
December	85	50	63.4	3,900
January	100	55	70	4,320
February	174	66	82	4,740
March	92	60	73	4,510
April	328	78	154	9,180
May	1,500	447	977	60,000
June	1,530	582	973	57,900
July	935	483	602	37,000
August	447	162	253	15,500
September	212	100	134	7,960
The year	1,540	50	326	237,000
1912.				
October	151	92	105	6,47[illegible]
November	100	60	83	4,9[illegible]

COLORADO RIVER BELOW MOUTH OF GRAND RIVER.

GENERAL FEATURES.

From the junction of Green and Grand rivers (Pl. IX, *B*) the Colorado flows southwestward, passes across the northwestern corner of Arizona, then turns to the south and for the remainder of its course forms a part of the southeastern boundary of Nevada and California and the western boundary of Arizona. It discharges into the Gulf of California about 119 miles below Yuma, Ariz.

B. C

From a point about 8 miles below Yuma and for a distance of 20 miles the river forms the boundary between the United States and Mexico, the position of this part of the international boundary being defined as the middle of the stream.

Technically the Colorado is navigable from its mouth up to Laguna dam and above the dam as far as Needles. The navigability of the lower river was apparently recognized in the treaties with Mexico regarding the international boundary line, but the current is so swift, the water over bars in the river itself is so shallow, and the range of tide in the tidal bore at the mouth is so great (30 feet) that there has been practically no commerce on the river below Yuma since the Southern Pacific Railroad completed its track in 1876. United States Army engineers who have investigated the river have always reported that expenditure for improvement of the river was not justified.

The delta[1] of the Colorado extends practically from the mouth of the Gila westward to the San Jacinto Mountains and southward to the tidewater of the Gulf, and on the north it merges with the Salton Basin. When the river is low the water winds deviously over a bed, in many places wide and shallow and everywhere confined by banks that seldom exceed 10 or 12 feet in height. At high stages the banks are overflowed at many points and in severe floods overflow is general. The overflow water gathers in little channels which follow the line of greatest slope, which is in general away from and down stream. The overflow channels build up their beds and banks exactly like the main channel and join to form overflow creeks, which in turn form the overflow rivers. The principal overflow channel on the east side of the river is about 40 miles long and joins the Gulf about 20 miles southeast of the present mouth of the river. West of the river there are five principal overflow channels.[2] One of these, Alamo River, is used as part of the Imperial Valley canal system; another, New River, heads in Volcano Lake and is probably the remnant of an overflow channel through which the ancient inland lake—Lake Cahuilla—discharged into the Gulf of California. From the edge of Volcano Lake the grade of New River is northward into Salton Basin.

On the south slope of the delta cone is a channel of considerable width and depth, which has within recent years had direct connection with the Colorado and which gathers the overflow water from a large area. The channel distributes water in part to Volcano Lake and in part to New River.

The fourth channel discharges into the west side of Volcano Lake. Since the summer of 1908 it has carried the entire low-water flow of the Colorado and the greater part of the flood flow.

[1] Abstracted from Cory, H. T., Irrigation and river control in the Colorado River delta: Am. Soc. Civil Eng. Trans., vol. 76, p. 1222, December, 1913.
[2] Op. cit., p. 1224.

The fifth channel discharges into a network of channels south of Volcano Lake. The bottom of Volcano Lake is about 22 feet above sea level, and its high-water stage is about 35 feet. At such a stage it extends about 10 miles northwest and southeast and is about 6 miles wide. It is on the summit of the low flat divide between the Salton Basin on the north and the Gulf on the south, and thus discharges both toward north and south. The size of the outlet channels indicates that its greatest discharge in recent times has been southward. Since 1908 a line of levees has prevented water from passing into New River and thus to Salton Sea. The lake's waters therefore go to the Gulf through Hardy's Colorado, which is an important channel, perhaps 500 feet wide and 20 feet deep at maximum stages, with a fall varying with the stage of the lake from less than 15 to more than 30 feet in a distance of 45 to 50 miles.

PRINCIPAL TRIBUTARIES.

The principal tributaries of the Colorado are Fremont,[1] Escalante, and Paria rivers, Kanab Creek, and Virgin River, which enter from the west, and San Juan, Little Colorado, Williams,[2] and Gila rivers, which enter from the east.

Fremont River.—Fremont River rises in the eastern slope of the Wasatch Mountains in Sevier County, Utah, one of its sources being Fish Lake. It flows in a general southerly direction to Thurber, thence easterly to Hanksville, where it turns southward and joins the Colorado at a point 45 miles below the junction of the Green and Grand. The Fremont has one important tributary, Curtis Creek.[3] In its lower course the river flows through deep canyons. In the upper regions of the Fremont basin, irrigation has been practiced for many years, although only a comparatively small area is being irrigated at the present time. The total drainage area of the Fremont is approximately 4,560 square miles. The mean annual run-off is estimated at approximately 200,000 acre-feet.

Escalante River.—Escalante River rises in the southern part of Garfield County, Utah, under the walls forming the east face of the Table Cliff Plateau, flows first northeast, then east, and finally southeast, and enters the Colorado in Kane County, about 10 miles above the mouth of the San Juan. It is about 90 miles long and the lower three-fourths of its course is through a narrow canyon whose nearly vertical walls range in height from 900 to 1,200 feet. In its upper course it is joined by several tributaries, all of which flow through close canyons. The area of the Escalante basin is 1,780 square

[1] Dirty Devil River on the General Land Office map.
[2] Known locally as Bill Williams River.
[3] Muddy River on the General Land Office maps.

miles. A record showing the discharge of Escalante Creek, one of the headwater streams of Escalante River, indicates an average annual run-off of approximately 40,000 acre-feet for that creek. The average annual run-off from the basin is probably about 75,000 acre-feet.

San Juan River.—San Juan River rises in the San Juan Mountains in southwestern Colorado, flows southwesterly into New Mexico, then turns to the west and northwest, passing from San Juan County, N. Mex., across the extreme southwest corner of Colorado into San Juan County, Utah, in the southwestern part of which it unites with the Colorado.

The drainage area comprises 25,800 square miles and includes parts of four States; its topography ranges in type from the mountains at the headwaters in Colorado to the valleys, plateaus, and eroded mesas of Utah, New Mexico, and Arizona. The headwater streams are protected by fine species of spruce and yellow pine, and in the lower elevations large areas of aspen. The lower basin is practically barren except for an extensive growth of sagebrush, scattered cedars and range grasses. The annual run-off ranges from 1,500,000 to 3,000,000 acre-feet.

The principal tributaries of the San Juan that enter from the north are Navajo, Piedra, Pine, Florida, Animas, La Plata, and Mancos rivers, McElmo, Montezuma, Hallett, Butler, Wash, and Comb Wash creeks; Animas River is the most important. The tributaries that enter from the south, of which Chaco River is the most important, are intermittent streams subject to sudden floods during violent rainstorms.

Paria River.—Paria River rises in the Escalante Mountains in Garfield County, Utah, flows southeasterly through Kane County into Arizona, and joins the Colorado at a point 31 miles below the Utah-Arizona line. The total area of the basin is 1,440 square miles.

Kanab Creek.—Kanab Creek rises on the Paunsagunt Plateau in Kane County, Utah, and flows southward into Arizona, where it joins the Colorado in the section known as the Granite Gorge. Its drainage basin comprises approximately 2,200 square miles, but the greater part of the run-off is derived from the 260 square miles lying above the settlement of Kanab. Kanab Creek ceases to flow as a surface stream at about the Utah-Arizona State line. Only the flood waters reach the Colorado. No regular gaging station has ever been maintained on the creek, although the results of a few miscellaneous discharge measurements are available.

Little Colorado River.—Little Colorado River drains a high plateau extending from the Continental Divide in northwestern New Mexico westward to the San Francisco Mountains in Arizona, and from the

Grand Canyon of the Colorado southward to the Mogollon Mesa. Through this plateau the river winds northwestward to its junction with the Colorado. The general elevation of the plateau is more than 4,000 feet above sea level and the greater part of it is composed of rolling plains with a few feet of soil at the surface underlain by rock.

The Little Colorado is a flashy stream, seldom clear even during low stages. The discharge fluctuates greatly, being insignificant during dry season. Its principal tributary is Puerco River.

The drainage basin comprises 25,900 square miles, of which 5,500 square miles is in the State of New Mexico and the remainder in northeastern Arizona. Though this area is as large as the area drained by Grand River the average annual run-off is far smaller, it being less than 200,000 acre-feet, whereas that from the basin of the Grand is 6,720,000 acre-feet. Precipitation in the basin of the Little Colorado ranges from 8 to 20 inches, but the physical conditions favor rapid run-off. So-called cloud-bursts or severe rainstorms of short duration are frequent, and during the short violent floods the river carries large quantities of silt in suspension.

Virgin River.—Virgin River, the last important tributary entering the Colorado from the west, rises in the southwestern part of Utah, flows southwestward, passing through the northeastern corner of Arizona into Nevada, and thence southward to its junction with the Colorado at a point 40 miles southeast of Moapa, Nev. Its principal tributaries are Santa Clara Creek and Muddy River. Its drainage area comprises 11,000 square miles. Altitudes in this basin range from 936 feet at the mouth of the Virgin to 9,000 feet at its headwaters. Precipitation ranges from 3 to 4 inches at St. Thomas, Nev., 25 miles above the mouth of the Virgin, to more than 20 inches near the headwaters in Utah. The mean annual precipitation at St. George, Utah, is approximately 7 inches.

The run-off from this basin is comparatively small and practically all the normal flow is used for irrigation during the last part of the irrigation season. The Virgin is a flashy stream, subject to sudden floods, and carries a large amount of sediment in suspension. During the last 10 years three violent floods have occurred in the Meadow Valley Wash in this basin, resulting in enormous damage to the San Pedro, Los Angeles & Salt Lake Railroad.

Williams River.—Williams River rises in the St. Cloud Mountains in the western part of Yavapai County, Ariz., and flows westward to its junction with the Colorado at Aubrey Landing. It is small and unimportant, though its drainage area comprises 5,400 square miles. The principal tributaries of Williams River are Santa Maria and Big Sandy creeks.

Gila River.—The most southerly section of the Colorado basin, including the greater part of southern Arizona, as well as parts of New Mexico and of Sonora in the Republic of Mexico, and comprising approximately 56,500 square miles, is drained by Gila River. The Gila rises in western and southwestern New Mexico, receiving its waters from mountains 7,000 to 8,000 feet in elevation. Where it crosses into Arizona it is still 6,000 feet above sea level. From this place it flows between mountain ranges, falling rapidly until at Florence, 180 miles away, it is about 1,500 feet above sea level. From the junction of the Salt, its principal tributary, the Gila continues west and southwest, and enters the Colorado at Yuma, Ariz., near the southwestern corner of the State. The principal tributaries are San Pedro and Santa Cruz rivers from the south and San Francisco, Salt, Agua Fria, and Hassayampa rivers from the north.

The floods of the upper Gila and its tributaries are commonly short and violent, and occur in the months of January and February. The period of high water comes usually during the late summer or early fall, and the season of low water comes in June and July. The drainage basin of the Gila includes 7,000 square miles of land covered with merchantable timber; 11,000 square miles of woodland, of which the San Francisco basin has 1,000 square miles of timberland; 45,000 square miles on which there is no timber; 1,300 square miles of scattered timber; and 300 square miles of open land.

The average annual precipitation over the greater part of the contributory drainage area of Gila and San Francisco rivers in New Mexico is between 10 and 15 inches, exceeding 20 inches in the high mountains of the headwater region.

The flow of the Gila is very irregular and the daily, monthly, and annual flow is subject to large variations. During the last 12 years the total annual run-off of the Gila at Yuma, Ariz., has ranged from less than 100,000 acre-feet to more than 3,000,000 acre-feet.

DISCHARGE RECORDS.

COLORADO RIVER AT HARDYVILLE, ARIZ.

Location.—One-fourth mile above deserted town of Hardyville, 7 miles above Fort Mohave.

Records presented.—May 11, 1905, to September 30, 1907.

Drainage area.—169,000 square miles.

Gage.—Staff in two sections; upper section vertical, lower inclined.

Channel.—Shifting.

Discharge measurements.—Made from cable and car.

Accuracy.—Estimates only fair, owing to shifting of channel.

Monthly discharge of Colorado River at Hardyville, Ariz., for the years ending Sept. 30, 1905–1907.

Month.	Discharge in second-feet. Maximum.	Minimum.	Mean.	Run-off (total in acre-feet).
1905.				
May 11–31	81,900	30,400	47,400	1,970,000
June	99,800	49,800	75,800	4,510,000
July	45,300	14,800	25,300	1,560,000
August	19,000	6,560	11,800	726,000
September	10,800	4,520	6,970	415,000
The period				9,180,000
1905–6.				
October	18,200	4,700	8,570	527,000
November	17,800	5,200	7,610	453,000
December	29,500	5,300	9,100	559,000
January	7,700	2,850	4,830	297,000
February	6,700	5,000	5,880	327,000
March	31,800	5,600	12,300	756,000
April	55,600	21,100	31,600	1,880,000
May	93,000	28,500	64,500	3,970,000
June	116,000	66,000	95,300	5,670,000
July	62,600	27,500	40,000	2,460,000
August	29,000	12,500	18,400	1,130,000
September	19,500	10,800	13,400	797,000
The year	116,000	2,850	26,000	18,800,000
1906–7.				
October	17,800	8,200	11,700	719,000
November	12,800	8,000	9,870	587,000
December	23,100	5,500	9,260	569,000
January	9,600	6,700	8,160	502,000
February	15,100	7,850	10,800	600,000
March	29,000	12,600	16,800	1,030,000
April	45,600	21,900	31,700	1,890,000
May	102,000	26,900	44,900	2,760,000
June	112,000	52,000	85,900	5,110,000
July	104,000	44,000	75,300	4,630,000
August	50,000	17,500	32,500	2,000,000
September	25,800	12,700	18,400	1,090,000
The year	112,000	5,500	29,600	21,500,000

COLORADO RIVER AT YUMA, ARIZ.

Location.—At Southern Pacific Co.'s railroad bridge at Yuma, in sec. 35, T. 16 S., R. 22 E., San Bernardino base and meridian, about 1½ miles below mouth of Gila River.

Records presented.—January 1, 1902, to September 30, 1914.

Drainage area.—242,000 [1] square miles.

Gage.—Vertical staff in two sections at the bridge; the zero of the gage is 102.79 feet above sea level.

Channel.—Shifting sand.

Discharge measurements.—Made from car and cable 600 feet below the gage.

Diversions.—Water is diverted for irrigation and power development above the station.

Accuracy.—Results considered good.

Cooperation.—Complete record published as furnished by the United States Reclamation Service.

[1] Published in previous reports as 225,000 square miles.

Monthly discharge of Colorado River at Yuma, Ariz., for the years ending Sept. 30, 1902–1914.

Month.	Discharge in second-feet. Maximum.	Minimum.	Mean.	Run-off (total in acre-feet).
1902.				
January	4,520	3,230	3,727	229,000
February	4,720	3,300	3,955	220,000
March	5,340	4,340	4,903	301,000
April	11,400	4,340	6,179	368,000
May	59,200	11,400	35,961	2,211,000
June	56,200	29,000	42,520	2,530,000
July	27,000	5,130	12,527	770,000
August	5,560	3,230	4,183	257,000
September	8,360	3,050	3,819	227,000
The period				7,110,000
1902–3.				
October	6,600	3,140	4,299	264,000
November	5,540	3,140	4,187	249,000
December	12,600	3,590	5,412	333,000
January	3,900	2,694	3,089	190,000
February	4,100	2,800	3,372	187,000
March	9,525	3,375	6,117	376,000
April	31,600	9,200	14,326	852,000
May	56,400	13,050	33,735	2,074,000
June	72,219	28,300	53,148	3,163,000
July	69,500	20,350	37,479	2,304,000
August	19,900	6,200	10,869	668,000
September	9,200	5,000	6,786	404,000
The year	72,000	2,694	15,200	11,100,000
1903–4.				
October	15,806	6,128	8,482	522,000
November	6,386	4,675	5,399	321,000
December	5,345	3,170	4,343	267,000
January	4,007	3,350	3,635	224,000
February	4,310	3,342	3,797	218,000
March	9,320	4,446	5,978	368,000
April	19,400	5,600	8,058	479,000
May	45,900	17,040	27,697	1,703,000
June	51,170	32,846	43,814	2,607,000
July	38,930	14,580	23,047	1,417,000
August	24,000	12,950	17,144	1,054,000
September	18,500	5,538	11,621	691,000
The year	51,170	3,170	13,600	9,870,000
1904–5.				
October	23,200	5,660	11,642	716,000
November	7,964	4,754	6,151	366,000
December	5,079	3,480	4,477	275,000
January	27,500	3,750	8,130	500,000
February	82,820	5,800	28,100	1,561,000
March	110,800	23,500	50,540	3,108,000
April	97,500	19,450	37,830	2,251,000
May	59,020	33,910	42,170	2,593,000
June	94,320	61,500	76,470	4,550,000
July	57,800	16,750	30,310	1,864,000
August	17,450	6,850	12,100	744,000
September	9,667	5,060	6,495	386,000
The year	110,800	3,480	26,200	18,900,000
1905–6.				
October	15,500	5,220	8,037	494,000
November	102,700	5,620	12,000	714,000
December	77,360	5,900	15,400	947,000
January	16,100	4,260	6,870	422,000
February	14,800	6,360	9,560	531,000
March	75,000	6,740	25,400	1,560,000
April	44,100	25,500	32,500	1,930,000
May	79,800	35,100	54,100	3,330,000
June	99,200	65,000	84,200	5,010,000
July	74,200	27,000	39,000	2,400,000
August	25,600	13,400	19,200	1,180,000
September	14,500	9,600	11,700	696,000
The year	102,000	4,260	26,500	19,200,000

Monthly discharge of Colorado River at Yuma, Ariz., for the years ending Sept. 30, 1902–1914—Continued.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1906–7.				
October	15,900	8,600	11,700	719,000
November	12,500	8,430	9,710	578,000
December	60,000	6,800	18,300	1,130,000
January	44,300	12,700	21,500	1,320,000
February	31,300	12,400	18,800	1,040,000
March	68,700	14,800	24,100	1,480,000
April	50,500	24,700	35,300	2,100,000
May	68,800	28,600	37,900	2,330,000
June	115,000	72,200	94,800	5,640,000
July	114,000	52,400	96,400	5,930,000
August	61,900	23,100	37,600	2,310,000
September	43,300	13,100	23,200	1,380,000
The year	115,000	6,800	35,800	26,000,000
1907–8.				
October	18,800	10,100	13,600	836,000
November	16,300	8,800	10,800	643,000
December	8,800	5,800	7,450	458,000
January	7,400	5,600	6,320	389,000
February	45,000	6,300	14,200	817,000
March	33,000	10,100	16,100	990,000
April	35,000	12,900	17,800	1,060,000
May	33,700	23,000	27,200	1,670,000
June	61,700	30,000	42,900	2,550,000
July	53,800	18,900	32,600	2,000,000
August	36,100	18,600	24,300	1,490,000
September	19,300	7,000	11,400	678,000
The year	61,700	5,600	18,700	13,600,000
1908–9.				
October	20,600	6,600	9,510	585,000
November	10,200	6,000	8,090	481,000
December	72,500	6,000	15,900	978,000
January	31,500	5,800	10,000	615,000
February	25,100	11,400	13,900	772,000
March	35,900	11,100	15,900	978,000
April	46,800	20,300	30,300	1,800,000
May	73,900	32,400	54,100	3,330,000
June	149,500	75,100	105,000	6,250,000
July	133,700	34,400	79,600	4,890,000
August	54,100	25,000	40,800	2,510,000
September	93,200	21,300	48,500	2,890,000
The year	149,500	5,800	36,000	26,100,000
1909–10.				
October	20,700	11,000	14,000	861,000
November	10,900	8,300	9,440	562,000
December	11,900	4,100	8,410	517,000
January	67,500	4,600	18,800	1,160,000
February	10,800	8,100	9,160	509,000
March	40,200	7,700	24,400	1,500,000
April	38,900	22,500	28,700	1,710,000
May	70,300	40,900	56,500	3,470,000
June	69,400	26,500	47,000	2,800,000
July	25,200	6,900	14,700	904,000
August	13,200	6,300	9,620	592,000
September	11,300	4,600	6,170	367,000
The year	70,300	4,100	20,600	15,000,000
1910–11.				
October	13,500	4,300	6,980	429,000
November	9,500	6,300	7,850	467,000
December	8,200	5,600	6,940	427,000
January	18,700	3,700	8,800	541,000
February	25,700	7,000	13,400	743,000
March	34,500	6,100	17,400	1,070,000
April	25,900	15,600	20,400	1,210,000
May	64,200	27,000	45,000	2,760,000
June	78,300	50,300	64,200	3,820,000
July	69,000	37,800	50,100	3,080,000
August	46,500	10,000	18,400	1,130,000
September	13,300	6,300	8,900	530,000
The year	78,300	3,700	22,400	16,200,000

Monthly discharge of Colorado River at Yuma, Ariz., for the years ending Sept. 30, 1902–1914—Continued.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1911–12.				
October	60,200	7,800	28,600	1,760,000
November	19,200	9,300	12,100	722,000
December	10,100	5,500	7,600	465,000
January	8,200	3,400	5,390	331,000
February	8,800	6,500	7,370	424,000
March	24,800	7,000	13,300	818,000
April	34,700	13,700	21,100	1,260,000
May	76,500	15,400	40,800	2,510,000
June	144,000	57,100	108,000	6,430,000
July	65,200	33,400	46,600	2,870,000
August	42,000	11,900	22,700	1,400,000
September	15,000	7,500	9,780	582,000
The year	144,000	3,400	26,900	19,600,000
1912–13.				
October	20,700	9,200	11,000	676,000
November	18,500	8,500	11,800	702,000
December	8,300	5,200	6,560	403,000
January	6,700	2,600	3,860	238,000
February	7,500	5,300	6,070	337,000
March	11,800	7,700	9,070	558,000
April	40,500	9,300	25,600	1,520,000
May	49,700	27,800	38,700	2,380,000
June	62,500	32,000	47,500	2,830,000
July	32,000	12,700	21,200	1,300,000
August	16,700	5,000	9,430	580,000
September	18,800	4,400	8,820	525,000
The year	62,500	2,600	16,600	12,000,000
1913–14.				
October	25,000	7,200	10,300	635,000
November	10,500	5,800	7,930	472,000
December	8,400	4,500	6,390	393,000
January	21,500	3,300	7,520	462,000
February	27,000	5,800	11,600	646,000
March	27,000	11,200	15,000	923,000
April	34,600	12,000	22,900	1,360,000
May	89,500	33,200	53,800	3,310,000
June	137,000	89,300	110,000	6,570,000
July	89,000	33,800	51,500	3,170,000
August	47,000	10,600	22,000	1,350,000
September	19,800	5,600	9,930	591,000
The year	137,000	3,300	27,400	19,900,000

FREMONT RIVER NEAR THURBER, UTAH.

Location.—In sec. 6, T. 29 S., R. 4 E., at the ranch of John Smith, 2 miles below the town of Thurber.

Records presented.—May 13, 1909, to December 31, 1912, when station was discontinued.

Drainage area.—720 square miles.

Gage.—Vertical staff.

Channel.—Shifts during high water.

Discharge measurements.—Made by wading at low stages and from a cable and car during high stages.

Winter records.—Ice affects discharge relation at times during the winter months.

Diversions.—Nearly all of the low-water flow of the river above Thurber is diverted and used for irrigation, most of the water in the channel at such periods being derived from springs southwest of Thurber. Mill ditch and the Torrey canal head about 500 feet below the station.

Artificial regulation.—The flow of the river is regulated by Johnson reservoir (capacity, 4,800 acre-feet), which is about 4 miles north of Fish Lake, the source of Fremont River.

Accuracy.—Records approximate at times, owing to shifting of the stream bed and possible backwater at gage from dam below.

Monthly discharge of Fremont River near Thurber, Utah, for the years ending Sept. 30, 1909–1913.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1909.					
May 13–31	172	116	146	5,500	D.
June	154	67	114	6,780	C.
July	138	71	93.6	5,760	B.
August	253	83	170	10,500	B.
September	240	159	196	11,700	C.
The period				40,200	
1909–10.					
October	218	148	180	11,100	C.
November	176	128	155	9,220	C.
December	205	161	180	11,100	C.
January	187	153	173	10,600	C.
February	218	153	178	9,890	C.
March	270	112	193	11,900	C.
April	150	100	118	7,020	C.
May	109	64	84.0	5,160	C.
June	87	63	71.7	4,270	C.
July	85	50	64.0	3,940	C.
August	98	63	77.6	4,770	B.
September	177	102	128	7,620	B.
The year	270	50	134	96,600	
1910–11.					
October	131	95	109	6,700	B.
November	124	104	109	6,490	B.
December	119	104	110	6,950	B.
January			a 80	4,920	D.
February			a 102	5,660	C.
March	312	113	170	10,500	B.
April	348	32	94.6	5,630	B.
May	128	43	96.3	5,920	B.
June	50	28	35.9	2,140	C.
July	77	23	47.8	2,940	C.
August	91	70	77.7	4,780	B.
September	98	70	82.8	4,930	B.
The year	348		92.9	67,600	
1911–12.					
October	91	77	82.7	5,080	B.
November			a 89.9	5,350	C.
December			a 60.0	3,690	D.
January			a 80	4,920	C.
February			a 90	5,180	C.
March	136	98	113	6,950	B.
April	420	106	206	12,300	B.
May	384	36	232	14,300	D.
June	120	18	45.9	2,730	C.
July	206	105	125	7,690	B.
August	214	63	103	6,330	B.
September	113	77	94.9	5,650	B.
The year	420		110	80,200	
1912.					
October	120	91	105	6,460	B.
November	136	100	116	6,900	B.
December			a 90	5,530	C.

a Estimated.

MUDDY CREEK AT COUNTY BRIDGE NEAR EMERY, UTAH.

Location.—In the NE. ¼ sec. 35, T. 21 S., R. 6 E., at the county bridge about 2½ miles north of Emery.

Records presented.—June 6, 1911, to September 30, 1912.

Drainage area.—Not measured.

Gage.—Chain gage attached to the highway bridge used until October 18, 1912; inclined staff gage at same datum as chain gage bolted to rock cliff used after October 19.

Channel.—Fairly permanent except at low stages.

Discharge measurements.—Made from the bridge at high water or by wading at other stages.

Winter flow.—Ice affects the relation of gage height to discharge for periods.

Diversions.—Below all diversions except a few small ditches.

Accuracy.—Results fair except for winter months and low-water periods.

Monthly discharge of Muddy Creek at county bridge near Emery, Utah, for the years ending Sept. 30, 1911–12.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1911.					
June 6–30	72	35	39.5	1,960	C.
July	102	2	17.2	1,060	C.
August	262		a 15.1	928	D.
September			a 3.0	178	D.
The period				4,130	
1911–12.					
October			a 3.5	215	D.
November			a 3.5	208	D.
December			a 2.0	123	D.
January			a 2.0	123	D.
February			a 3.0	173	D.
March			a 3.5	215	D.
April	68	.0	a 22.2	1,320	B.
May	142	.0	76.6	4,710	B.
June	182	22	100	5,950	C.
July	19	3.2	7.12	438	C.
August	3.0	.0	.22	14	
September	12	.0	.73	43	
The year	182	.0	18.7	13,500	

a Estimated.

ESCALANTE CREEK NEAR ESCALANTE, UTAH.

Location.—In sec. 9, T. 35 S., R. 3 E., just below the mouth of Winslow or Pine Creek and about 2 miles below the town of Escalante.

Records presented.—August 5, 1909, to December 31, 1912.

Drainage area.—315 square miles.

Gage.—Vertical staff.

Channel.—Shifting.

Discharge measurements.—Made from cable and car or by wading.

Winter flow.—Ice affects the relation of gage height to discharge for periods during the winter months.

Diversions.—All the low-water flow is used for irrigation above the station; the records at this point indicate unappropriated and waste waters.

Floods.—This stream is subject to sudden floods of short duration, with resulting changes in the character of the stream bed and control.

Accuracy.—Poor, owing to shifting character of stream bed and lack of discharge measurements. Yearly total is probably correct within 15 per cent, but monthly means during certain periods are apt to be in error by a greater amount.

Monthly discharge of Escalante Creek near Escalante, Utah, for the years ending Sept. 30, 1909–1913.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1909.				
August 5-31			116	6,210
September			39.5	2,350
1909-10.				
October			8.19	504
November			10.8	643
December			33.2	2,040
January			89.4	5,500
February			112	6,220
March			127	7,810
April			81.8	4,870
May			103	6,330
June			27.8	1,650
July			43.1	2,650
August			51.1	3,140
September			60.6	3,610
The year			62.3	45,000
1910-11.				
October			25.7	1,580
November			17.9	1,070
December			31.8	1,960
January			30.6	1,880
February	37	22	26.8	1,490
March	240	25	44.6	2,740
April	44	18	23.7	1,410
May	44	14	25.5	1,570
June	28	8	15.5	922
July	810	6	138	8,480
August	388	4	37.3	2,290
September	710	4	40.0	2,380
The year	810		381	27,800
1911-12.				
October	557	6	30.4	1,870
November	36	8	14.2	845
December	36	8	22.4	1,380
January			10.9	670
February	36	17	27.8	1,600
March	88	19	39.6	2,430
April	43	15	31.0	1,840
May	154	22	72.7	4,470
June	170	12	59.5	3,540
July	446	2	40.2	2,470
August	408	2	43.0	2,640
September	56	12	30.6	1,820
The year	557		352	25,600
1912.				
October	850	3	138	8,480
November	112	30	61.9	3,680
December			25.8	1,590

SAN JUAN RIVER AT FARMINGTON, N. MEX.

Location.—In sec. 17, T. 29 N., R. 13 W., half a mile southwest of Farmington, at an old bridge site near Bentleys Ferry, 1,500 feet below the confluence of the San Juan and Animas rivers; from 1904 to 1906, at a point 3 miles south of Farmington and about 2 miles below the confluence.

Records presented.—June 19, 1904, to September 30, 1905; October 1, 1912, to September 30, 1914.

Drainage area.—Not measured.

Gage.—Vertical staff; chain gage during 1904 and 1905.

Channel.—Shifting.

Discharge measurements.—Made by wading at low stages and from cable at high and medium stages.

Winter flow.—Little affected by ice.

Diversions.—Considerable water is diverted for irrigation above this station.

Accuracy.—Estimates of discharge only fair, because of shifting of channel.

Monthly discharge of San Juan River at Farmington, N. Mex., for the years ending Sept. 30, 1904–5, 1913–14.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1904.					
June 19-30	1,300	780	1,030	24,500	
July	1,580	20	375	23,100	
August	4,980	1,450	2,630	162,000	
September	8,620	400	1,380	81,800	
The period				291,000	
1904-5.					
October	20,000	2,620	5,940	365,000	
November	1,700	630	1,090	64,700	
December	780	90	348	21,400	
January	338	40	242	14,900	
February	2,580	230	682	37,900	
March	3,410	780	1,620	99,900	
April	7,460	1,080	4,290	255,000	
May	19,100	4,640	10,100	622,000	
June	24,800	11,000	18,300	1,090,000	
July	8,240	2,180	3,600	222,000	
August	3,740	840	1,750	107,000	
September	4,870	1,180	1,670	99.600	
The year	24,800	40	4,140	3,000,000	
1912-13.					
October	1,970	502	945	58,100	B.
November	1,450	621	1,090	64,900	B.
December	796	240	498	30,600	B.
January			464	28,500	D.
February	602	366	471	26,200	C.
March	2,510	394	683	42,000	C.
April	6,570	2,760	4,650	277,000	C.
May	11,100	4,520	8,020	493,000	C.
June	9,860	3,500	5,880	350,000	C.
July	4,340	673	1,770	109,000	C.
August	1,310	353	621	38,200	B.
September	4,150	628	1,450	86,300	B.
The year	11,100		2,210	1,600,000	
1913-14.					
October	7,350	673	1,480	91,000	B.
November	1,080	688	932	55,500	B.
December	992	550	684	42,100	C.
January	620	501	597	36,700	D.
February	6,520	580	1,870	104,000	B.
March	4,900	2,470	3,460	213,000	B.
April	5,360	3,430	4,480	267,000	B.
May	15,100	3,540	7,940	488,000	B.
June	20,400	4,540	9,900	589,000	B.
July	8,620	2,680	4,260	262,000	B.
August	3,310	866	2,020	124,000	B.
September	4,380	887	1,610	95,800	B.
The year	20,400	501	3,270	2,370,000	

SAN JUAN RIVER AT SHIPROCK, N. MEX.

Location.—About sec. 13, T. 12 N., R. 2 W., at highway bridge, one-fourth mile south of Shiprock Indian Agency.

Records presented.—January 14 to October 6, 1911.

Drainage area.—13,100 square miles (from Land Office map).

Gage.—Chain gage on bridge.

Channel.—Somewhat shifting.

Discharge measurements.—Made from bridge or by wading.

Winter flow.—Practically no ice.

Diversions.—Considerable water diverted above the station for irrigation.

Floods.—During the first week of October, 1911, the most severe flood of many years occurred. The crest of this flood was approximately 22 feet on the gage.

Accuracy.—Estimates fair.

Monthly discharge of San Juan River at Shiprock, N. Mex., for 1911.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
January 14–31	2,800	850	1,400	50,000	C.
February	1,450	600	979	54,400	C.
March	9,920	1,050	4,390	270,000	C.
April	9,920	4,250	7,090	422,000	C.
May	15,000	7,100	10,700	658,000	C.
June	14,300	6,000	10,600	631,000	C.
July	20,400	3,200	10,000	615,000	C.
August	4,950	325	1,140	70,100	C.
September	4,250	300	872	51,900	C.
October 1–6	47,600	9,600	19,300	230,000	D.
The period				3,050,000	

ANIMAS RIVER AT FARMINGTON, N. MEX.

Location.—In sec. 15, T. 29 N., R. 13 W., about three-fourths mile east of Farmington and one-fourth mile above the confluence of the Animas and San Juan rivers.

Records presented.—June 20, 1904, to September 30, 1905; October 1, 1912, to September 30, 1914.

Drainage area.—Not measured.

Gage.—Automatic recording; chain gage during 1904 and 1905.

Channel.—Permanent.

Discharge measurements.—By wading at low stages and from cable during high stages.

Winter flow.—Discharge relation affected by ice.

Diversions.—Considerable water taken from the stream above this point.

Accuracy.—Estimates of discharge for 1912 and 1913 good; those for earlier years fair.

Monthly discharge of Animas River at Farmington, N. Mex., for the years ending Sept. 30, 1904–5, 1913–14.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1904.					
June 20–30	885	332	588	12,800	
July	430	4	112	6,890	
August	1,220	437	687	42,200	
September	1,180	144	414	24,600	
The period					
1904–5.					
October	4,170	462	1,300	80,000	
November	438	160	245	14,600	
December	229	127	158	9,720	
January	239	135	176	10,800	
February	358	95	186	10,300	
March	988	402	695	42,700	
April	2,670	595	1,340	79,600	
May	7,470	1,670	3,960	244,000	
June	11,200	4,270	7,660	456,000	
July	3,900	669	1,450	89,000	
August	1,570	119	534	32,800	
September	2,260	83	275	16,400	
The year	11,200	95	1,500	1,090,000	
1912–13.					
October	534	276	386	23,700	A.
November	445	316	363	21,600	A.
December	336	170	237	14,600	C.
January	451	183	311	19,100	C.
February	514	230	366	20,300	B.
March	718	238	293	18,000	A.
April	1,690	481	956	56,900	A.
May	3,940	900	2,380	146,000	A.
June	3,480	1,470	2,210	132,000	A.
July	1,240	388	711	43,700	A.
August	421	64	182	11,200	A.
September	1,470	294	623	37,100	A.
The year	3,940	64	752	544,000	
1913–14.					
October	2,300	366	653	40,200	A.
November	591	326	372	22,100	A.
December	410	204	302	18,600	C.
January	547	212	323	19,900	B.
February	804	242	368	20,400	A.
March	1,550	411	875	53,800	A.
April	1,870	768	1,410	83,900	A.
May	6.670	960	3,610	222,000	A.
June	9,040	2,560	4,990	297,000	A.
July	3,880	1,540	2,500	154,000	A.
August	1,490	268	606	37,300	A.
September	551	255	360	21,400	A.
The year	9,040	204	1,370	991,000	

LA PLATA RIVER NEAR LA PLATA, N. MEX.

Location.—In sec. 14, T. 31 N., R. 13 W., at highway bridge 16 miles northwest of Aztec, at Williams Ranch house, and 1 mile south of La Plata post office. No important tributary between the station and the mouth of the river, 15 miles below.

Records presented.—May 25, 1905, to December 31, 1910.

Drainage area.—Approximately 340 square miles.

Gage.—Chain gage.

Channel.—Extremely shifting.

Discharge measurements.—By wading.

Winter flow.—Thin ice frequently forms across the stream during the winter and thick ice forms along the shore.

Diversions.—Nearly all the normal flow of the river is diverted above the station during the irrigation season; a few small ditches take water below.

Accuracy.—Estimates poor.

Monthly discharge of La Plata River near La Plata, N. Mex., for the years ending Sept. 30, 1905–1911.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1905.					
May 25–31	565	165	337	4,680	C.
June	817	95	358	21,300	C.
July	107		7.8	480	D.
August	0	0	.0	0	
September	970		64.0	3,810	D.
The period				30,300	
1905–6.					
October	800		79.7	4,900	D.
November	8		1.2	71	D.
December	5	4	4.2	258	D.
January			[a] 10.0	615	D.
February			[a] 5.0	278	D.
March	190		[a] 29.5	1,810	C.
April	368	44	160	9,520	B.
May	450	74	238	14,600	B.
June	320	2	154	9,160	C.
July	182		[a] 9.3	572	D.
August			[a] 2.0	123	D.
September 1–24			[a] 2.0	95	D.
The period				42,000	
1907.					
June 7–30	260	46	139	6,620	C.
July	750	.5	45.7	2,810	C.
August	1,280	.5	123	7,560	C.
September	246	1.0	38.7	2,300	C.
The period				19,300	
1907–8.					
October			[a] 0.5	31	D.
November			[a] .5	30	D.
December			[a] .6	37	D.
January			[a] .6	37	D.
February	600	0.5	49.7	2,860	C.
March	106	.5	27.1	1,670	B.
April	85	.9	22.1	1,320	B.
May	12.4		3.17	195	C.
June	1.5		.14	8	
July	247		12.9	793	D.
August	2,300		154	9,470	D.
The period				16,500	
1908–9.					
December	5.5		1.33	82	B.
January	27	0.9	5.35	329	B.
February	27	.9	6.38	354	
March	890	52	158	9,720	
April	970	67	278	16,500	B.
May	570	85	222	13,600	A.
June	498	7	161	9,580	A.
July	6	.5	1.53	94	D.
August	920	.5	93.7	5,760	C.
September	5,000	23	336	20,000	C.
The period				76,000	

[a] Estimated.

Monthly discharge of La Plata River near La Plata, N. Mex., for the years ending Sept. 30, 1905–1911—Continued.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1909–10.					
October	23	3	9.6	590	C.
November	3		1.36	81	
December	2.5	.1	.49	30	
January	18	4.5	11.4	701	C.
February	331	10.2	47.5	2,640	B.
March	495	73	202	12,400	B.
April	331	66	138	8,210	C.
May	138	.5	39.1	2,400	C.
June	58	.3	3.46	206	C.
July	1.5	1.0	1.08	66	D.
August	7,000	.1	258	15,900	D.
September	670	.1	23.5	1,400	D.
The year	7,000		61.3	44,600	
1910.					
October	570	0.5	23.8	1,460	D.
November	3	1.0	1.27	76	D.
December	2	.5	.90	55	

MANCOS RIVER AT MANCOS, COLO.

Location.—100 feet below wagon bridge in center of town of Mancos.

Records presented.—March 1, 1898, to November 30, 1899.

Drainage area.—Not measured.

Gage.—Vertical staff.

Channel.—Gravel and bowlders; shifting.

Discharge measurements.—Made from bridge or by wading.

Diversions.—Numerous diversions for irrigation above the station.

Accuracy.—Estimates only fair.

Monthly discharge of Mancos River at Mancos, Colo., for 1898–99.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1898.				
March			[a] 50	3,070
April			[a] 261	15,500
May	270	144	206	12,700
June	291	144	213	12,700
July	333	2	104	6,400
August	12	8	9	553
September	12	3	6.7	399
October			[a] 5	307
November			[a] 3	179
The period				51,800
1899.				
March			[a] 90	5,530
April	91		[a] 42	2,500
May	144	19	74	4,550
June	81	5	33	1,960
July	19	3	9	533
August	102	8	41	2,520
September	123	5	33	1,960
October	60	1	22	1,350
November			[a] 5	298
The period				21,200

[a] Estimated.

WEST MANCOS RIVER NEAR MANCOS, COLO.

Location.—About sec. 14, T. 36 N., R. 13 W., at Crane's ranch, 4 miles above Mancos.
Records presented.—September 18, 1910, to September 30, 1911.
Drainage area.—46 square miles (State engineer's report).
Gage.—Vertical staff.
Channel.—Shifting.
Discharge measurements.—Made by wading.
Cooperation.—Station maintained and records furnished complete for publication by the State engineer.

Monthly discharge of West Mancos River near Mancos, Colo., for 1910–11.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1910.				
September 18–30	8.7	8.7	8.7	224
October	27.4	8.7	12.4	762
November	14.7	10.2	11.2	666
December 1–23	10.2	8.7	9.08	414
The period				2,070
1911.				
April	169	48	93	5,540
May	253	143	192	11,800
June	225	86	161	9,570
July	252	77	113	6,940
August	96	24	36	2,210
September	114	9	14	842
The period				36,900

LITTLE COLORADO RIVER AT HOLBROOK, ARIZ

Location.—At county bridge at Holbrook.
Records presented.—March 17, 1905, to April 30, 1907.
Drainage area.—17,600 miles.
Gage.—Vertical staff fastened to bridge pier.
Channel.—Sandy and very shifting.
Discharge measurements.—Made from bridge.
Diversions.—Diversions for irrigation both above and below the station.
Accuracy.—Estimates good; based on numerous discharge measurements.

Monthly discharge of Little Colorado River at Holbrook, Ariz., for the years ending Sept. 30, 1905–1907.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1905.				
March 17–31	1,190	718	863	25,700
April	2,080	504	915	54,400
June	145	44	82.6	4,920
July	488	5	67.9	4,180
August	1,200	33	163	10,000
September	1,760	15	302	18,000
1905–6.				
October	220	19	50.7	3,120
November	20,200	30	1,160	69,000
December	325	45	113	6,950
January	1,330	165	452	27,800
February	325	73	170	9,440
March	3,540	66	621	38,200

Monthly discharge of Little Colorado River at Holbrook, Ariz., for the years ending Sept. 30, 1905–1907—Continued.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1905–6.				
April	987	100	245	14,600
May	150	5	54.0	3,320
June	5	3	4.1	244
July	140	3	24.9	1,530
August	275	15	71.5	4,400
September	600	4	68.7	4,090
The year	20,200	3	253	183,000
1906–7.				
October	250	5	26.6	1,640
November	63	4	11.3	672
December	890	25	181	11,100
January	1,000	90	276	17,000
February	380	73	176	9,780
March	2,100	115	444	27,300
April	573	290	401	23,900
The period				91,400

VIRGIN RIVER AT VIRGIN, UTAH.

Location.—In sec. 23, T. 41 S., R. 12 W., half a mile east of Virgin, 600 feet below the mouth of North Creek.
Records presented.—April 18, 1909, to September 30, 1914.
Drainage area.—1,010 square miles.
Gage.—Inclined staff.
Channel.—Gravel, sand, and bowlders; shifts during heavy floods.
Discharge measurements.—Made from cable and car and by wading.
Floods.—Virgin River is subject to occasional short but severe floods.
Winter flow.—Some ice occasionally forms at this station during the winter months.
Diversions.—Several small canals divert water above the station.
Accuracy.—Records fair for discharges below 1,000 second-feet.

Monthly discharge of Virgin River at Virgin, Utah, for the years ending Sept. 30, 1909–1914.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1909.					
April 18–30	2,580	675	1,330	34,300	C.
May	1,550	440	819	50,400	C.
June	440	78	314	18,700	B.
July	550	24	128	7,870	B.
August 1–7	101	40	67.3	934	B.
The period				112,000	
1909–10.					
October 13–31	321	131	182	6,860	B.
November	418	158	233	13,900	B.
December	1,930	118	226	13,900	C.
January	2,770	144	286	17,600	C.
February	300	144	226	12,600	C.
March	2,410	445	822	50,500	C.
April			a 620	36,900	D.
May	755	160	332	20,400	C.
June	155	80	108	6,430	C.
July	127	84	100	6,150	B.
August	875	98	247	15,200	B.
September	1,510	127	317	18,900	C.
The period				219,000	

a Estimated.

Monthly discharge of Virgin River at Virgin, Utah, for the years ending Sept. 30, 1909–1914—Continued.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1910–11.					
October	1,020	60	163	10,000	C.
November	274	70	108	6,430	C.
December	274	100	147	9,040	C.
January	9,050	72	791	48,600	C.
February	....	226	278	15,400	B.
March	6,350	226	766	47,100	B.
April	1,330	356	938	55,800	B.
May	1,280	327	746	45,900	B.
June	316	160	226	13,400	B.
July	9,500	134	484	29,800	B.
August	170	120	131	8,060	B.
September	10,600	126	504	30,000	C.
The year	10,600	60	440	320,000	
1911–12.					
October	420	136	189	11,600	C.
November	144	122	138	8,210	C.
December	152	129	144	8,850	C.
January	128	118	121	7,440	B.
February	134	113	124	7,130	B.
March	198	113	140	8,610	B.
April	318	148	191	11,400	B.
May	1,320	209	434	26,700	B.
June	233	108	162	9,640	B.
July	5,100	104	279	17,200	C.
August	2,200	113	190	11,700	B.
September	156	104	134	7,970	B.
The year	5,100	104	187	136,000	
1912–13.					
October	8,100	134	493	30,300	C.
November	182	150	165	9,820	B.
December	171	121	143	8,790	B.
January	171	110	143	8,790	B.
February	193	130	153	8,500	B.
March	690	140	226	13,900	B.
April	880	200	401	23,900	B.
May	330	171	216	13,300	B.
June	171	140	151	8,990	B.
July	610	86	146	8,980	B.
August	2,940	84	207	12,700	B.
September	500	117	164	9,760	B.
The year	8,100	84	217	158,000	
1913–14.					
October	155	126	141	8,670	B.
November	500	126	188	11,200	B.
December	198	155	169	10,400	B.
January	920	144	280	17,200	B.
February	1,500	144	287	15,900	B.
March	510	166	315	19,400	B.
April	1,340	396	809	48,100	B.
May	870	290	651	40,000	B.
June	690	82	247	14,700	C.
July	2,500	87	279	17,200	C.
August	510	86	115	7,070	C.
September	116	90	104	6,190	C.
The year	2,500	82	298	216,000	

SANTA CLARA CREEK NEAR ST. GEORGE, UTAH.

Location.—In sec. 27, T. 42 S., R. 16 W., about 2 miles west of St. George and miles above mouth of creek.

Records presented.—April 16, 1909, to January 31, 1913.

Drainage area.—540 square miles.

Gage.—Inclined staff.

Channel.—Shifting.

Discharge measurements.—Made from cable and car or by wading.

Winter flow.—Ice affects relation of gage height to discharge at times during the winter months.

Diversions.—The Bloomington and Seep canals divert water from Santa Clara Creek below the station; except for these canals the records indicate the amount of unappropriated water flowing from Santa Clara Creek into Virgin River.

Accuracy.—Records poor, owing to shifting stream bed, lack of discharge measurements, and proper gage readings.

Monthly discharge of Santa Clara Creek near St. George, Utah, for the years ending Sept. 30, 1909–1913.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1909.					
April 16–30	179	50	89.8	2,670	B.
May	115	42	72.4	4,450	A.
June	59	....	a18.5	1,100	B.
July	....	....	a.5	31	C.
August	....	....	a.5	31	C.
The period	....	....	....	8,280	
1909–10.					
October	43	2	16.1	990	B.
November	43	0	16.5	982	B.
December	153	17	30.5	1,880	B.
January 21–31	40	32	37.7	823	B.
February	36	18	25.7	1,430	B.
March	107	22	76.2	4,690	C.
April	108	49	63.2	3,760	A.
May	102	8	50.9	3,130	A.
June	15	6	8.73	519	A.
July	40	4	8.48	521	A.
August	43	4.5	10.3	633	B.
September	200	4.5	19.4	1,150	B.
1910–11.					
October	39	5	15.6	959	B.
November	27	12	20.0	1,190	B.
December	24	18	21.4	1,320	B.
January	280	7	38.1	2,340	C.
February	....	....	60.0	3,330	D.
March	....	....	59.5	3,660	C.
April	95	57	76.2	4,530	C.
May	95	7	63.0	3,870	C.
June	14	4	7.6	452	D.
July	12	2	5.5	338	D.
August	5	1.0	2.55	157	C.
September	490	2.5	22.3	1,330	D.
The year	490	....	32.6	23,500	
1911–12.					
October	138	25	83.2	5,120	D.
November	35	13	19.2	1,140	C.
December	51	10	25.3	1,560	C.
January	46	8	21.4	1,320	C.
February	16	10	13.4	771	C.
March	68	13	35.6	2,190	C.
April	160	35	73.2	4,360	D.
May	117	46	78.3	4,810	D.
June	85	4	25.9	1,540	D.
July	223	2.5	21.7	1,330	D.
August	34	2.5	11.5	707	D.
September	9	2.5	3.98	237	D.
The year	223	2.5	34.4	25,100	
1912–13.					
October	155	20	52.0	3,200	D.
November	46	30	38.9	2,310	C.
December	39	35	36.0	2,210	B.
January	90	25	31.	1,910	D.
The period	....	....	....	9,630	

a Estimated.

WILLIAMS RIVER NEAR SWANSEA, ARIZ.

Location.—In the canyon, 1 mile below Planet mine, 9 miles northwest of Swansea, and 28 miles north of Bouse.

Records presented.—January 1, 1913, to September 30, 1914.

Drainage area.—Not measured.

Gage.—Staff in four sections. The two low-water sections are on right bank a short distance above cable. Upper sections are bolted to cliffs on left bank just above cable.

Channel.—Shifting sand.

Diversions.—A ranch diverts water for irrigating a few acres about 1 mile above the station. Desert claims of about 500 acres 20 miles above the station have been partly irrigated, principally from flood waters. Other small ranches above the station pump water from the river sands.

Discharge measurements.—Made from car and cable near gage or by wading.

Accuracy.—Monthly estimates only approximate, owing to shifting of the channel and lack of high-water measurements. Low-water flow controlled by springs above the station.

Monthly discharge of Williams River near Swansea, Ariz., for the years ending Sept. 30, 1913–14.

Month.	Mean discharge in second-feet.	Run-off (total in acre-feet).
1913.		
January	17.5	1,080
February	93.5	5,190
March	205	12,600
April	26.5	1,580
May	19.5	1,200
June	17.5	1,040
July	21.5	1,320
August	16.5	1,010
September	22.5	1,340
The period		26,400
1913–14.		
October	17.5	1,080
November	16	952
December	16	984
January	199	12,200
February	908	50,400
March	59.5	3,660
April	26.0	1,550
May	23.6	1,450
June	25.3	1,510
July	24	1,480
August	24	1,480
September	23	1,370
The year	108	78,100

GILA RIVER AT DOME, ARIZ.

Location.—One mile north of depot at Dome, 20 miles above the junction with Colorado River.

Records presented.—January 1, 1904, to December 31, 1906.

Drainage area.—Not measured.

Gage.—Various staff gages have been used.

Channel.—Sand; extremely shifting.

Discharge measurements.—Made from a boat or by means of floats.

Diversions.—Large number of diversions for irrigation above the station.

Accuracy.—Estimates poor, owing to the extreme shifting of the channel.

Monthly discharge of Gila River at Dome, Ariz., for the years ending Sept. 30, 1904–1907.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1904.				
January	....	....	0	0
February	....	....	0	0
March	....	....	0	0
April	....	....	0	0
May	....	....	0	0
June	....	....	0	0
July	1,650	0	94.2	5,790
August	4,560	940	2,270	140,000
September	2,490	50	700	41,700
The period	....	....	....	187,000
1904–5.				
October	2,670	10	534	32,800
November	260	0	109	6,490
December	0	0	0	0
January	26,000	0	3,080	189,000
February	82,000	0	12,200	680,000
March	95,000	300	16,600	1,020,000
April	64,000	5,150	12,900	768,000
May	9,500	2,150	4,870	300,000
June	1,850	300	725	43,100
July	280	0	70.6	4,340
August	0	0	0	0
September	390	0	49.7	2,960
The year	95,000	0	4,260	3,050,000
1905–6.				
October	940	0	179	11,000
November	95,000	0	4,560	271,000
December	30,700	3,300	6,100	375,000
January	6,640	1,470	2,220	136,000
February	11,800	1,720	3,020	168,000
March	54,600	1,600	9,370	576,000
April	16,800	4,560	7,100	422,000
May	4,400	420	1,990	122,000
June	380	0	77	4,580
July	0	0	0	0
August	2,000	0	408	25,100
September	550	0	72	4,280
The year	....	....	2,930	2,110,000
1906.				
October	0	0	0	0
November	0	0	0	0
December	29,000	0	5,400	332,000
The period	....	....	....	332,000

IRRIGATION.[1]

HISTORY OF DEVELOPMENT.

The raising of crops by the artificial application of water to the land was first practiced in the Colorado River basin by ancient peoples at a date that has not been definitely fixed. Unmistakable remnants of ditches and reservoirs are, however, found in the basins of the Gila and Little Colorado in Arizona, together with ruins of cliff dwellers and the communal houses of tribes that had been scattered long before the advent of the Spanish explorers in the sixteenth century. The character of these remains indicates that these ancient inhabi-

[1] In this section totals are given in round numbers.

tants of the region possessed considerable skill in the art of irrigating. Their ditches and reservoirs were finished with hard linings of tamped or burnt clay, and one of the main canals known was cut for a considerable distance through solid rock. In places a smaller ditch was sunk in the bottom of a large canal to facilitate the carriage of small runs of water and thus diminish seepage and evaporation in times of scant flow.

The ancient canals in Salt River valley, Ariz., are at least 150 miles in aggregate length, and were sufficient to serve 250,000 acres of land, but it is not likely that the whole of this area was ever watered at any one time. In the ruins of the houses of grouted clay are found relics of cotton and corn, and it is known that beans, squash, and tobacco were also grown.[1]

The first European irrigators in Arizona were, without doubt, the Jesuits, who established themselves at the old missions of Cuevavi and San Xavier in 1732. Not until the most prosperous period, however, from about 1768 to 1822, was there any considerable development of irrigation at favorable points along Santa Cruz River, near the missions and Spanish presidios of Tubac and Tucson. During the chaotic period of Mexican rule which followed, acequias were maintained, orchards were planted, and annual crops of barley, wheat, corn, tobacco, beans, melons, squashes, and peppers were cultivated. Although the headworks and canals of this period were small and of the simplest construction, the Mexicans were skillful in the management of water and possessed an agricultural aptitude well expressed in their phrase "La mano por sembrar"—the planting hand. They also adopted certain ideas in equity and customs relating to the distribution and use of water which are approved in the best irrigation practice of the present time. Among these was the rule that water is appurtenant to the land. The Americans in Arizona received their first instruction in irrigation from the Mexicans.

The third or modern stage of agricultural development may be said to date from the Gadsden purchase in 1854, after which increasing numbers of Americans—military followers, stragglers from the immigrant stream to California, and pioneers by instinct—began to make permanent homes in the land.[2]

In the Colorado River basin in Wyoming, Utah, and Colorado the first modern irrigation works date back to the fifties. In this early stage of irrigation only bottom lands were reclaimed and the works were simple. In the early nineties irrigation in many parts of the basin had reached a stage where the need for storage reservoirs began

[1] Hodge, F. W., Prehistoric irrigation in Arizona: Am. Anthropologist, July, 1893. Forbes, R. H., Univ. Arizona Agr. Exper. Sta. Bull. 63, 1911.

[2] Forbes, R. H., Univ. Arizona Agr. Exper. Sta. Bull. 63, 1911.

to be recognized. After the passage of the reclamation act by the Federal Government in 1902, the Reclamation Service began investigations to determine the feasibility of constructing large irrigation works in the Western States. As a result of these investigations construction was begun on the following projects affecting the Colorado River basin:

Government irrigation projects affecting Colorado River basin.

Project.	Source of water.	Irrigable area.
		Acres.
Uncompahgre	Gunnison River, Colo	140,000
Grand Valley	Grand River, Colo	53,000
Salt River	Salt River, Ariz	182,000
Yuma	Colorado River, Ariz	158,000
Strawberry Valley [a]	Strawberry and Spanish Fork rivers, Utah.	50,000

[a] The lands to be irrigated under the Strawberry Valley project are in the Salt Lake basin, but a large part of the water is taken from the headwaters of Strawberry River in the Colorado River basin.

With the beginning of construction on Government projects interest in the development of irrigation by private capital was renewed, and during the period 1903 to 1909 many irrigation systems were planned, most of them under the Federal law known as the Carey Act and under the various State irrigation-district laws. Among the important irrigation works which affect the Colorado River basin and which are now under construction or proposed is that of the California Development Co.[1] Through the activities of this strictly private corporation more than 300,000 acres of land in Imperial Valley, Cal., and in the Republic of Mexico are being irrigated, and more than 500,000 acres are covered by the canal system.

Up to 1902 irrigation in the Colorado River basin was carried on at first by the individual farmer and later by communities of farmers who united to construct one ditch to cover lands that would otherwise have required several ditches. Still later came the organization of local water companies and the construction of large canal systems. The rapid progress made after 1902 should, no doubt, be credited to the activities of the Federal Government and private corporations.

Few if any of the irrigation projects in the Colorado River basin do not involve storage, and all the larger projects will require a large amount of storage to insure a permanent water supply. Indeed the irrigated area in the Colorado River basin can not be greatly increased without storing the flood waters of the rivers for use in times of deficient flow.

[1] See Cory, H. T., Irrigation and river control in the Colorado River delta: Am. Soc. Civil Eng. Trans., vol. 76, pp. 1204-1453, December, 1913.

PRESENT AND PROSPECTIVE IRRIGATION SYSTEMS.

BASINS BELOW GRAND RIVER.

GILA RIVER BASIN.

Gila River drains the greater part of the southern half of Arizona, a part of New Mexico, and the State of Sonora in the Republic of Mexico. The total area comprised within the boundaries of the basin is approximately 56,500 square miles. Of this area approximately 283,000 acres were irrigated during 1913.

The following table shows the situation and extent of lands irrigated in the basin during 1913:

Area irrigated in Gila River basin, 1913.

	Acres.
New Mexico	10,000
Salt River Valley	170,000
Utah and Tempe canal systems	30,000
Buckeye and Arlington districts	16,000
Gila Valley from monument to San Carlos	13,000
Gila Valley, San Carlos to San Jose	21,000
Gila Valley, San Jose to New Mexico line	2,700
San Francisco, Blue, Eagle, and Pinal creeks	820
San Pedro Valley	5,800
Santa Cruz basin	6,000
Upper Verde Valley	8,000
	283,320

Wonderful progress has been made in irrigation in the Gila basin during the last few years, but it is difficult to estimate the area of lands irrigable in the future. A conservative estimate, however, places it at 150,000 acres.

The Gila is subject to sudden and violent floods, its flow is irregular, and the range in variation from the annual mean discharge is high. In 1903 approximately 60,000 acre-feet were contributed by the Gila to Colorado River, whereas in 1905 the discharge into the Colorado was about 3,700,000 acre-feet. On account of this great variation in flow of the river and its tributaries, further development of irrigation will necessitate storage. The aggregate capacity of possible storage sites in the Gila basin, as shown by the following table, is approximately 4,000,000 acre-feet. Some of these sites are being utilized; others are doubtless commercially unfeasible owing to the great depth to suitable foundation, to the presence of transcontinental railroads, patented mining claims, and other private properties the cost of which, if damaged, must be charged against the storage project. A large number, however, appear to be commercially feasible. It would not be necessary to utilize all these storage sites to control the flow of Gila River and its tributaries.

Storage reservoir sites in the Gila basin.

Name.	Stream.	Location.	Height of dam.	Capacity.
			Feet.	*Acre-feet.*
Redrock	Gila River	Above Duncan, N. Mex	100	80,000
Alma	San Francisco River	Near Alma, N. Mex		135,000
Dix Creek	do	22 miles north of Clifton, Ariz	110	12,000
Guthrie	Gila River	Near Guthrie, Ariz	140	256,000
San Carlos	do	Near San Carlos, Ariz	130	241,000
Riverside	do	Near Riverside, Ariz	153	344,000
Buttes	do	Near Florence, Ariz	150	174,000
Queens	Queens Creek	do	130	51,000
Two Forks	Gila River	New Mexico	150	82,400
Walnut Grove	Hassayampa River	Near source	135	60,000
Agua Fria	Agua Fria River	Near head	150	150,000
Frog Tanks	do	do	100	50,000
Cave Creek	Cave Creek	Near source	100	100,000
New River	New River			133,000
Horseshoe	Verde River		150	205,000
McDowell	do	Near mouth	210	280,000
Roosevelt	Salt River	Mouth of Tonto Creek	284	1,280,000
Santa Cruz	Santa Cruz River	Santa Cruz basin	45	295,000
San Pedro	San Pedro River		120	120,000
				4,048,400

The complete control of the Gila for irrigation will require reservoirs capable of storing water to augment the flow during periods of low run-off extending over two or three years. If such control is accomplished in the interest of irrigation in the valleys of the Gila and its tributaries the river will contribute little water to the Colorado except during years of abnormally high run-off. As a source of water for increased irrigation on the lower Colorado the Gila should therefore be considered uncertain.

The possibility of reclaiming lands in the Gila basin by use of ground waters has also been established, but no close estimate can be made of the area reclaimable in this manner.

WILLIAMS RIVER BASIN.

Williams River, which enters the Colorado at Aubrey Landing, drains an area that lies chiefly in Mohave County, Ariz., and comprises approximately 5,400 square miles. The river is subject to large daily, monthly, and annual variations in flow and does not furnish a dependable supply of water for irrigation. A record showing the daily discharge of the stream for the year 1913 was obtained near Swansea, Ariz., about a mile below the Planet mine. The minimum flow during the year was 1 second-foot, the maximum 477 second-feet, and the mean 34.9 second-feet, the total run-off for the year being 25,300 acre-feet. In 1913 the irrigated tracts in this basin comprised only about 600 acres of land.

By constructing storage reservoirs it might be possible to reclaim 5,000 acres of additional lands. About 5 miles below the confluence of Big Sandy and Santa Maria creeks, the principal tributaries, there is a dam site at which a reservoir having a storage capacity of approximately 80,000 acre-feet could be created by a dam 110 feet high, 250 feet long on top, and 70 feet long on the bottom. There are also reservoir sites on both Santa Maria and Big Sandy creeks. The aggregate storage capacity of these reservoir sites is apparently sufficient to store the entire run-off from the Williams River basin. The cost of storage would, however, probably be greater than would be justified by the small area of reclaimable land, and it seems unlikely that more than 2,000 acres of additional land will ultimately be reclaimed in the Williams River basin.

If storage dams controlling the run-off of the river for irrigation in its basin were constructed the contribution of the Williams to the Colorado would be exceedingly small.

KANAB CREEK BASIN.

Irrigation has been practiced in the basin of Kanab Creek since 1870, and all the low-water flow of the creek has been used for irrigation for many years. About 2,000 acres were being irrigated in this basin in 1913—1,500 acres in Utah and 500 acres in Arizona. It seems probable that 1,500 acres of new land may be irrigated from Kanab Creek if the flood waters are stored. The capacity of available reservoir sites is sufficient to control the entire run-off.

PARIA RIVER BASIN.

Irrigation has been practiced in the basin of Paria River for more than 40 years, but it is estimated that in 1913 only about 2,000 acres were under irrigation, all the irrigated land being in Utah near the headwaters of the stream.

No records are available to show the run-off from the basin, but a probable run-off of 50,000 or 60,000 acre-feet has been estimated by measuring the drainage area above the reservoir site near Pahreah and assuming that the run-off per square mile would be practically the same as the run-off from the drainage area above the gaging station on Escalante River, which drains the area immediately north of the basin of the Paria.

The area that may be placed under irrigation by future development is difficult to estimate. It seems probable, however, that by utilizing storage reservoirs the Paria may furnish sufficient water to reclaim approximately 10,000 acres of additional land. Private parties interested in an irrigation project on the stream propose to reclaim approximately 25,000 acres of land on the lower Paria near the Utah-Arizona line by constructing near Pahreah a dam 125 feet high which would form a reservoir having a storage capacity of 126,000 acre-feet.

In 1892 the Tropic & East Fork Irrigation Co. completed a canal to divert water from the East Fork of Sevier River across the rim of the Great Basin to lands in the Paria basin near the settlement of Tropic. This canal is about 4 miles long and is said to have a capacity of 8 or 10 second-feet.

Irrigation will grow slowly in the basin of the Paria on account of its isolated position, but the flood waters may ultimately be stored for use in irrigation.

VIRGIN RIVER BASIN.

Although the basin of the Virgin comprises approximately 11,000 square miles, the areas available for agriculture are comparatively small. The more important irrigated areas are in the vicinity of St. George, Utah, and on Muddy River between Moapa and St. Thomas, Nev.

The low-water flow of the Virgin and its tributaries is practically all used for irrigation. Some small storage reservoirs have been constructed to augment the low-water flow. The principal storage site in the Virgin basin now utilized is in Pine Valley, where the New Castle Reclamation Co. has built a dam creating a reservoir that will store 23,000 acre-feet of water for diversion through the rim of the Great Basin to irrigate lands outside the Colorado River basin.

Incomplete records are available showing the run-off from the Virgin and its tributaries at various points for the period 1904 to date, but no records have been obtained showing the flow of the Virgin below the mouth of its principal tributary, Muddy River.

Approximately 20,000 acres of land were irrigated in the Virgin River basin in 1913. A number of projects are under construction, but it seems improbable that more than 48,000 acres of additional land will be placed under cultivation even if the flood waters are completely controlled by means of storage reservoirs.

If irrigation systems now proposed are completed the flow of the Virgin and its tributaries during years of normal run-off will be completely controlled and little water will reach the Colorado. The occasional violent floods will, however, continue to reach the Colorado. Three such floods have occurred within recent years in the basin of Muddy River, causing enormous damage to the San Pedro, Los Angeles & Salt Lake Railroad in the Meadow Valley Wash. Five days' steady rain during February, 1914, caused a flood in this wash which reached a maximum discharge of about 6,000 second-feet at a point on Muddy River near St. Thomas, Nev. The peak discharge of this flood in Meadow Valley Wash was doubtless 7,000 or 8,000 second-feet. The flood lasted less than 24 hours and it is likely that not more than 7,000 acre-feet was discharged into the Colorado as a result of this particular storm. The unusual storms that take place at intervals of two or three years probably do not contribute more than 40,000 acre-feet to the Colorado during any one year.

LITTLE COLORADO RIVER BASIN.

The average annual run-off from the 25,900 square miles drained by the Little Colorado, as indicated by records for 1905 to 1907, inclusive, is less than 200,000 acre-feet, and the maximum probably does not greatly exceed 300,000. Storms of short duration are frequent and the run-off is irregular. It is evident that the flood waters must be stored if any large part of the run-off is to be used for irrigation. The available records show that the annual rainfall ranges from 8 to 20 inches and indicate that during periods of six or seven years the flow of the river was barely sufficient to satisfy the then-existing demands of irrigation. Lands along the Little Colorado and its tributaries were taken up by settlers about 40 years ago, and in 1913 approximately 20,000 acres were irrigated in the basin. In recent years several small storage reservoirs have been utilized.

A record showing the discharge of the Little Colorado at Holbrook, Ariz., below the confluence of Silver Creek and Rio Puerco from March 17, 1905, to April 30, 1907, shows approximately the water available for the irrigation of additional lands if storage reservoirs are utilized.

Run-off of Little Colorado River at Holbrook, Ariz.

	Acre-feet.
1905 (Mar. 17 to Dec. 31)	213,700
1906	117,000
1907 (Jan. 1 to Apr. 30)	77,980

The table indicates that a dependable supply of 200,000 acre-feet annually might be obtained by storage, but old settlers in the basin report droughts extending over periods of six or seven years. Losses by evaporation from the reservoirs would be high. Consideration of these losses and those in the main canal and distributing system leads to the conclusion that sufficient water might be made available by storage to irrigate not more than 30,000 acres. That the basin contains more than 100,000 acres of good agricultural land which could be reached by canals from the Little Colorado at a reasonable cost has been shown by the United States Reclamation Service.[1]

The existence of reservoir sites whose aggregate capacity is greatly in excess of the annual run-off is shown by the following table:

[1] Third Ann. Rept., 1903-4, p. 174, 1905.

Reservoir sites in the Little Colorado basin.

Name.	Height of dam.	Location of dam.			Capacity.
		Section.	Township.	Range.	
	Feet.				*Acre-feet.*
Woodruff	100	36	17 N.	21 E.	108,000
Forks	85	19	16 N.	22 E.	148,000
Leroux	35	23	18 N.	20 E.	54,000
Tucker Flat	50	26	20 N.	15 E.	118,000
Greer	60	5	14 N.	25 E.	260,000
Zuni	60	2	14 N.	26 E.	107,000
Colorado	60	21	14 N.	27 E.	140,000
Lyman	65	9	11 N.	28 E.	40,000
Baum	82	9	23 N.	12 E.	437,000
					1,412,000

It seems probable that some of these reservoir sites will be found commercially feasible of development.

SAN JUAN RIVER BASIN.

In the area drained by the San Juan, comprising approximately 25,800 square miles, irrigation has been practiced for more than 40 years, and on many of the tributaries the low-water flow is not sufficient to meet present needs. Only a small quantity of stored water is, however, being utilized. The area irrigated in the San Juan basin in 1913, consisting largely of bottom lands, is shown by the following table:

Land irrigated in San Juan River basin in 1913.

Stream.	State.	Area irrigated.
		Acres.
Navajo River Little Colorado River San Juan River Rio Piedro	Colorado	12,000
Los Pinos River	do	17,000
Florida River	do	6,000
Animas River	do	7,000
La Plata River	do	5,000
Mancos River	do	10,000
McElmo Creek[a]	do	20,000
San Juan and its tributaries	New Mexico	30,000
Do	Utah	10,000
		117,000

[a] Water obtained from Dolores River. See U. S. Geol. Survey Twentieth Ann. Rept., pt. 4, p. 417, 1900.

Trustworthy records of the quantity of water discharged by the San Juan into the Colorado are not available, but incomplete records obtained at gaging stations established on the San Juan near Farmington and Shiprock, N. Mex., indicate that the stream may contribute to the Colorado between 1,500,000 and 3,000,000 acre-feet annually.[1] Evidently there is sufficient unappropriated water in the

[1] In October, 1914, a station was established on the San Juan at Bluff, Utah, below all diversions for irrigation. Records from this station may be expected to furnish information of more definite value.

San Juan and its tributaries to reclaim large tracts of new lands, but to increase the present irrigated area storage reservoirs must be utilized. The most important irrigation projects in the basin, any of which may, of course, prove unfeasible, are listed below:

Irrigation projects in San Juan basin.

	Acres.		Acres.
Turley	1,225,000	Eden canal	30,000
La Plata	50,000	Turley ditch	23,500
Citizens ditch	10,000		
Illinois ditch	13,000		1,361,500
Coolidge ditch	10,000		

Under the Turley project it is planned to construct a storage dam on San Juan River, approximately in sec. 1, T. 29 N., R. 9 W., New Mexico principal meridian. The storage capacity of the reservoir that would be created by a 200-foot dam at this point is given as 1,640,000 acre-feet. The lands to be irrigated comprise 1,225,000 acres on the south side of the San Juan in San Juan County, N. Mex.

The La Plata project[1] of the United States Reclamation Service, now abandoned, was planned to serve an area of approximately 50,000 acres of land north of San Juan River in San Juan County, N. Mex., the greater part of the land to be irrigated bordering La Plata River, a tributary of the San Juan. Water for this project was to have been obtained mainly from Animas River and its tributaries and possibly also from Los Pinos River in Colorado. Water diverted from Animas River in Colorado, 3 miles above Durango, was to be conveyed to land in and along La Plata Valley by means of canals aggregating in length approximately 100 miles (including distributing canals) and a tunnel 2 miles long through the high ridge between Animas and La Plata rivers. Storage reservoirs would have been necessary to maintain a dependable supply during periods of low water. This project may be completed by private capital.

Under the Citizens ditch project it is planned to reclaim approximately 10,000 acres of land lying north of San Juan River in San Juan County, N. Mex. The water is to be taken from San Juan River, the proposed point of diversion being in sec. 4, T. 29 N., R. 9 W.

Under the Illinois ditch project it is proposed to reclaim approximately 13,000 acres of land in the Animas Valley north of Animas River and northeast of Farmington, N. Mex. The water is to be taken from Animas River.

Under the Coolidge ditch project it is planned to reclaim 10,000 acres of land lying immediately north of San Juan River below the confluence of La Plata and San Juan rivers. Water is to be obtained from San Juan River, the proposed point of diversion being in sec. 17, T. 29 N., R. 13 W.

[1] U. S. Recl. Service Third Ann. Rept., 1903-4, p. 392, 1905.

Under the Eden canal project it is proposed to reclaim 30,000 acres of land lying south of Animas River in the vicinity of Aztec, N. Mex. The water is to be diverted from Animas River in sec. 10, T. 32 N., R. 10 W.

The Turley ditch project is planned to reclaim 23,500 acres of land lying immediately south of San Juan River, southeast of Farmington, N. Mex. The water is to be taken from San Juan River, the proposed point of diversion being in sec. 2, T. 29 N., R. 9 W.

The projects outlined in the foregoing paragraphs are intended to reclaim 1,361,500 acres. Probably several thousand acres included under these proposed canals are now irrigated from small ditches. The records of discharge of San Juan River and its tributaries indicate that the streams will not furnish sufficient water to reclaim all the land listed under the proposed schemes, and afford a basis for the following estimate of the additional areas that may be irrigated in the San Juan basin:

Additional areas that may be irrigated in San Juan basin.

	Acres.
Colorado	90,000
New Mexico	500,000
Utah	5,000
	595,000

More than 75 reservoir sites in the San Juan basin, ranging in capacity from 20 acre-feet to more than 2,500,000 acre-feet, have been investigated by Government and private engineers. Reservoirs at some of the smaller sites are already being utilized.

The Bluff reservoir site, on San Juan River near Bluff, Utah, was surveyed by engineers of the United States Reclamation Service in October, 1914. A dam raising the water level 214 feet would form a reservoir having a storage capacity of 1,600,000 acre-feet; one raising the water level 264 feet would make a reservoir having a capacity of 2,600,000 acre-feet. The entire run-off from the San Juan basin could be controlled at the Bluff reservoir site.

Although many plans have been made to utilize the water of the San Juan and its tributaries, it seems improbable that the entire run-off from this basin can be used for irrigation.

ESCALANTE RIVER BASIN.

In the basin of Escalante River, in south-central Utah, approximately 1,500 acres were irrigated in 1913, and it is estimated that water is available to irrigate approximately 12,000 acres of additional lands.

Only one reservoir site of appreciable size is known in the Escalante basin. At this site, which is near the town of Escalante in Garfield County, Utah, a dam 125 feet high would make a reservoir having a capacity of about 35,000 acre-feet. The utilization of this site is, however, remote, owing to the fact that lands suitable for irrigation lie south of the reservoir site and away from the river and could not be reached without expensive construction work. The average annual run-off available for storage in this reservoir site is about 40,000 acre-feet. A gaging station was maintained on Escalante Creek near Escalante, Utah, from 1909 to 1912, inclusive. The drainage area above this station is 315 square miles, whereas the total area of the basin is 1,780 square miles. The average annual run-off from this basin is probably about 75,000 acre-feet.

FREMONT RIVER BASIN.

Records showing the discharge of Fremont River near Thurber for the years 1909 to 1912, inclusive, indicate an average annual run-off of approximately 75,000 acre-feet from the 720 square miles of drainage area above the gaging station. Similarly, records of the discharge of Muddy River near Emery, Utah, indicate an average annual run-off of 40,000 acre-feet from a drainage area of 87 square miles. No records are available showing the total discharge of Fremont River into the Colorado, but the incomplete records obtained at Thurber and Emery indicate that the average annual discharge from the Fremont basin into the Colorado is about 200,000 acre-feet. Except during the floods practically the entire flow passing the gaging stations on Fremont River and Muddy Creek is used for irrigation.

There are no large bodies of land in this basin that can be reclaimed at a reasonable cost. It is probable, however, that numerous small areas will be reclaimed. Three small reservoirs, with an aggregate capacity of about 9,000 acre-feet, have been constructed in the Fremont basin to augment the low-water flow.

Reservoirs in Fremont River basin.

Name of reservoir.	Location.	Height of dam.	Capacity.
		Feet.	*Acre-feet.*
Johnson	Above Fish Lake	22	4,800
Fremont	Right Fork	70	3,41[illegible]
Grover	Fish Creek	8	....

Only one comparatively large reservoir site in this basin is not being utilized. At this site, which is known as the Thurber reservoir site and is situated on Fremont River near the town of Thurber in Wayne County, Utah, a dam 85 feet high would create a reservoir having storage capacity of 136,000 acre-feet. The elevation of the reservoir site is about 6,800 feet. The average annual run-off available for storage in the Thurber reservoir site is approximately 75,000 acre-feet. In 1913 about 15,000 acres were irrigated, and the present irrigation systems can doubtless be extended to cover more lands. The additional area that will be placed under cultivation in the Fremont basin has been estimated at 40,000 acres.

GRAND RIVER BASIN.

About 25,900 square miles of land, ranging in elevation from 3,900 to 14,000 feet above sea level, is drained by Grand River and its tributaries. Irrigation is practiced in the higher parts of the basin at elevations above 7,000 feet. The most important irrigated sections, however, in this basin are Uncompahgre Valley and Grand Valley. The average elevation of these irrigated areas is between 5,500 and 6,000 feet.

Near the headwaters of the Grand and its various tributaries—Fraser, Eagle, Williams, Roaring Fork, Gunnison, and Dolores rivers—considerable water is used to irrigate grasses grown for hay, and water is also diverted onto meadow lands used for pasture. Discharge measurements made during the irrigation season would probably show that some of the irrigators divert as much as 20 acre-feet per acre, but it is also probable that not more than half an acre-foot per acre is actually consumed, the remainder being returned to the stream by surface waste and seepage. On Grand River near Grand Junction, Colo., and on Gunnison and Uncompahgre rivers near Montrose and Delta, Colo., are a number of irrigation systems that have been in operation for many years. The Grand Valley project of the United States Reclamation Service will, when completed, serve 53,000 acres of land in the vicinity of Grand Junction, the water being obtained from Grand River. The Uncompahgre project of the Reclamation Service has finished structures capable of irrigating about 58,000 acres, and the completed project will serve approximately 140,000 acres of land. In the middle basin, from the lower end of Gore Canyon to about Rifle, 30,000 to 35,000 acres may be irrigated under half a dozen small projects now planned. Under other schemes 40,000 to 50,000 acres more may be irrigated.

By extending the high-line canal now being constructed by the Reclamation Service in connection with the Grand Valley project and by installing a pumping plant, it may be possible to reclaim 40,000 acres in Utah, but this development appears to be remote.

On the completion of the Uncompahgre and Grand Valley projects of the Reclamation Service and the projects in the Dolores basin, irrigation in the Grand River basin will be approaching its limit.

It has been difficult to obtain reliable information in regard to the areas irrigated on Grand River and its various tributaries in 1913; however, the least reliable estimates relate to irrigated acreage known to be small, and the total irrigated and irrigable area shown in the following table is reasonably accurate.

Area irrigated in Grand River basin in 1913 and additional area that may be irrigated.

Stream.	Area irrigated.	Additional area that may be irrigated.
	Acres.	*Acres.*
Grand River above Eagle River	14,000	16,000
Eagle River	5,000	1,000
Roaring Fork	20,000	5,000
Grand River and tributaries between Eagle River and Palisades, except Roaring Fork	40,000	10,000
Grand River between Palisades and Westwater	50,000	68,000
Grand River between Westwater and mouth	5,000	40,000
Gunnison River	144,000	115,000
Dolores River basin	24,000	220,000
	302,000	475,000

The largest and perhaps the most valuable reservoir site in the Grand River basin is that known as the Kremmling site, at the head of Gore Canyon, near the headwaters of Grand River. At this site a dam constructed to raise the water level 180 feet would form a reservoir having a capacity of 1,240,000 acre-feet; the reservoir formed by a dam raising the water level 230 feet would have a capacity of 2,200,000 acre-feet. The average annual run-off past the Kremmling reservoir site is a little more than 1,000,000 acre-feet. Although the floods on lower Grand River could be considerably reduced, the river could not be completely controlled by utilizing the Kremmling reservoir site because of the large area tributary to the river below the site. Unfortunately there are no other large storage sites in the Grand River basin where the available run-off is sufficient to make them valuable in connection with river control. A number of small reservoir sites near the headwaters of Gunnison River have been investigated by the Reclamation Service. One, known as the Taylor Park site, has been considered for future use to augment the water supply available for the Uncompahgre project. In October, 1914, two reservoir sites were surveyed by the Reclamation Service on Dolores River—one at the town of Bedrock, Colo., where a dam 235 feet high would create a reservoir having a storage capacity of 1,330,000 acre-feet, the other near the town of Dolores, Colo., where the reservoir formed by a dam 230 feet high would have a capacity of 315,000 acre-feet. The average annual run-off of the Dolores is about 300,000 acre-feet. A large part of the run-off of this stream will be stored in small reservoir sites near the headwaters if the projects in this region are completed.

Many of the hundreds of smaller sites in the Grand River basin will be used in connection with future development of irrigation. For example, the records in the State engineer's office at Denver, Colo., show that 261 reservoir sites, ranging in capacity from one-third of an acre-foot to 40,000 acre-feet, have been filed on in water

district No. 42, which comprises only a very small part of the Grand River basin, extending up the Grand as far as De Beque and including the basin of Plateau Creek, Gunnison River to a point about halfway between Grand Junction and Delta, and a part of the basin of the Little Dolores. The aggregate capacity of the sites is 235,000 acre-feet, and the average capacity is about 900 acre-feet. A number of them are now being utilized and many of the remaining sites may be put to use at some future time.

For many years gaging stations have been maintained on Grand River and its tributaries, the longest records being those obtained on Grand River at Palisades, Glenwood Springs, and Kremmling, Colo. Studies of the records showing the discharge of Grand River at Palisades, Grand Junction, and Fruita, Colo., and Moab, Utah, and of Gunnison River at Grand Junction, Colo., indicate that the total annual run-off from the Grand River basin has ranged from about 4,280,000 acre-feet to about 8,900,000 acre-feet. The mean annual run-off for the period 1895 to 1914, inclusive, was, in round numbers, about 6,720,000 acre-feet.

To estimate the loss to the flow of Grand River when all the irrigable lands of the basin have been brought under cultivation—that is, when in addition to the 302,000 acres now irrigated 457,000 acres are placed under irrigation—it has been assumed that 70 per cent of the total area will receive water each year, that the head-gate duty (see p. 136) for this net area is 3.5 acre-feet, and that the return seepage from the irrigated lands will be 25 per cent of the water diverted from the river. Under these assumptions the average annual loss to the flow of Grand River will be about 873,000 acre-feet. About 50,000 acre-feet annually may also be lost by evaporation from the water surface of the various storage reservoirs. The average annual loss to the flow of Grand River due to diversions from the Grand River basin to other drainage basins may amount to about 260,000 acre-feet. (See pp. 156, 157.) The average annual loss under this condition of complete utilization of the waters of the Grand may be about 1,163,000 acre-feet. Comparison of this amount with the estimated average annual run-off from the Grand River basin during the period 1895 to 1914, inclusive—about 6,720,000 acre-feet—indicates that if the proposed developments are completed the average annual discharge of Grand River at its mouth may be reduced to about 5,560,000 acre-feet.

GREEN RIVER BASIN.

GENERAL CONDITIONS.

The waters of Green River and its tributaries are practically unused except for irrigation. The oldest and most extensive developments in this basin are on the upper Green in Wyoming. Large irrigation systems have recently been constructed in the Duchesne River basin, and considerable irrigation is practiced around Vernal, Utah, and in the vicinity of Green River, Utah, along the line of the Denver & Rio Grande Railroad. Along White and Yampa rivers in Colorado meadow irrigation is extensively practiced.

Excellent reservoir sites, by means of which the entire flow of the streams could be equalized, are found on the headwaters of the Green and its upper tributaries, and also along Yampa and White rivers, on Ashley Creek, and at the headwaters of Duchesne River.

SAN RAFAEL RIVER.

The San Rafael, the first important tributary received by the Green above its junction with the Grand, unites with the Green 24 miles below the town of Green River, Utah. The average annual run-off from this basin, which comprises approximately 2,080 square miles of country ranging in altitude from 4,020 feet to more than 10,000 feet, is about 230,000 acre-feet.

Practically all the lands irrigated in the San Rafael basin lie along Ferron, Cottonwood, and Huntington creeks, which unite to form the San Rafael at a point about 10 miles below Castledale. Of the 35,000 acres irrigated in this basin in 1913, only a few hundred acres were irrigated from the San Rafael proper. Several irrigation projects in the San Rafael basin are under construction. If these projects are completed practically all the normal run-off will be utilized for irrigation, but some water may flow into Green River during periods of high floods. It is estimated that future irrigation developments on this stream may place 30,000 acres of additional lands under cultivation.

PRICE RIVER.

Price River, which joins the Green in Gray Canyon, 20 miles above the town of Green River, Utah, drains an area ranging in elevation from 4,200 feet to more than 10,000 feet and comprising about 1,860 square miles, from which the average annual run-off is approximately 180,000 acre-feet.

In 1913 the irrigated area in the Price basin comprised 15,000 acres. The flow of the Price is very irregular and it has been necessary to use storage reservoirs to maintain a dependable supply of water for lands now being irrigated. The Price River Irrigation Co. has constructed a storage dam on one of the headwater tributaries of the Price, and the height of the dam is being increased each year to meet the demand for irrigation of the lands reclaimed by the company near Helper and Price, Utah.

Under a project to reclaim land in the vicinity of Woodside, Utah, it is planned to construct a storage dam on Price River a short distance above Woodside. The average elevation of the tract is about 4,700

feet. The amount of silt carried by Price River during floods has no doubt retarded the development of irrigation on the lower Price. There appears to be sufficient unused water in Price River to serve approximately 30,000 acres near Woodside, but the feasibility of the project depends on the possibility of taking care of the silt. For the Price basin as a whole it is estimated that future development of irrigation on this stream may place 50,000 acres of additional land under irrigation.

MINNIE MAUD CREEK.

Little information is available concerning the possibilities of irrigation on Minnie Maud Creek, a small stream draining an area immediately south of the Duchesne River basin. The creek flows through a comparatively narrow valley and the limit of irrigation has probably been reached. About 2,000 acres were irrigated in 1913.

WHITE RIVER.

White River, which unites with Green River in west-central Uinta County, Utah, drains an arid, broken, and much eroded plateau region comprising about 4,620 square miles. In the spring its numerous small tributaries carry considerable water derived mainly from melting snow, but in the summer they are nearly dry.

A considerable area in the White River basin in the vicinity of Meeker and Rangely is under cultivation, and during the last part of the growing season the low-water flow of White River is practically all used for irrigation. If the irrigated area is to be increased storage reservoirs must be utilized. Near the headwaters of the White and its tributaries are a number of reservoir sites, the most important of which are listed below, and small sites that might be utilized in regulating the flow of the tributaries are numerous.

Storage reservoir sites in White River basin, Colo.

	Acre-feet.
White River and Beaver Creek	
Stillwater	105,000
Lost Park	68,000
Fawn Creek	28,000
Marvine Lakes	1,800

The water of the White would be practically exhausted by either of two irrigation schemes under consideration. Under the White River-Axial basin project it is planned to store the flood waters of White River and its tributaries in a reservoir in the White River Forest Reserve to reclaim a small area in the vicinity of Meeker and a much larger area in the Axial basin south of Maybell, in the Yampa River drainage basin. The main canal of this system would cross from the White River basin over Yellow Jacket Pass in T. 2 N.,

R. 92 W. sixth principal meridian, into the Yampa River basin. The canal system would cover 250,000 acres, of which perhaps 90,000 acres is good agricultural land.

Under the White River project it is planned to reclaim approximately 200,000 acres on the Blue Mountain bench, between White and Yampa rivers, near the Utah-Colorado line. The proposed point of diversion is at the present heading of the Powell Park ditch, in the SE. ¼ SW. ¼ sec. 29, T. 1 N., R. 94 W., sixth principal meridian. It is estimated that by extending the main canal into Utah 175,000 to 200,000 acres of first-class land could be irrigated. The main canal would be 125 miles long. A study of the run-off of the White and its tributaries proves conclusively that the water supply is not sufficient to irrigate properly the agricultural lands that lie under the proposed White River-Axial Basin project and the White River project.

Records of discharge of the White at Meeker, Colo., averaged in the following table, indicate that the mean annual run-off at Meeker is 475,000 acre-feet, all of which would be available for irrigation if storage reservoirs are utilized.

Annual run-off of White River at Meeker, Colo.[1]

	Acre-feet.		Acre-feet.		Acre-feet.
1902	392,000	1905	476,000	1911	440,000
1903	512,000	1906	533,000	1912	563,000
1904	467,000	1910	419,000	Mean	475,000

During 1913 about 26,000 acres were irrigated in the White River basin, and the water supply is probably sufficient for the proper irrigation of 150,000 acres additional.

DUCHESNE RIVER.

Duchesne River, which joins the Green at Ouray, Utah, drains approximately 4,000 square miles. Irrigation has been practiced in this basin for many years.[2] The Federal Government has constructed for the Uinta Indian Reservation an irrigation system which serves an area of 85,880 acres and under which about 12,000 acres were irrigated in 1913. The area brought under cultivation by private interests greatly exceeds that which has been reclaimed by the aid of the Federal Government. The total area irrigated in this basin in 1913 was about 60,000 acres. The more important of the irrigation schemes in this basin are the Myton Bench, Blue Bench, West Bench, and Lott projects. The total area included under these projects exceeds the area that can be reclaimed with the water available. The only known large reservoir site in this basin is that at the headwaters of Strawberry River, which is now being used by the United States Reclamation Service (p. 146). Small reservoir sites are, however, numerous. At the headwaters of the Duchesne, Rock Creek, Lake Fork, and Uinta River are many small lakes that would store considerable water if dams were constructed at their outlets. In estimating the amount of additional land that may be irrigated in the Duchesne basin it has been assumed that a sufficient number of these small reservoir sites can be utilized to control for irrigation the average annual run-off from the Duchesne and its tributaries—approximately 700,000 acre-feet. On this assumption the additional area that may be placed under cultivation in this basin is estimated at 180,000 acres.

[1] Flow during winter months estimated.

[2] A preliminary study of the possibilities of irrigation in the basin of Duchesne River has been made by the United States Reclamation Service and the results published in the Third Annual Report of the bureau.

ASHLEY CREEK.

Ashley Creek joins Green River from the west about 3 miles below Jensen, Utah. Irrigation has been practiced in the vicinity of Vernal for many years, and during the later part of the growing season practically the entire normal flow is used for irrigation. The flood waters of the stream have not, however, been controlled. The Uinta Land & Water Co. has planned the reclamation of 25,000 acres under a Carey Act project, the water to be taken from Dry Fork of Ashley Creek, Deep Creek, White Rocks Creek, and Uinta River. The construction of a high-line canal from Ashley Creek, to reclaim approximately 10,000 acres of new land, has also been proposed.

During 1913 about 30,000 acres were irrigated in the basin of Ashley Creek, and it seems probable that the water supply is sufficient, if controlled, to reclaim 15,000 acres of additional land.

YAMPA RIVER.

Of the 7,600 square miles drained by Yampa River and its tributaries, 1,870 square miles are in Wyoming and the remainder in Routt and Moffat counties, Colo. The average annual run-off from the basin is in excess of 1,000,000 acre-feet, but the area of irrigated land is relatively small.

The average fall of the Yampa between Steamboat Springs and Craig, a distance of 43 miles, is approximately 12 feet to the mile, the elevation of the water surface being 6,677 feet at Steamboat Springs and 6,165 feet at Craig. In this stretch there are no large bodies of land that could be irrigated by direct diversion from the river; only small areas of bottom land are cultivated, the largest areas being in the neighborhood of Craig and Hayden. Between Craig and Cross Mountain Canyon—75 miles by river—the average fall is 4.63 feet per mile. The elevation of the water surface at the entrance of Cross Mountain Canyon is 5,815 feet. There are no irrigated lands on this section of the river except in Maybell Valley, above Cross Mountain Canyon, and in the small valley above Juniper Canyon. Just below Juniper Canyon two canals take water from the main river to irrigate lands on the north and south sides of Yampa River in Maybell Valley. Below Cross Mountain Canyon, at the mouth of Little Snake River, is Lily Valley, where a small area is cultivated. The possibilities of future irrigation in this valley are limited to a few thousand acres. Six miles below the mouth of Little Snake River the Yampa enters Blue Mountain Canyon, through which it flows to its confluence with Green River. There are no lands susceptible of irrigation in Blue Mountain Canyon. In the first 29 miles of this canyon the average fall of the river is 15.7 feet per mile.

Little Snake River, the principal tributary of the Yampa, drains 3,380 square miles, of which 1,870 square miles is in Wyoming. The average run-off from this tributary is about 100,000 acre-feet annually. A few thousand acres are being irrigated near the headwaters of the Little Snake, near the Colorado-Wyoming line. The Routt County Development Co. is building storage reservoirs that will serve to reclaim about 40,000 acres of new lands. If this project is completed, the Little Snake will probably contribute little water to the Yampa.

Among the proposed irrigation schemes in the Yampa basin three are important. The Great Northern Irrigation & Power Co. has obtained a Carey Act segregation of 144,000 acres of land north of Yampa River, north and east of Craig, to be irrigated with water taken from Elk and Fortification creeks. Several reservoirs are to be built and a small amount of construction work has been done. The water available is probably not sufficient to reclaim the entire area segregated.

Under another project it is proposed to divert the headwaters of Williams Fork to reclaim approximately 28,000 acres south of Yampa River in the vicinity of Hayden. A number of reservoirs are to be constructed in connection with this project.

The Elk River Irrigation & Construction Co. proposes to reclaim 250,000 acres of lands between Little Snake and Yampa rivers with water from Elk River and various small streams in the vicinity of Hahns Peak. A number of reservoirs are to be constructed in connection with this project also. The water supply is not sufficient to reclaim all the land covered by the proposed canal system.

In the Yampa basin as a whole about 40,000 acres were irrigated in 1913, and possibly 260,000 acres additional may be irrigated.

HENRYS FORK.

In the area drained by Henrys Fork, comprising 644 square miles, about 15,300 acres were irrigated in 1913, of which 10,300 acres are in Wyoming. The water supply will, if controlled, probably suffice to reclaim approximately 10,000 acres of additional land in Utah. Records showing the run-off from Henrys Fork basin are not available.

MINOR TRIBUTARIES.

A number of small tributaries enter Green River between Henrys Fork and Ashley Creek, the more important being Sheep, Carters, Pot, Grouse, and Brush creeks. It is estimated that these five tributaries furnished water to irrigate 3,000 acres in 1913 and that they may be made to serve additional areas aggregating about 4,000 acres

STREAMS OF THE BASIN IN WYOMING.

In Wyoming the Green drains an area comprising 17,340 square miles, of which 1,870 square miles form part of the basin of Little Snake River, a tributary of the Yampa. The altitude of the basin in Wyoming ranges from 6,000 to more than 13,000 feet. The growing season is short, but good crops are raised and a comparatively large area has been placed under cultivation.

Practically all the streams in the Green River basin in Wyoming have been adjudicated by the State board of control since its organization in 1891. The tabulation of adjudicated water rights in the basin, published by the board, shows fairly accurately the areas irrigated up to July 1, 1914, and forms the basis of the following table:

Lands irrigated in Green River basin, Wyo., in 1913.

	Acres.		Acres.
Green River direct	27,356	Cottonwood Creek	16,856
Vermilion Creek	537	Horse Creek	10,902
Red Creek	284	Failer Creek	895
Henrys Fork	10,495	Green River or Grass Creek	4,527
Marsh Creek	98	Spring Branch	127
Currant Creek	236	Big Twin Creek	1,028
Blacks Fork	55,131	Little Twin Creek	264
Sage Creek	486	Springs	110
Bitter Creek	2,458	Boulder Creek	868
Big Sandy Creek	8,075	Mud Creek	80
Slate Creek	60	Lime Creek	193
Fontenelle Creek	6,342	Crow Creek	80
Little Muddy Creek	60	Tosi Creek	335
La Barge Creek	13,134	Wagon Creek	100
Birch Creek	112	Goodwater Creek	116
Dry Piney Creek	1,841	Mill Creek	57
South Piney Creek	11,219	Red Creek	1,070
Middle Piney Creek	24,722	Jim Creek	450
Muddy Creek	538	Alkali Creek	570
New Fork River	45,783		248,000

Taking into account a number of partly completed projects not considered in preparing the preceding table, it is estimated that about 280,000 acres were irrigated from the Green and its tributaries in

Wyoming during 1913, and by noting the acreages included in the various projects it is estimated that 300,000 acres additional may be irrigated in the basin of the Green in Wyoming.

IRRIGATION IN UTAH DIRECTLY FROM GREEN RIVER.

Practically no lands are irrigated by direct diversion from Green River between the Utah-Wyoming line and the mouth of Price River. A few thousand acres have been irrigated by direct diversion in the vicinity of Green River, Utah, and a few hundred acres have been irrigated in Little Valley, on Green River near the mouth of the San Rafael. Altogether about 4,000 acres were irrigated in 1913 by direct diversion from the Green below the Utah-Wyoming State line.

Unfortunately the topography in the vicinity of Green River in Utah makes it extremely difficult to divert the waters of this stream for irrigation. For a number of years private parties have attempted to finance a project to irrigate lands on both banks of Green River near Green River, Utah. The plan includes the construction of a diversion dam 160 feet high on Green River at the mouth of Coal Creek, which joins Green River from the east at a point 29 miles by river above the town of Green River. The distance from the diversion dam to the mouth of the canyon is 15 miles. Construction work in this section of the main canal, the capacity of which is to be 2,000 second-feet, would be difficult. The total area covered by the proposed canal system is 264,000 acres. The arable land is estimated at 200,000 acres. A temporary Carey Act segregation has been obtained for all the irrigable land in the basin, estimated at 170,000 acres, of which 117,000 acres will be reclaimed by a gravity system and about 53,000 acres by pumping.

SUMMARY FOR GREEN RIVER BASIN.

The total annual run-off from the Green River basin, estimated from records showing the discharge of Green River at Green River, Utah, and of San Rafael River near its mouth, for the period 1895 to 1914, inclusive, has ranged from 3,820,000 to 9,250,000 acre-feet; the mean was about 5,680,000 acre-feet. Six reservoir sites in the basin range in capacity from 1,000,000 to over 4,000,000 acre-feet. The largest known reservoir site in the area drained by the Colorado is that at the junction of Green and Grand rivers. A dam to raise the water level 270 feet, constructed on the Colorado immediately below this junction, would create a reservoir having storage capacity of 8,600,000 acre-feet. Recent investigations by the Reclamation Service throw some doubt on the feasibility of developing this site on account of the absence of satisfactory foundation for a high dam. In addition to these large reservoir sites, which may prove of value in connection with the control of the Colorado, numerous small reservoir sites on the various tributaries of the Green will doubtless be used in connection with future development of irrigation. The aggregate capacity of the sites is sufficient to control completely the flow of the Green.

In Green River basin as a whole about 500,000 acres were irrigated in 1913, and it is estimated that additional areas aggregating about 1,170,000 acres may be irrigated. The basis for these estimates is presented in the following table:

Irrigation in the Green River basin.

Stream.	Area irrigated in 1913.	Additional area that may be irrigated.
	Acres.	*Acres.*
White River	26,000	150,000
Yampa River	40,000	260,000
Green River and its tributaries, Wyoming	280,000	300,000
Henrys Fork, Utah	5,000	10,000
Sheep Creek	200	0
Carters Creek	200	0
Pot and Grouse creeks	600	100
Brush Creek	2,000	4,000
Ashley Creek	30,000	15,000
Duchesne River	60,000	180,000
Minnie Maud Creek	2,000	0
Price River	15,000	50,000
San Rafael River	35,000	30,000
Green River direct in Utah	4,000	170,000
	500,000	1,170,000

To estimate the loss to the flow of the Green that will result from the complete utilization of the waters of the basin for irrigation, it has been assumed that 70 per cent of the total area will receive water each year, that the head-gate duty for this net area is 3.5 acre-feet, and that 25 per cent of the water diverted from the river will be returned as seepage from the irrigated lands. Under these assumptions the average annual loss to the flow of Green River may be about 2,150,000 acre-feet. There may also be a loss of about 100,000 acre-feet annually due to evaporation from the water surface of the various storage reservoirs. The average annual loss in the flow of Green River, due to diversions from the Green River basin to other drainage basins, will amount to about 100,000 acre-feet. The total loss under conditions of complete development may therefore amount to about 2,350,000 acre-feet annually. Deducting this amount from the 5,680,000 acre-feet, indicated by records for the period 1895 to 1914, inclusive, as the average annual run-off from the basin, gives 3,330,000 acre-feet as the average annual discharge of Green River at its mouth, if full use for irrigation is made of the water of the river and its tributaries.

IRRIGATION FROM COLORADO RIVER DIRECT.

GENERAL CONDITIONS.

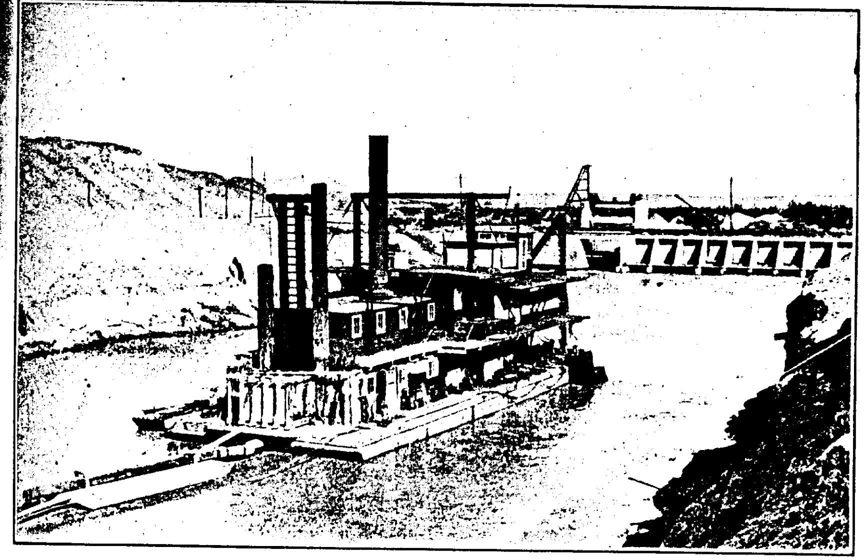
For a distance of 100 miles above their junction to form the Colorado, both the Green and the Grand occupy canyons whose walls are almost vertical. At the junction of the two rivers the canyon walls are about 1,200 feet high; immediately below the junction the canyon is about 1,300 feet wide from wall to wall. Then for 616 miles the Colorado flows through canyons whose walls range in height from 1,200 feet above the river at the junction of the Green and Grand to 6,000 feet in the Grand Canyon, below which they gradually become lower and finally disappear near the mouth of Virgin River. Below the Virgin the Colorado passes through a series of open valleys separated by short canyons. Between the Grand-Green junction and Cottonwood Valley the average distance between the canyon walls at an elevation of 100 feet above the water is probably less than 2,000 feet. In the 616-mile section of the Colorado above Cottonwood Valley no water will ever be diverted for irrigation. Below Cottonwood Valley are vast areas of fertile land susceptible of irrigation by diversion from the river.

Colorado River carries enormous quantities of silt (see pp. 218–226) which passes into the canals and if allowed to remain soon reduces their capacity. All irrigation projects on the lower Colorado must face the silt problem. Thousands of dollars are spent annually by the California Development Co. and the mutual water companies in the Imperial Valley keeping the canal systems in operation. The California Development Co. keeps two suction dredges (Pl. X, *A*) in the main heading on Colorado River, one at the head of the channel that leads from the river to the head gates (Pl. X, *B*) and the other immediately below the head gates in the main canal.

DUTY OF WATER.

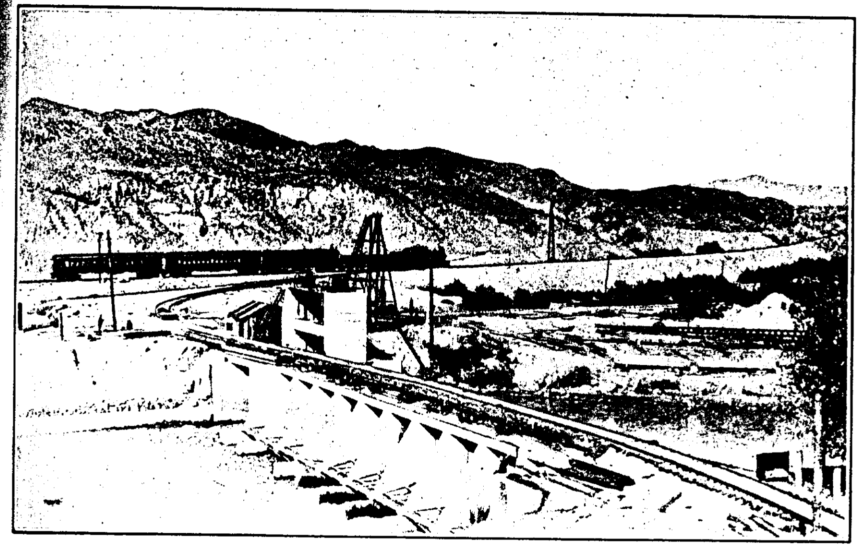
To determine the quantity of water necessary for the proper irrigation of land in the Colorado basin it is necessary to know not only the duty of water but also the monthly and yearly demand.

The "duty" of water may be expressed (1) in terms of area of the ground whose agricultural requirements are satisfied by the application of a given quantity of water, generally one second-foot continuous flow through the irrigation season; or (2) in total depth of water which must be applied in the irrigation season to satisfy the agricultural requirements of the ground cropped. Under either definition the point at which the water is measured should be stated. For example, measurement at the point of diversion from the natural stream gives the head-gate duty; measurement at the point where the main canal enters the lands to be irrigated gives the distributary duty; measurement in such a way as to represent the actual depth or quantity of water which the crop receives gives the net duty.



A. SUCTION DREDGE IMMEDIATELY BELOW HANLON HEADING, IMPERIAL CANAL.

Dredge is operated intermittently and removes silt deposited below the head gates.



B. HANLON HEADING, IMPERIAL CANAL.

In determining the duty of water in the valleys of the lower Colorado a number of factors must be considered. In Utah, Colorado, and Wyoming, in the upper basin, water is diverted for irrigation during a more or less definite period commonly called "the irrigation season," which usually extends from April 1 to October 1; on the lower Colorado, though the rate of demand varies from month to month, there is no definite irrigation season, water being diverted for irrigation throughout the year. In determining the adequacy of the water supply for irrigable lands below the mouth of the Virgin the "head-gate duty," expressed in acre-feet of water that must be diverted from the river to satisfy the requirements of the area cropped, will be used, that is, an attempt will be made to estimate the quantity of water (in acre-feet) that must be diverted from the Colorado to satisfy during a calendar year the agricultural requirements of the area to be irrigated.

On the Yuma project, for example, a head-gate duty of 5.5 acre-feet per acre irrigated has been assumed by the United States Reclamation Service, the monthly distribution being as follows:

Contemplated use of water on the Yuma project of the United States Reclamation Service.

Month	Acre-foot.	Month	Acre-foot.
January	0.20	August	.80
February	.25	September	.56
March	.30	October	.38
April	.41	November	.26
May	.52	December	.22
June	.70		5.50
July	.90		

It is probable that a head-gate duty of 5.5 acre-feet will be found to be too low, that is, that less than 5.5 acre-feet will meet the requirements of the crops.

To serve lands in Imperial Valley (see pp. 140–144) the total diversion by the Imperial canal during 1913 amounted to 5.38 acre-feet per acre irrigated, as indicated by the following table:

Quantity of water diverted in 1913 through the Imperial Valley canal for the irrigation of 314,000 acres of land in the United States and Mexico.

Month.	Diversion.	Diversion per acre.
	Acre-feet.	*Acre-foot.*
January	103,000	0.33
February	107,000	.34
March	150,000	.48
April	157,000	.50
May	177,000	.56
June	173,000	.55
July	196,000	.62
August	186,000	.59
September	165,000	.53
October	136,000	.43
November	76,000	.24
December	67,000	.21
	1,693,000	5.38

That is, the table shows that the head-gate duty for the Imperial Valley for the year 1913 was 5.38 acre-feet. The California Development Co., which owns the canal and the main distribution system, has entered into a contract with the mutual water companies in the Imperial Valley, agreeing to deliver water to the mutual water companies on demand, the quantity to be delivered during any one year not to exceed 4 acre-feet per acre irrigated. The water is measured to the various mutual water companies at specified points on the main supply canals near the boundary of the respective projects of the mutual water companies. The California Development Co. agrees to stand a loss of 10 per cent to cover losses due to seepage and evaporation in the distribution system within the projects of the mutual water companies. In other words, the California Development Co. receives pay for 90 per cent of the water measured to the various mutual water companies, which pay 50 cents per acre-foot for the water so delivered.

Owing to the fact that the California Development Co. is under contract to deliver water on demand, there is always an uncertainty as to the quantity that will be required to meet the demand one day in advance. It requires about 30 hours for the water to pass from the heading of the Imperial Valley canal to Sharp's heading. (See p. 143.) It has therefore been necessary for the California Development Co. to predict the demand about two days in advance. At times the demand has been less than that which was predicted, and the water having already been diverted from the Colorado was necessarily wasted into the Alamo channel and passed on to Salton Sea. Some of this waste of water will doubtless be avoided when a greater proportion of the lands under the Imperial canal system are irrigated. The rotation system of irrigation has not been used in the Imperial Valley. The problem of disposing of silt in the Imperial Valley is serious, and a system of irrigation that would result in fluctuating heads of water in the various distributary canals would probably not be practicable. It does, however, seem likely that the head-gate duty of water for the Imperial Valley will be raised.

From the record of diversions through the Imperial canal during the years 1911, 1912, and 1913 the percentage of the total diversions for each month of the year has been computed and a head-gate duty of 5 acre-feet has been assumed, as shown by the following table:

Monthly distribution of water for irrigation of lands below Virgin River.

Month.	Per cent.	Acre-foot per acre.
January	5.97	0.30
February	5.64	.28
March	7.86	.40
April	8.46	.42
May	9.14	.46
June	9.17	.46
July	11.38	.57
August	10.88	.53
September	9.65	.48
October	9.14	.46
November	6.46	.33
December	6.25	.31
	100.00	5.00

A head-gate duty of 5 acre-feet, therefore, forms the basis for the estimates of the water necessary for the proper irrigation of the 2,730,000 acres of irrigable land in the Colorado River basin below the mouth of the Virgin.

IRRIGATION BETWEEN COTTONWOOD VALLEY AND LAGUNA DAM.

Although definite plans have not been perfected covering the possibilities of irrigation on the section of the Colorado between Cottonwood Valley and Laguna dam, a number of investigations have been made by the Federal Government and private engineers. The United States Geological Survey made a topographic survey of a part of this section of the river in 1902–3, and the United States Indian Service has made special investigations covering Mohave and Chemehuevis valleys and the Colorado River Indian Reservation. Private engineers have investigated the possibilities of irrigation in the Palo Verde Valley, Palo Verde Mesa, Chuckwalla Valley, and Cibola Valley. From the information thus made available a map has been prepared showing roughly the location of the irrigable areas between Bulls Head Rock and Cibola Valley (Pl. XI, in pocket). The shaded areas on this map include lands irrigable by both gravity and pumping systems. In only one place has a lift of more than 100 feet been considered, the exception being the Chuckwalla Valley project, which has been investigated by private engineers and under which it is proposed to reclaim about 214,000 acres by pumping; the average lift would be 282 feet. The soil and climatic conditions in the Chuckwalla Valley are said to be especially adapted to the growing of oranges. If oranges and other fruit can be grown successfully the lands in this valley may stand the high operating cost which would result with an average pumping lift of 282 feet. Although this development may be remote the project is included in the estimate of areas irrigable by gravity and pumping systems on the lower Colorado. The areas at present irrigated and the possibilities of future irrigation in Mohave, Chemehuevis, and Calzona valleys, the Colorado River Indian Reservation, Palo Verde Valley, Palo Verde Mesa, and Cibola Valley are shown by the following table:

Irrigated and irrigable areas between Cottonwood Valley and Laguna dam.

From—	Area irrigated in 1913.	Additional area that may be irrigated.
	Acres.	*Acres.*
Cottonwood Valley above Bulls Head Rock	200	5,000
Mohave Valley between Bulls Head and Mellen	5,000	48,000
Chemehuevis Valley	0	28,000
Colorado River Indian Reservation (gravity system)	2,000	120,000
Colorado River Indian Reservation (by pumping)	0	60,000
Calzona Valley, near Parker	0	18,000
Palo Verde Valley	25,000	75,000
Palo Verde Mesa (by pumping)	0	100,000
Chuckwalla Valley (by pumping)	0	214,000
Cibola Valley	1,000	18,000
	33,200	686,000

BELOW LAGUNA DAM.

YUMA PROJECT.

The possibilities of irrigation on the Colorado below the Laguna dam can be estimated with fair accuracy for the areas in the United States, but those in Mexico have been only partly investigated. Two of the most important projects in the entire basin are the Yuma project of the United States Reclamation Service and the Imperial Valley project of the California Development Co., under which lands in the United States and Mexico are irrigated. From data collected by the United States Reclamation Service, the California Development Co., and private engineers, a map has been prepared showing roughly the areas now irrigated and the lands that may be irrigated by future development on Colorado River below the Laguna dam (Pl. XII, in pocket).

The Yuma project is in Yuma County, Ariz., and Imperial County, Cal. If this project is completed 160,000 acres will be reclaimed, 90,000 acres by gravity and 70,000 by pumping. The water is diverted from Colorado River at the Laguna dam, which was constructed at a cost of about $1,673,000. This is the only dam that has been built on Colorado River. In 1913 about 20,000 acres were irrigated under the Yuma project.

IMPERIAL VALLEY PROJECT.

The Imperial Valley project is in Imperial County, Cal., in what is known as the Salton Basin, the name Salton Basin being applied to the region in southeastern California and northern Lower California earlier known as the Colorado Desert. The basin has been defined as

the area that would ultimately be submerged if the Colorado discharged inland instead of into the Gulf of California.[1] It extends northward to a point a few miles beyond Indio and southward overlaps the international boundary some 15 to 20 miles. The northern, narrow end of the Salton Basin (or the Colorado Desert), lying between the base of San Jacinto Peak and the margin of Salton Sea, is known as the "Indio region" or the Coachella Valley.[2]

The cultivated portion of the Salton Basin, south of Salton Sea, whether north or south of the international boundary line, is called the Imperial Valley.

Physically the Salton Basin forms part of the great depression whose southern end is occupied by the Gulf of California. The lowest point in the basin is about 280 feet below sea level, and the rainfall on the area does not flow or tend to flow into the Colorado or any of its tributaries. The waste and seepage water from the irrigated lands in Imperial Valley, however, passes northward into Salton Sea, which receives also the overflow from Colorado River through Alamo and New River channels. Alamo River heads in the northern edge of the Colorado River delta cone, immediately south of the international boundary line; New River formerly flowed from Volcano Lake. At the present time Colorado River flows into Volcano Lake and finds its way to the Gulf of California through Hardys River. A levee north of this lake now prevents any water reaching New River from this source. According to McDougal[3]—

> The earliest existence of Salton Sea within historic times is that shown on Rocque's map, 1762. * * * Collated reports give the presence of flood water in some volume in the sink in 1828, 1840, 1849, 1852, 1859, 1862, 1867, and 1891.[3]

In 1903 and 1904 only waste water reached the Salton Sink. During the summer of 1905, after a succession of winter and spring floods in Gila River followed by exceptionally heavy summer floods in the Colorado, the flow into the sink was repeated on a much larger scale. During this period the Colorado abandoned its old channel to the Gulf and flowed north into Salton Sink, which it filled to a depth of 76 feet, submerging about 291,000 acres. On February 11, 1907, the break was closed and the river forced again to flow south into the Gulf of California.[4] The following table shows the condition of Salton Sea since March, 1907.

[1] Grunsky, C. E., The lower Colorado River and the Salton Basin: Am. Soc. Civil Eng. Trans., vol. 59, pp. 1-51, December, 1907.

[2] Mendenhall, W. C., Ground waters of the Indio region, Cal., with a sketch of the Colorado Desert: U. S. Geol. Survey Water-Supply Paper 225, p. 9, 1909.

[3] McDougal, D. T., The Salton Sea, Carnegie Inst. Washington Pub. 193, 1914.

[4] For detailed accounts of the causes that led to the formation of Salton Sea and of the various attempts and final successful effort to shut the flood flow of Colorado River from the Salton Sink, see the following reports:

Grunsky, C. E., The lower Colorado River and the Salton Basin: Am. Soc. Civil Eng. Trans., vol. 59, pp. 1-51; discussion pp. 52-62, December, 1907.

Cory, H. T., Irrigation and river control in the Colorado River delta: Am. Soc. Civil Eng. Trans., vol. [illegible], pp. 1204-1453; discussion, pp. 1454-1571, December, 1913.

Water levels, area submerged, and annual evaporation of Salton Sea.

Date.	Water levels (sea level datum).	Area submerged.	Depth of evaporation. [a]	Evaporation. [a]
	Feet.	*Acres.*	*Feet.*	*Acre-feet.*
March, 1907	−197.5	291,000	....	....
January, 1908	−201.2	282,000	3.7	1,060,000
January, 1909	−206.0	271,000	4.8	1,327,000
January, 1910	−210.1	262,000	4.1	1,093,000
January, 1911	−215.1	250,000	5.0	1,280,000
January, 1912	−219.4	240,000	4.3	1,054,000
January, 1913	−223.5	229,000	4.1	961,000
January, 1914	−227.7	218,000	4.2	939,000
January, 1915	−231.8	208,000	4.1	873,000

[a] Rainfall and inflow disregarded.

From incomplete records showing the inflow from Alamo and New rivers since February 11, 1907, the total inflow into Salton Sea from February 11, 1907, to December 31, 1913, is estimated at approximately 1,700,000 acre-feet. The rainfall during this period was about 18 inches. Had there been no rainfall and no inflow the

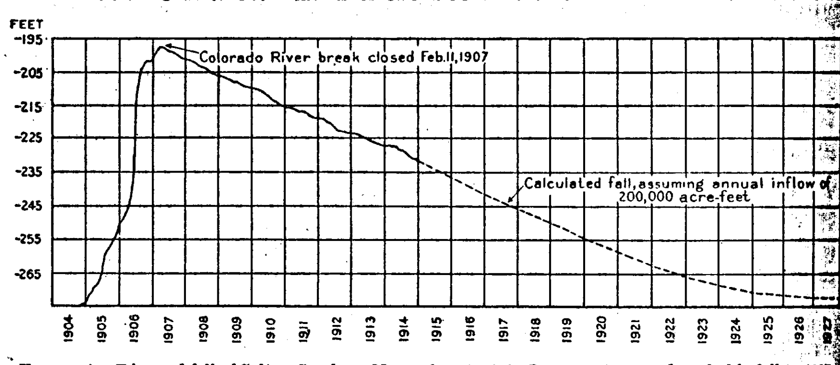


FIGURE 1.—Rise and fall of Salton Sea from November, 1904, to January, 1915, and probable fall to 1927.

lake level on January 1, 1914, would have been −237.6 feet, indicating that the average annual evaporation from Salton Sea is 5.8 feet. As the water surface lowers, the area exposed to evaporation becomes smaller and the tendency of the inflow to hold up the water level becomes greater. Rough estimates of the fall in the water level of Salton Sea for each year to 1927, based on the assumptions that there will be no overflow from Colorado River and that the annual inflow is 200,000 acre-feet, and disregarding rainfall, indicate that Salton Sea will continue to decrease in size until about 1926 or 1927, when evaporation will equal inflow and the area periodically flooded will be between 40,000 and 50,000 acres. (See fig. 1.)

The Imperial Valley canal system covers lands that extend from Salton Sea to a point south of the international boundary and range in altitude from 30 feet above sea level to 231 feet below sea level, the elevation of the water surface of Salton Sea on October 1, 1914.

In 1913 the Imperial canal system covered more than 500,000 acres of land in Imperial Valley in the United States and Mexico

and approximately 314,000 acres were irrigated—264,000 acres in the United States and 50,000 acres in Mexico.

The canal takes water from Colorado River at the Hanlon heading (altitude 114 feet above sea level) in California, a few hundred feet above the international boundary line, about 7 miles by river below Yuma, Ariz. It passes into Mexico, and extends westward about 50 miles to Sharps heading, where the water is carried back into the United States through several smaller canals.

The capacity of the canal at the present time is about 5,000 second-feet. Owing to physical conditions it was necessary to construct a part of the main canal through Mexican territory. This canal was constructed by the California Development Co., a private corporation, which on April 25, 1899, acquired water rights in Colorado River under a notice of appropriation posted in conformity with the laws of California. The notice of appropriation called for 10,000 cubic feet per second. As the laws of Mexico prohibit the acquisition by foreigners of lands within certain distances of the international boundary, the promoters of the California Development Co. organized under the laws of Mexico a subsidiary corporation entitled La Sociedad de Irrigación y Terrenos de la Baja California (Sociedad Anónima). On May 17, 1904, the Mexican company obtained from the Mexican Government a concession authorizing it to construct a canal through Mexican territory with a capacity of 284 cubic meters per second (10,000 second-feet), and to convey the water to the lands in the United States, excepting only the quantity required to irrigate Mexican lands in Lower California, the quantity so used not to exceed one-half the volume of water passing through the canals.

In 1914 about 1,900,000 acre-feet of water was diverted through the Imperial canal for lands in Imperial Valley in the United States and Mexico. The maximum quantity diverted was 4,307 second-feet in July. All lands under the Imperial canal system in the United States and Mexico were, however, not under cultivation in 1914, and it appears probable that within a few years the total annual diversion through this canal may exceed 2,250,000 acre-feet.

The Imperial Valley irrigation district, which has been organized for the purpose of taking over the canal system of the California Development Co., proposes to construct what is locally known as the All-American Aqueduct. If this plan is carried out Imperial Valley in the United States will receive its water from the Colorado at the Laguna dam. The proposed canal would follow the foothills west of the Yuma project to the international boundary and then parallel the boundary on the American side to Imperial Valley. It would be necessary to construct a tunnel or deep cut through the sand hills between the Colorado and Imperial Valley. The elevation of the water surface at the forebay at the Laguna dam is 151 feet above sea level. If the All-American Aqueduct were constructed water could be delivered to irrigable lands in Imperial Valley at an elevation of approximately 140 feet above sea level. With this system completed, and with the installation of pumping plants to raise a part of the water to higher levels, approximately 900,000 acres of land could be watered in Imperial Valley in the United States. In 1913 the Imperial canal served 1,693,000 acre-feet of water to 314,000 acres in the United States and Mexico. The present canal system of the California Development Co. could be extended in Mexican territory to cover an additional area of approximately 200,000 acres.

IRRIGABLE LANDS IN MEXICO.

The Del Rio project is in Sonora, Mexico, immediately south of the international boundary and directly south of the Yuma project of the United States Reclamation Service. Preliminary investigations of this project have been made by private engineers. Practically the entire tract of 297,000 acres could be watered by a gravity system if the water were diverted from the Colorado at Laguna dam. A part of this tract could be watered by a gravity system with a canal heading at the international boundary on the Arizona side, and nearly all of the remainder of the tract could be watered by a pumping plant installed to lift the water 50 feet.

Vast areas of irrigable land also lie south and east of Volcano Lake and east of the dry channel of the Colorado (Pl. XII, in pocket). No field examinations have been made for the purpose of determining the feasibility of irrigating these lands, but the following estimate of the number of acres susceptible of irrigation is believed to be conservative:

	Acres.
South and east of Volcano Lake	250,000
East of the dry channel of the Colorado and west of the Del Rio tract	150,000

The following table is probably fairly indicative of the conditions of irrigation, present and future, on Colorado River below Laguna dam:

Irrigation on Colorado River below Laguna dam.

Projects.	Area irrigated in 1913.	Additional area that may be irrigated.
	Acres.	*Acres.*
Yuma project, U. S. Reclamation Service:		
By gravity	20,000	70,000
By pumping	0	70,000
Imperial Valley:		
United States	264,000	636,000
Mexico	50,000	200,000
Lands east and south of Volcano Lake in Mexico	0	250,000
Lands east of dry channel of Colorado River and west of Del Rio tract, Mexico	0	150,000
Del Rio tract, in Mexico	0	297,000
	334,000	1,670,000

WATER DIVERTED FROM THE COLORADO BASIN TO OTHER DRAINAGE BASINS.

POINTS OF DIVERSION.

The drainage basin of a stream comprises the area the run-off from which reaches or tends to reach the stream naturally. The boundary between a drainage basin and other basins is rightly termed the "divide" or the "watershed."[1] On the map (Pl. XIII, in pocket) the drainage basin of the Colorado is the area inclosed within the heavy broken line. At certain points, indicated on the map by a cross inclosed by a circle, water is or may be diverted from the basin of the Colorado to other basins.

The projects under which water is diverted from the Colorado River basin to other basins or under which such diversion is contemplated are listed in the following table. The numbers and symbols correspond to those used on the map (Pl. XIII) to indicate the points of diversion, and the arrangement is determined by the amount of water to be used.

Present and proposed diversions from Colorado River basin.

No. on map.	Diversion.	State.	Annual diversion.
			Acre-feet.
13	Imperial Valley [a]	California	1,900,000
2	Strawberry Valley	Utah	90,000
8	Blue River system	Colorado	[b] 90,000
5	Fraser River system	do	[b] 80,000
7	Williams Fork system	do	[b] 46,000
1	New Castle reclamation project	Utah	25,000
9	Eagle River system	Colorado	[b] 21,000
4	Grand River ditch	do	16,000
6	Church ditch	do	4,000
10	Daniels Pass	Utah	4,200
11	Soldier Summit	do	1,500
12	Breckenridge Pass	Colorado	650
3	Duchesne-Provo	Utah	([b])
14	Piney Creek	Colorado	([c])
			2,280,000

[a] Described in connection with irrigation from Colorado River direct; see pp. 140–144.
[b] Proposed.
[c] In operation; amount diverted small.

If all these projects are put in operation about 380,000 acre-feet will be diverted from the Colorado River basin annually in addition to the amount diverted through Imperial Valley canal.

[1] By some writers "watershed" is used in the sense of "drainage basin," but as "watershed" primarily means the "divide" and is generally used with that meaning, the use of the word in the two senses results in uncertainty and confusion. The United States Geological Survey has therefore adopted the practice of restricting "watershed" to the divide and using "drainage basin" for the area drained.

DIVERSION FROM GREEN RIVER BASIN.

STRAWBERRY VALLEY TUNNEL.

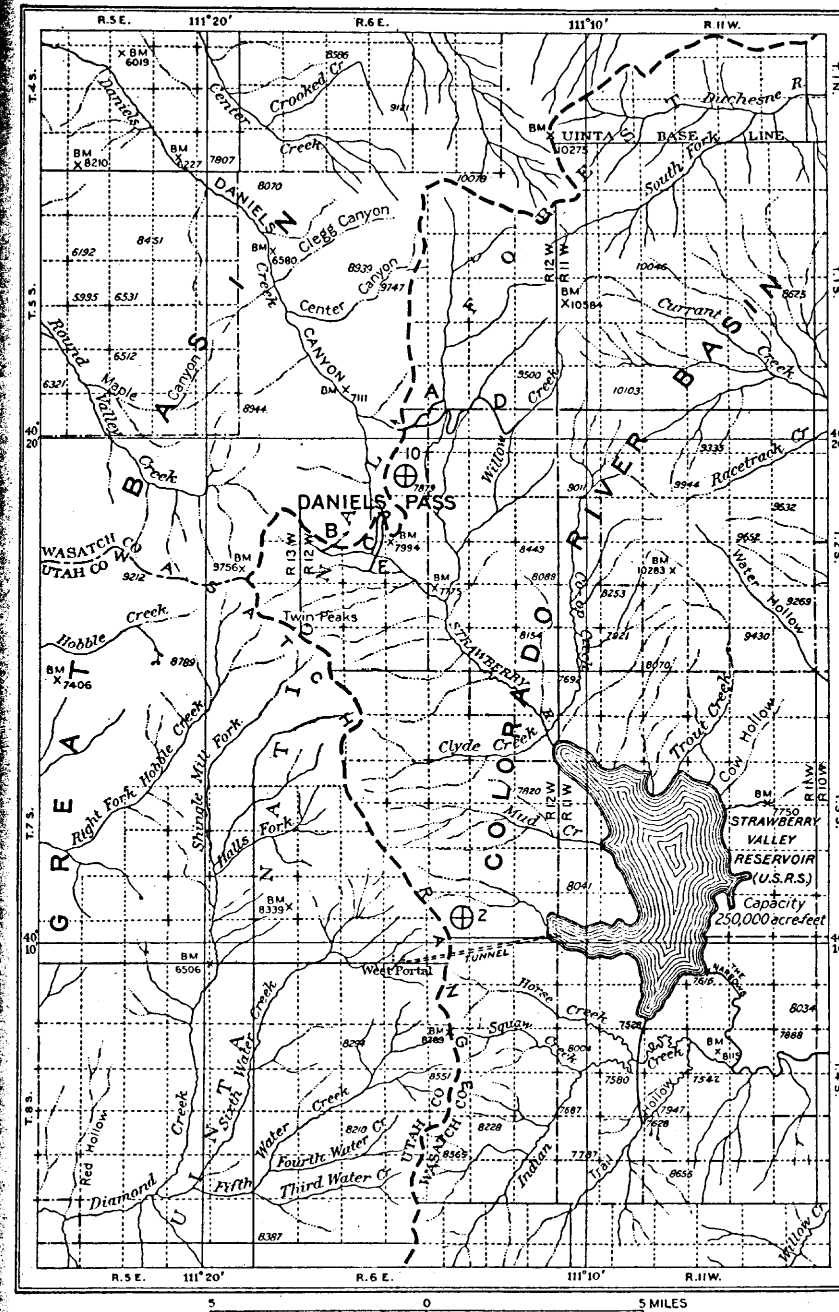
The Strawberry Valley project (⊕ 2, Pl. XIV) of the United States Reclamation Service is in Utah and Wasatch counties in the State of Utah. Water is obtained from Strawberry and Spanish Fork rivers and a number of small outlying streams and springs. The irrigation plan of the Strawberry Valley project provides for the storage of water in a reservoir on Strawberry River in the Colorado basin, the discharge of this water through Strawberry tunnel into Diamond Fork, a tributary of Spanish Fork River in the Great Basin, and the diversion of water from Spanish Fork River into canal systems, watering 50,000 acres of land east and south of Utah Lake.

The Strawberry reservoir was created by the construction of a dam 72 feet high, giving a storage capacity of 278,000 acre-feet. The sills of the outlet are, however, so high that only 250,000 acre-feet of storage is available. The dam was completed September 20, 1913. In addition to the run-off of Strawberry River above the dam the run-off of Indian and Trail Hollow creeks is diverted into the reservoir by means of a feed canal. The capacity of the reservoir exceeds the maximum run-off from its tributary basin. Except for slight seepage through the dam, the entire run-off from the basin to the reservoir will be diverted through Strawberry tunnel.

The Strawberry tunnel was constructed through the Wasatch Range, its east portal being in Wasatch County and its west portal in Utah County. (See Pl. XIV.) The tunnel is 19,897 feet long and is lined with concrete. The inside dimensions are as follows: Width, 7 feet; height of spring line, $6\frac{1}{2}$ feet; height to top of arch, $8\frac{1}{2}$ feet. The gates of the reservoir were closed November 19, 1912, and on November 30, 1914, the quantity of water stored in the reservoir was 170,000 acre-feet. The tunnel was formally opened by allowing reservoir water to flow through the tunnel September 13, 1913. The Reclamation Service reported the entire project 81 per cent completed June 30, 1915.[1]

The annual run-off available for storage in the Strawberry Valley reservoir, as estimated from records showing the discharge of Strawberry River below the mouth of Indian Creek for the period 1903-1906, and from 1908 to date, ranges from about 50,000 acre-feet to 160,000 acre-feet. The mean for the period 1904 to 1910, inclusive, the run-off for 1907 being estimated, was 97,000 acre-feet. The area of the water surface of the reservoir full, is 8,200 acres. The sea level elevation of the water surface with the reservoir full is 7,558 feet. The seepage loss from the reservoir is about 4,000 acre-feet annually, and the average annual loss due to evaporation will probably be about 10,000

[1] U. S. Recl. Service Fourteenth Ann. Rept., 1914-15, p. 265, 1915.



⊕ Diversion —A— Ditch + Land corner found
—·—·— Boundary of Colorado River Basin.

MAP SHOWING DIVERSIONS FROM COLORADO RIVER BASIN TO THE GREAT BASIN AT HEADWATERS OF STRAWBERRY RIVER, UTAH.

cre-feet. To determine the annual run-off available for storage in the trawberry Valley reservoir for a long period of years, the discharge f Strawberry River below the mouth of Indian Creek has been compared with the run-off of Green, Provo, and Spanish Fork rivers. he run-off of the Strawberry has also been compared with the total nnual discharge into Great Salt Lake. These comparisons indicate hat with an available storage capacity of 250,000 acre-feet about 0,000 acre-feet may be diverted annually through the Strawberry alley tunnel. With 80,000 acre-feet diverted and 10,000 acre-feet st by evaporation, the loss to Colorado River and its tributaries ould be 90,000 acre-feet annually, distributed as shown in the table n page 157.

DANIELS PASS DIVERSIONS.

Daniels Pass (⊕ 10, Pl. XIV) lies between the headwaters of Strawrry River and Daniels Creek, a tributary of Provo River, about 10 iles north of Strawberry tunnel (Pl. XIV). Five small ditches ivert water from the headwaters of Strawberry River over Daniels ass into the basin of Daniels Creek. These ditches were constructed y private parties for the purpose of augmenting the water supply vailable for the irrigation of lands at or near the mouth of Daniels anyon. A part of the water is also used for domestic supply and r watering stock.

Ditches in Daniels Pass diversion system.

Designation.	Name of ditch.	Capacity.	Ownership.	Approximate date of priority.
		Sec.-ft.		
[illegible]	Strawberry Creek	10-15	Strawberry Canal Co.	1879
[illegible]	Hobble Creek	5-10	do.	1888
[illegible]	Hobble Creek branch	5-10	do.	1888
[illegible]	Willow Creek	8-10	Willow Creek Canal Co.	1893
[illegible]	McDonald	5-10	McDonald Bros.	1888

The position of the point of diversion of each ditch with respect to ction, township, and range is shown on Plate XIV.

uantity of water, in acre-feet, diverted over Daniels Pass by the five ditches, A to E, inclusive.

Year.	May.	June.	July.	August.	September.	October.	Total.
12	[a] 1,820	1,509	811	383	313	123	4,958
13	[a] 1,600	1,197	647	306	287	....	4,037

[a] Estimated.

Water is diverted over Daniels Pass only during the open season and reservoirs are not used. The average annual loss to the Colorado River basin by diversions over Daniels Pass is about 4,200 acre-feet. The distribution of this loss is shown in the table on page 157.

SOLDIER SUMMIT DIVERSION.

Soldier Summit (⊕ 11, Pl. XIII, in pocket) is the crest of the divide between Price River and Spanish Fork River in T. 10 S., R. 8 E., Salt Lake base and meridian. In about 1896 the Spanish Fork East Bench Irrigation & Manufacturing Co. constructed a ditch over Soldier Summit in T. 10 S., R. 8 E., a short distance north of the tracks of the Denver & Rio Grande Railroad. This ditch, which is known as the White River ditch, diverts water from White River, a tributary of Price River, over the rim of the Great Basin into the basin of Spanish Fork River. The capacity of the ditch is approximately 15 second-feet. Water is used on lands in T. 8 S., R. 3 E. The following table shows approximately the quantity of water diverted over Soldier Summit.

Quantity of water diverted over Soldier Summit, Utah.

	Second-feet.			Acre-feet.
	Maximum.	Minimum.	Mean.	
May (12 days)	15.4	14.6	15.0	358
June	14.6	10.3	12.4	740
July	10.1	.8	4.5	270
August	.8	.8	.8	11
				1,385

Water is diverted only during the irrigation season and no reservoirs are used. The average annual loss to the Colorado River drainage basin by diversion over Soldier Summit is about 1,500 acre-feet and distributed as indicated in the table on page 157.

DUCHESNE AND PROVO RIVERS DIVERSION.

Preliminary investigations have been made by private parties to determine the feasibility of irrigating lands in Utah and Salt Lake counties, Utah, west of Jordan River, by water diverted from the Provo and from the headwaters of the Duchesne over the rim of the Great Basin into the Provo basin. The proposed point of diversion (⊕ 3, Pl. XIII, in pocket) is in T. 3 S., R. 9 E., Salt Lake base and meridian. As water could not, however, be diverted from Duchesne River to Provo River without interfering with the rights of water users on lower Duchesne River during the last half of the irrigation season, the quantity of water which it is physically possible to divert from the basin of the Duchesne into that of the Provo is not here estimated.

DIVERSION FROM VIRGIN RIVER BASIN.

The New Castle Reclamation Co., a private corporation, controls a project (⊕ 1, Pl. XIII, in pocket) in southeastern Utah in Washington and Iron counties. The irrigation plan provides for a reservoir on Grass Valley Creek, a feed canal leading from Santa Clara Creek to the reservoir, a tunnel through the rim of the Great Basin to the drainage basin of Pinto Creek, diversion works on Pinto Creek, and a canal system to serve about 15,000 acres of lands near New Castle, Utah, in T. 36 S., R. 15 W., Salt Lake base and meridian.

Santa Clara Creek, Grass Valley Creek, and Pine Valley are in Virgin River basin. The reservoir and diversion tunnel are in Tps. 38 and 39 S., Rs. 14 and 15 W. (See fig. 2.) A reservoir having a capacity of 23,000 acre-feet is formed by a 90-foot dam on Grass Valley Creek. The diversion tunnel, which leads from the reservoir to the basin of Pinto Creek, is 5½ feet by 6½ feet, inside dimensions, is 5,000 feet long, and for 500 feet is lined with concrete; its capacity is 200 second-feet. This tunnel was completed in August, 1913, but no water was diverted through it during that year. In 1914 about 4,000 acre-feet of water was diverted through the tunnel up to July. A canal having an elevation about 180 feet above the floor of the tunnel has been used at this site since 1909, the average annual diversion through it being 2,000 acre-feet. When this project is completed its average annual diversion from the Colorado River basin will be about 25,000 acre-feet. Owing to the fact that the reservoir is in the Virgin River basin the quantity of water lost to the Colorado River basin will depend on the total run-off from the basin tributary to the reservoir, as the run-off will be stored during the entire year though the diversion to the Great Basin will be made during the irrigation season. The monthly distribution of the loss to the Colorado River basin is shown by the table on page 157.

DIVERSIONS FROM GRAND RIVER BASIN, COLO.

GENERAL CONDITIONS.

The eastern boundary of the Grand River basin is the Continental Divide. For 130 miles along the Continental Divide, between Mount Richthofen and Homestead Peak, there are no passes at altitudes lower than 10,000 feet. Some of the more important passes in this section of the Continental Divide are Tennessee Pass (10,229 feet[1]); Fremont Pass (11,320 feet[1]); Breckenridge Pass (11,500 feet[2]); Rollins Pass (11,680 feet[2]); Devil's Thumb Pass (11,750 feet[3]) and Hoosier Pass (12,450 feet[3]).

[1] Authority, Denver & Rio Grande Railroad survey.
[2] Authority, Wheeler Survey.
[3] Authority, U. S. Geol. Survey.

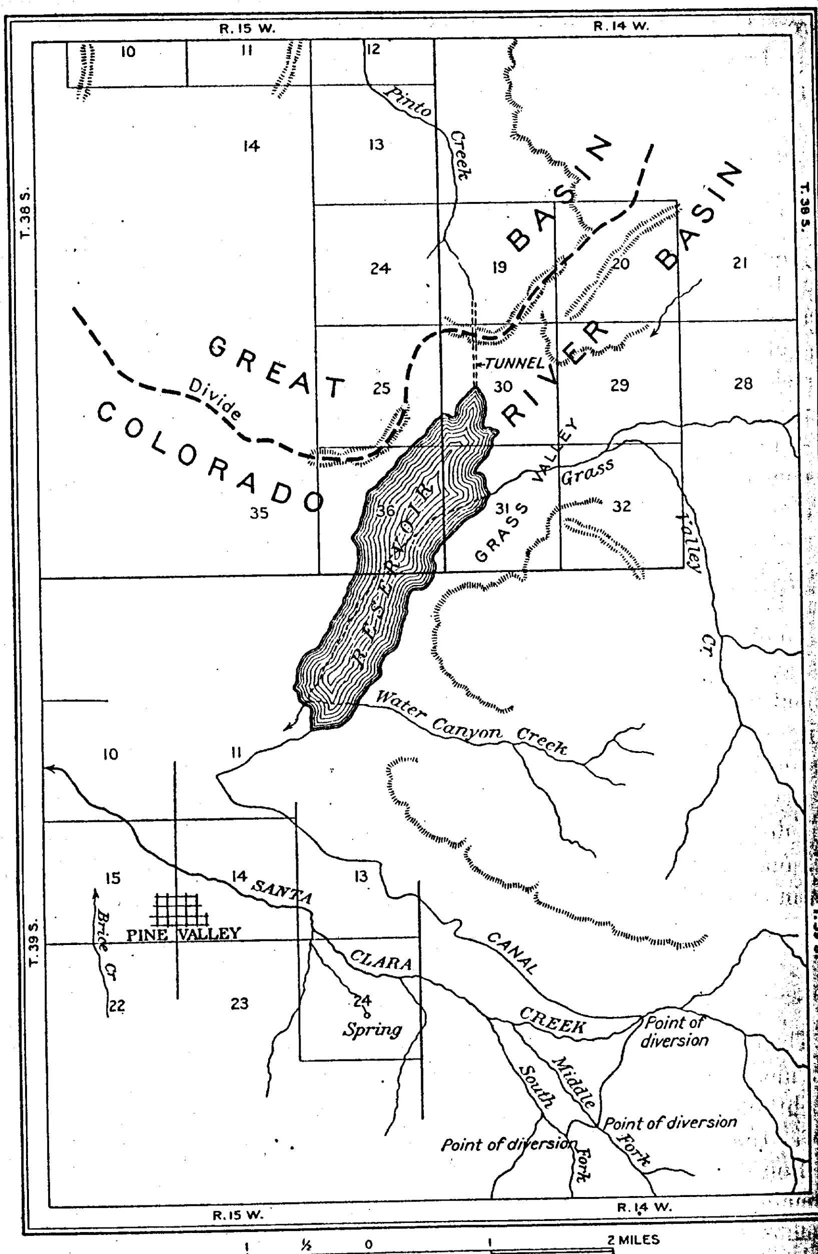


FIGURE 2.—Map showing diversion from Colorado River basin to the Great Basin at headwaters of Virgin River, Utah.

In that part of the Grand River basin between 9,000 feet above sea level and the summit of the Continental Divide the mountain slopes are exceedingly steep, rough, and partly forested, and the run-off is carried in many small channels. As a whole the elevation of the drainage area tributary to the supply canals of constructed and proposed systems under which water is to be diverted over the Continental Divide exceeds 9,500 feet. No known feasible reservoir sites exist on the western slope above the 9,000-foot altitude. Therefore if a relatively large diversion to the eastern slope is to be made the feed canals must be very long and of capacity sufficient to carry the run-off during the flood period, for the water can be diverted only during the open season. The plan of diversion under proposed systems calls for the construction of tunnels varying from 3 miles to 6 miles in length. By utilizing long tunnels some of the feed canals may be constructed at an elevation of 9,300 feet. It is evident that any water diverted to the eastern slope from the Grand River basin will be costly. The quantity of water that will ultimately be carried across the divide will be limited by the value of the water in the South Platte basin.

GRAND RIVER DITCH.

The largest and most successfully operated ditch now diverting water from the Grand River basin to the eastern slope is the Grand River ditch, in Tps. 5 and 6 N., Rs. 75 and 76 W. sixth principal meridian, Colo. (Pl. XV, in pocket). This ditch, which is owned by the Water Supply & Storage Co., is about 9 miles long and diverts the waters of Bennett Creek, Lulu Creek, Sawmill Creek, Dutchtown Creek, and Lost Creek, all tributaries of the North Fork of Grand River. Waters are diverted over a pass south of Lulu Pass into the South Fork of Cascade Creek, a tributary of Cache La Poudre River. A survey has been made for an extension of the ditch to divert the flow from Baker Gulch, 6 miles farther south, but this part of the system has not been constructed. The Water Supply & Storage Co. has been awarded a decree of 524.6 second-feet, with the priority dating back to September 1, 1890. The elevation of the Grand River ditch is between 10,500 feet and 10,800 feet. The drainage basin tributary to the ditch is well forested, the slopes on which the ditch is constructed are not excessively steep, and they are covered with sufficient soil to make practicable the construction of a fairly tight ditch. The operation of the ditch has been fairly successful. A watchman who can be reached by telephone is employed the year round. In order that the ditch may be operated early in the spring it is necessary to remove slide rock and snow. Water is never diverted prior to May 1, and usually the first diversion is made during the period May 15 to 20, but in years of heavy snowfall, with unfavorable weather in the spring, the ditch may not be operated until after June 1.

The drainage area tributary to Grand River ditch is about 15 square miles and the average annual diversion to the eastern slope will be about 16,000 acre-feet, distributed as indicated in the table on page 157. The following records show approximately the quantity of water diverted through the Grand River ditch.

Grand River ditch diversions, in acre-feet.

[From reports of the State engineer of Colorado.]

Month.	1910	1911	1912	1913	1914
May	2,356	1,150	280	1,470	0
June	5,640	3,470	5,308	5,736	2,000
July	1,736	3,906	7,634	2,454	4,574
August	496	948	2,332	434	1,043
September	0	235	168	0	0
October	0	126	0	0	0
November	0	0	0	0	0
	10,228	9,835	15,722	10,094	7,617

FRASER RIVER SYSTEM.

MOFFAT TUNNEL.

The project under which it is proposed to divert water from the headwaters of Fraser River, a tributary of the Grand, to the South Platte basin on the eastern slope affects Tps. 1, 2, and 3 S., Rs. 74, 75, and 76 W. sixth principal meridian, Colo. (Pl. XV, in pocket). Several investigations have been made to determine the feasibility of this project. For a number of years the Denver & Salt Lake Railroad Co. (Denver, Northwestern & Pacific Railway Co.) has been working to obtain funds for the purpose of constructing a tunnel (the Moffat tunnel) 6.04 miles long through the Continental Divide near Rollins Pass at the site (⊕5) shown in Plate XV. The plans finally adopted provide for the construction of the tunnel on a grade of 0.25 per cent for the east half and 0.78 per cent for the west half. The elevation of the east portal would be 9,190 feet and that of the west portal 9,100 feet; the elevation at the midway point in the tunnel would be 9,230 feet. The city of Denver has investigated the feasibility of obtaining an additional municipal supply by diverting water from the Fraser River basin through the proposed railway tunnel (the Moffat tunnel). It would be necessary to carry the water to the midway section of the tunnel under pressure. The elevation of pipe-line intake would be about 9,300 feet. The elevation of the proposed system of supply canals would therefore range from 9,300 feet to perhaps 9,500 feet. The proposed feed canals would extend north and south from the west portal of the tunnel. The north canal would divert the waters of North Ranch, Middle Ranch,

nd South Ranch creeks; the south canal would divert the waters of asquez Creek and Fraser River. Many small intervening streams ould also be intercepted by the canals. The drainage area tributary o this proposed system of feed ditches is about 80 square miles. here are no known feasible reservoir sites above the proposed supply ditches on the western slope, and water could therefore be diverted only during the open season. The diversion period would range rom May to November, inclusive. It is estimated that during years of average run-off about 80,000 acre-feet could be diverted. The verage monthly loss to the Colorado River basin is indicated in the able on page 157.

CHURCH DITCH.

The Church ditch (⊕ 6, Pl. XV, in pocket) or Berthoud Pass anal, was constructed by George H. Church. This ditch is in T. 3 ., R. 75 W., sixth principal meridian, and diverts from the head-aters of Fraser River over the Continental Divide to the basin of lear Creek, a tributary of the South Platte. The maps on file in he State engineer's office show two feeder canals, one from the north nd one from the south, intercepting the headwaters of Fraser River nd several of its tributaries, conveying the water over Berthoud ass to the headwaters of Clear Creek. No work has been done on he north feeder ditch. Of the south feeder ditch about 3 miles have een completed and 3 miles partly excavated. The completed part the ditch, which intercepts Currant Creek and several small streams, onsists of 1 mile of 30-inch wood-stave pipe, about half a mile of nlined open ditch, and about 1 mile of open ditch lined with rubble oncrete and dry rubble. The water is conveyed through the Con-inental Divide by means of a timber-lined tunnel 400 feet long, ving a clear section of 3 feet by 5 feet. The tunnel has a capacity 136 second-feet. This ditch is more than 11,300 feet above sea vel and the season through which it can be operated is short, rely opening before June. The following table, based on reports the State water commissioner, shows the quantity of water di-rted by the Church ditch during the years 1910 to 1913, inclusive:

Church ditch diversions.

Year.	Period.	Acre-feet.
[illegible]0	June 25 to Oct. 15	420
[illegible]1	June 3 to Sept. 9	434
[illegible]2	Oct. 10 to Sept. 14	210
[illegible]3	May 17 to Sept. 20	1,162
[illegible]4		476

The Church ditch was completed prior to 1907, was put in opera-n in 1910, and has a decreed right of 53 second-feet, dated June , 1902. The drainage area tributary to the ditch is about 3 square miles. It seems probable that with better care about 4,000 acre-feet annually could be diverted through the Church ditch from the Fraser River drainage. The manner in which the loss to the Colorado River basin would be distributed through the year is indicated in the table on page 157.

WILLIAMS FORK DIVERSION.

Two companies have investigated the feasibility of diverting water from the upper basin of Williams Fork (⊕ 7, Pl. XV, in pocket), a tributary of Grand River, to the basin of Clear Creek, a tributary of the South Platte. The plans of one of the companies, filed in the State engineer's office January 4, 1909, call for the construction of a tunnel 14,725 feet long and two main feed ditches, one extending north 2 miles and the other south 20 miles from the proposed location of the tunnel, at an elevation of 10,300 to 10,500 feet above sea level. The drainage area tributary to the proposed ditches above the 10,300-foot contour is about 33 square miles. This project has been under consideration since 1902. A small amount of work has been done on both portals of the tunnel but none on the canals. If the feed ditches were constructed to intercept McQueary, Steelman, and Bobtail creeks, South Fork of Williams River, and numerous small intervening streams, about 46,000 acre-feet could probably be diverted annually. Water could, however, be diverted only during the open season, as there are no feasible reservoir sites above the proposed feed canals. The probable monthly diversion is shown in the table on page 157.

BLUE RIVER SYSTEM.

SWAN-TARRYALL CREEK DIVERSION.

For many years private parties have been interested in a plan (⊕ 8, Pl. XV, in pocket) to divert water by means of a tunnel 23,252 feet long leading from the headwaters of Swan Creek, a tributary of Blue River, to the headwaters of Tarryall Creek, a tributary of South Platte River. According to the plans on file in the State engineer's office two feed canals, with an aggregate length of about 80 miles, will convey water to the tunnel. The following streams would be intercepted by the feed ditches: Blue River, Miners Creek, Indian Creek, French Creek, Swan River, Snake Creek, Keystone Creek, Tenmile Creek, and a large number of small intervening streams. The drainage area tributary to the proposed canal system is about 175 square miles. There are no reservoir sites at the headwaters of Blue River above the proposed canals, but storage reservoirs on the eastern slope could be utilized and water would be diverted only during the open season. The elevation of the proposed tunnel is about 10,300 feet. The elevation of the feed ditches would range from 10,300 to about 10,600 feet. If this system were completed as planned it is probable that during an average year about 90,000 acre-feet could be diverted to the South Platte drainage. The probable distribution of the loss to the flow of Grand River throughout the year is shown by the table on page 157.

There are two power plants near the headwaters of Blue River which might limit the diversion of water during certain periods of the year. The Spruce Creek hydroelectric plant, on Blue River a few miles south of Breckenridge, was constructed in 1902 and is operated during the summer and fall; it uses 20 second-feet under a head of 500 feet. The Summit County Power Co. has a hydroelectric plant at Dillon, on Snake River, which was constructed in 1908 and uses about 50 second-feet under a head of 500 feet. The plant is operated only during the summer months. Power is used for mining.

BRECKENRIDGE PASS DIVERSION.

A small ditch, known as the Link-Slater canal, diverts water from the headwaters of Blue River across Breckenridge Pass (⊕12, Pl. XV, in pocket), in T. 7 S., R. 77 W., sixth principal meridian, to the basin of Tarryall Creek, a tributary of the South Platte. Its capacity is about 6 second-feet. The elevation of the ditch is 11,500 feet, but the season through which it can be operated is very short. The quantity of water actually diverted is not known, but it is probably not greater than 700 acre-feet annually. The distribution of the loss to the flow of Grand River indicated by the table on page 157 is based on the assumption that only 650 acre-feet is diverted.

EAGLE RIVER SYSTEM.

Private parties have proposed to divert the headwaters of Eagle River (⊕ 9, Pl. XV, in pocket), which joins the Grand about 20 miles above Glenwood Springs, across Tennessee Pass to the headwaters of the Arkansas. The plan of development provides for a short tunnel at Tennessee Pass, in T. 8 S., R. 80 W., sixth principal meridian, at an elevation of 10,000 feet above sea level, and north and south feed ditches to convey the water to the tunnel. The south canal would be about 5 miles long and would intercept Bennett Creek and Eagle River; the north canal would intercept the East Fork of Eagle River, Tenmile Creek, Searl Gulch, Mayflower Gulch, and Clinton Gulch, tributaries of Tenmile Creek. The development of this project would interfere somewhat with the proposed south canal of the Blue River system, which has been planned to intercept Tenmile Creek, Mayflower Gulch, and Clinton Gulch, tributaries of Tenmile Creek. In estimating the amount of water that could be diverted under the proposed Blue River system (pp. 154–155) the water from the Tenmile Creek basin was included. The quantity of water that can be diverted across Tennessee Pass has been estimated on the assumption that 22 square miles, including 6 square miles on the west side of the Tenmile Creek basin, would be tributary to the proposed canal system. The elevation of the north and south canals would range from 10,000 feet to about 10,300 feet. Excluding that part of the drainage area of Tenmile Creek tributary to the proposed Blue River system, the quantity of water that can be diverted across Tennessee Pass annually is approximately 21,000 acre-feet. The table on page 157 shows the manner in which this loss to the flow of Grand River would be distributed through the year.

For a number of years a small ditch has diverted water from Piney Creek, a small tributary of Eagle River, across Tennessee Pass to the Arkansas River basin. The drainage area of Piney Creek above the point of diversion is 3.67 square miles. The water is used in mining. The annual diversion probably does not exceed a few hundred acre-feet.

SUMMARY OF DIVERSIONS FROM COLORADO RIVER BASIN.

The only works diverting water from the western part of the Colorado River basin are in the State of Utah near the headwaters of Virgin, Price, and Duchesne rivers. Four systems are in operation, and one which affects the headwaters of Duchesne River is proposed but will probably never be constructed.

From the headwaters of Grand River and its tributaries four ditches divert annually about 21,000 acre-feet of water to the drainage basins of South Platte and Arkansas rivers, and four large systems have been planned to divert to the eastern slope about 237,000 acre-feet annually, making a total of 258,000 acre-feet for systems in operation and proposed. Most of this water would be diverted during the high-water period. When the Grand Valley project of the United States Reclamation Service is completed the normal flow of Grand River during years of low run-off will barely meet the demands of irrigation. It is therefore apparent that during such years any appreciable quantity of water diverted from the headwaters of Grand River to the eastern slope will increase the shortage in the supply available for irrigation in the vicinity of Palisade and Grand Junction, Colo. The operation of the hydroelectric plant on Grand River above Glenwood Springs, owned by the Central Colorado Power Co., may also be affected. The shortage due to such diversions might possibly be remedied by constructing on the headwaters of the Grand a storage reservoir having a capacity of approximately 100,000 acre-feet. The utilization of the Kremmling reservoir site, the capacity of which is

more than 1,000,000 acre-feet, in connection with a plan to control the floods of lower Colorado River, would also dispose of the problem.

The total quantity of water diverted from the Colorado River basin by all ditches now in operation and that would be diverted if proposed ditches were completed is shown by the following table to be about 378,000 acre-feet. If retained in the basin, however, all this water would not be available for the irrigation of lands below Virgin River, for there would be a certain loss—probably not greater than 10 per cent—due to evaporation. It is possible, therefore, that diversions from the basin may in the future result in a direct loss to the flow of the lower Colorado of 340,000 acre-feet.

Estimate of present and proposed diversions from the Colorado River basin.

From the Virgin and Green River basins to the Great Basin.

[All projects in Utah.]

Month.	Strawberry Valley tunnel.	Daniels Pass diversion.	Soldier Summit diversion.	New Castle reclamation project.	Total.	Total.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Second-feet.*
January	2,000	0	0	3,400	5,400	88
February	1,800	0	0	2,600	4,400	79
March	2,200	0	0	3,200	5,400	88
April	10,000	0	0	3,000	13,000	218
May	38,000	1,600	400	3,500	43,500	707
June	14,000	1,200	800	2,800	18,800	316
July	8,000	700	280	1,100	10,080	164
August	3,500	320	20	700	4,540	74
September	2,800	280	0	900	3,980	67
October	3,100	100	0	2,000	5,200	85
November	2,300	0	0	1,100	3,400	57
December	2,300	0	0	700	3,000	49
	90,000	4,200	1,500	25,000	120,000	....

From Grand River basin to South Platte and Arkansas river basins.

[All projects in Colorado.]

Month.	Grand River ditch.[a]	Church ditch.[a]	Breckenridge Pass ditch.[a]	Fraser River system.	Williams Fork system.	Blue River system.	Eagle River and Tenmile Creek system.	Total.	Total.
	Acre-ft.	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Sec.-ft.*
January	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0
May	1,600	200	0	10,000	1,000	2,000	2,000	16,800	273
June	6,000	1,600	200	32,000	23,000	40,000	10,000	112,800	1,900
July	5,500	1,000	300	18,000	10,000	21,000	5,000	60,800	989
August	2,500	600	100	8,000	5,000	8,000	2,000	26,200	426
September	300	400	50	5,000	2,000	9,000	1,000	17,750	298
October	100	200	0	4,000	3,000	6,000	800	14,100	229
November	0	0	0	3,000	2,000	4,000	200	9,200	155
December	0	0	0	0	0	0	0	0	0
	16,000	4,000	650	80,000	46,000	90,000	21,000	258,000	....

[a] In operation.

Estimate of present and proposed diversions from the Colorado River basin—Continued.

Summary of estimates.

Month.	Ditches in Utah.		Ditches in Colorado.		Total all ditches in Colorado River basin.	
	Acre-feet.	*Second-ft.*	*Acre-feet.*	*Second-ft.*	*Acre-feet.*	*Second-ft.*
January	5,400	88	0	0	5,400	88
February	4,400	79	0	0	4,400	79
March	5,400	88	0	0	5,400	88
April	13,000	218	0	0	13,000	218
May	43,500	707	16,800	273	60,300	981
June	18,800	316	112,800	1,900	131,600	2,210
July	10,080	164	60,800	989	70,880	1,160
August	4,540	74	26,200	426	30,740	500
September	3,980	67	17,750	298	21,730	365
October	5,200	85	14,100	229	19,300	314
November	3,400	57	9,200	155	12,600	212
December	3,000	49	0	0	3,000	49
	120,000	....	258,000	....	378,000	....

NOTE.—Discharge in second-feet computed from estimates of approximate discharge in acre-feet.

SUMMARY OF IRRIGATION IN THE COLORADO RIVER BASIN.

The available information concerning the irrigated and irrigable areas in the entire basin of the Colorado are conveniently summarized in the following tables. The first presents data for the areas between the heads of Green and Grand rivers, to and including the basin of Virgin River; the second gives similar data for areas lying below the mouth of the Virgin, and including areas irrigated in Salton Basin. Between these two sections the Grand Canyon stands as a natural barrier. The only lands irrigable by direct diversion in this 616-mile stretch of the river are garden patches a few acres in extent.

Irrigated and irrigable lands in upper basin of the Colorado, including Virgin River.

From—	Area irrigated in 1913.	Additional area that may be irrigated.
	Acres.	*Acres.*
Green River and tributaries in Wyoming	280,000	300,000
Henry's Fork in Utah	5,000	10,000
Sheep Creek	200	0
Carter Creek	200	0
Pot and Grouse creeks	600	100
Brush Creek	2,000	4,000
Ashley Creek	30,000	15,000
Duchesne River	60,000	180,000
Minnie Maud Creek	2,000	0
Price River	15,000	50,000
San Rafael River	35,000	30,000
Fremont River	15,000	40,000
Escalante River	1,500	12,000
Paria River	2,000	10,000
Kanab Creek	2,000	1,500
Virgin River	20,000	48,000
Yampa River	40,000	260,000
White River	26,000	150,000
Grand River	302,200	475,000
San Juan River	117,000	595,000
Little Colorado River	20,000	30,000
Green River direct, in Utah	4,000	170,000
Colorado River direct	300	0
	980,000	2,380,000

Irrigated and irrigable lands in lower basin of the Colorado, including all areas below mouth of Virgin River.

From—	Area irrigated in 1913.	Additional area that may be irrigated.
Colorado River direct, as follows:	*Acres.*	*Acres.*
Cottonwood Valley above Bulls Head	200	5,000
Mohave Valley between Bulls Head and Mellen	5,000	48,000
Chemehuevis Valley	....	28,000
Colorado River Indian Reservation, by gravity	2,000	120,000
Colorado River Indian Reservation, by pumping	....	60,000
Calzona Valley	....	18,000
Palo Verde Valley	25,000	75,000
Palo Verde Mesa, by pumping	....	100,000
Chuckwalla Valley, by pumping	....	214,000
Cibola Valley	1,000	18,000
Yuma project, U. S. Reclamation Service, by gravity	20,000	65,000
Yuma project, U. S. Reclamation Service, by pumping	....	83,000
Imperial Valley in the United States	264,000	636,000
Imperial Valley in Mexico	50,000	200,000
Lands east and south of Volcano Lake in Mexico	....	250,000
Lands east of dry channel Colorado River and west of Del Rio tract, Mexico	....	150,000
Del Rio tract, in Mexico	....	297,000
	367,200	2,367,000
Tributaries:		
Williams River	600	2,000
Gila River	283,000	150,000
	651,000	2,519,000

Total area irrigated in Colorado River basin in 1913:
United States..........acres.. 1,581,000
Republic of Mexico..........do.... 50,000
— 1,631,000

Total additional area that may be irrigated:
United States..........acres.. 4,002,000
Republic of Mexico..........do.... 897,000
— 4,899,000

Total area ultimately irrigable in Colorado River basin.acres.. 6,530,000

If irrigation in the Colorado River basin reaches its extreme development, about 5,580,000 acres may be under irrigation in the United States and 947,000 acres in Mexico.

In the following table the areas irrigated and irrigable from Colorado River and tributaries are summarized by States:

Areas irrigated and irrigable from Colorado River and its tributaries.

State.	Within the basin.		Outside the basin.	Total area ultimately irrigable.	Approximate percentage.
	Area irrigated in 1913.	Additional area that may be irrigated.			
	Acres.	*Acres.*	*Acres.*	*Acres.*	
Wyoming	280,000	300,000	....	580,000	9.0
Utah	204,000	610,000	43,000	857,000	13.0
Colorado	440,000	937,000	100,000	1,477,000	22.0
New Mexico	40,000	508,000	....	548,000	8.0
Arizona	315,000	570,000	....	885,000	13.0
Nevada	5,000	9,000	....	14,000	.2
California	*a* 297,000	*a* 1,068,000	....	1,365,000	20.8
United States	1,581,000	4,002,000	143,000	5,726,000	86.0
Republic of Mexico	50,000	897,000	....	947,000	14.0
Total	1,631,000	4,899,000	143,000	6,673,000	100.0

a Includes Imperial Valley projects.

ADEQUACY OF WATER SUPPLY FOR LANDS ON LOWER COLORADO.

The quantity of water that would be required to irrigate properly the 2,730,000 acres of land irrigable from the Colorado below Virgin River, with a head-gate duty of 5 acre-feet, is shown by the following table. The probable distribution of water diverted each month of the year in per cent of the total diversion for the year is based on the record of diversions through the Imperial canal during the years 1911, 1912, and 1913.

Water necessary to serve irrigable lands below Virgin River.

Month.	Total demand.		Acre-feet per acre.	Per cent.
	Acre-feet.	*Second-feet.*		
January	820,200	13,300	0.30	5.97
February	765,520	13,800	.28	5.64
March	1,093,600	17,800	.40	7.8[illegible]
April	1,148,280	19,300	.42	8.46
May	1,257,640	20,500	.46	9.14
June	1,257,640	21,100	.46	9.17
July	1,558,380	25,300	.57	11.[illegible]
August	1,449,020	23,600	.53	10.8[illegible]
September	1,312,320	22,100	.48	9.65
October	1,257,640	20,500	.46	9.14
November	902,220	15,200	.33	6.46
December	847,540	13,800	.31	6.2[illegible]
	13,670,000		5.00	100.00
Yearly mean		18,930		

It will be noted that with 2,730,000 acres under irrigation below the mouth of the Virgin, the minimum mean monthly demand of 13,300 second-feet would occur in January; the maximum mean monthly demand—25,300 second-feet—would occur in July. The total annual demand would be 13,670,000 acre-feet. It has already been shown that the lower tributaries, Gila, Williams, Virgin, Little Colorado, and Paria rivers, and Kanab Creek will discharge little if any water to the Colorado if full use for irrigation is made of the waters of those streams within their own basins. The drainage area of the lower Colorado outside that tributary to the above-named streams yields little run-off, as the mean annual precipitation over this section is only about 3 inches. It therefore seems probable that water for the irrigation of the 2,730,000 acres below the mouth of the Virgin must ultimately come from the region above the mouth of Paria River or above the Grand Canyon. It is difficult to estimate the quantity of water that will reach the Colorado when all lands susceptible of irrigation in the basin above and including Virgin River are placed under cultivation, but doubtless some seepage water will reach the main stream from the irrigated lands. The water available for the irrigation of lands on the lower Colorado can not be accurately estimated for lack of discharge records.

The following table shows the water that was available during the period 1902 to July, 1914, inclusive, the estimated demand for the

irrigation of 2,730,000 acres below Virgin River, with a head-gate duty of 5 acre-feet, the surplus for the period in which the actual flow was greater than the irrigation demand, and the shortage for the period in which the actual flow was less than the irrigation demand. The supply available was estimated by deducting from the recorded discharge of the Colorado at Yuma the recorded flow of the Gila and probably represents fairly the discharge of the Colorado at Hardyville during the period:

Mean annual supply of and estimated demand for water to irrigate land in the lower Colorado basin.

Year.	Supply.	Demand.	Surplus for period in which actual flow was greater than demand.	Shortage for period in which actual flow was less than demand.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1902	7,959,000	13,670,000	2,225,000	
1903	11,268,000	13,670,000	3,467,000	7,480,000
1904	9,892,000	13,670,000	1,794,000	6,156,000
1905	15,946,000	13,670,000	6,030,000	3,543,000
1906	17,423,000	13,670,000	6,898,000	4,293,000
1907	21,818,000	13,670,000	12,315,000	2,099,000
1908	12,590,000	13,670,000	2,146,000	2,295,000
1909	25,314,000	13,670,000	13,420,000	2,809,000
1910	14,111,000	13,670,000	4,847,000	1,334,000
1911	17,565,000	13,670,000	6,085,000	4,651,000
1912	18,145,000	13,670,000	7,766,000	2,909,000
1913	11,697,000	13,670,000	3,051,000	3,670,000
1914 [a]	16,307,000	13,670,000	9,191,000	4,205,000
	203,035,000	177,710,000	79,235,000	45,444,000

[a] January to July, inclusive.

It will be noted that during the period covered by the table 203,035,000 acre-feet passed Hardyville, Ariz.; the demand for water to irrigate 2,730,000 acres during this same period would have been 177,710,000 acre-feet. This table apparently indicates that the flow of the Colorado is sufficient to serve properly the irrigable land below Virgin River if the flow of the Colorado is under complete control (Pl. XVI, in pocket). The mass curve (Pl. XVII) shows that theoretically 14,000,000 acre-feet storage would have been required to meet the demand during the low-water stage covering the period July 1, 1902, to February 1, 1905. This estimate is based on the assumption that there would be no losses in transportation of stored water, but it is probable that 20 per cent of the stored water would be lost by evaporation or wasted by improper regulation. The reservoirs would be several hundred miles above the lands to be irrigated, and it would be necessary to deliver more water than was actually required in order to avoid the probability of a shortage. No doubt considerable water would be necessarily wasted during periods of violent storms that might affect the Colorado River basin below the storage reservoirs, as the outlet gates at the reservoirs could not be closed in sufficient time to prevent the discharge of the lower Colorado from greatly exceeding the demand for irrigation. Assuming, therefore, that 20 per cent would cover all losses in stored water, storage reservoirs would be required with an aggregate capacity of 18,000,000 acre-feet. This estimate of storage requirement is based on the assumption that the entire run-off of Colorado River is to be regulated for the irrigation of lands below Virgin River and that there will be no increase in the irrigated area above Virgin River. To make up the shortage during the years of low run-off—1902 to 1905—would have required 18,000,000 acre-feet storage. This may therefore be considered the maximum storage requirement under most unfavorable conditions.

There are reservoir sites on the upper Colorado and its tributaries which, if utilized, would place the Colorado under complete control (p. 218).

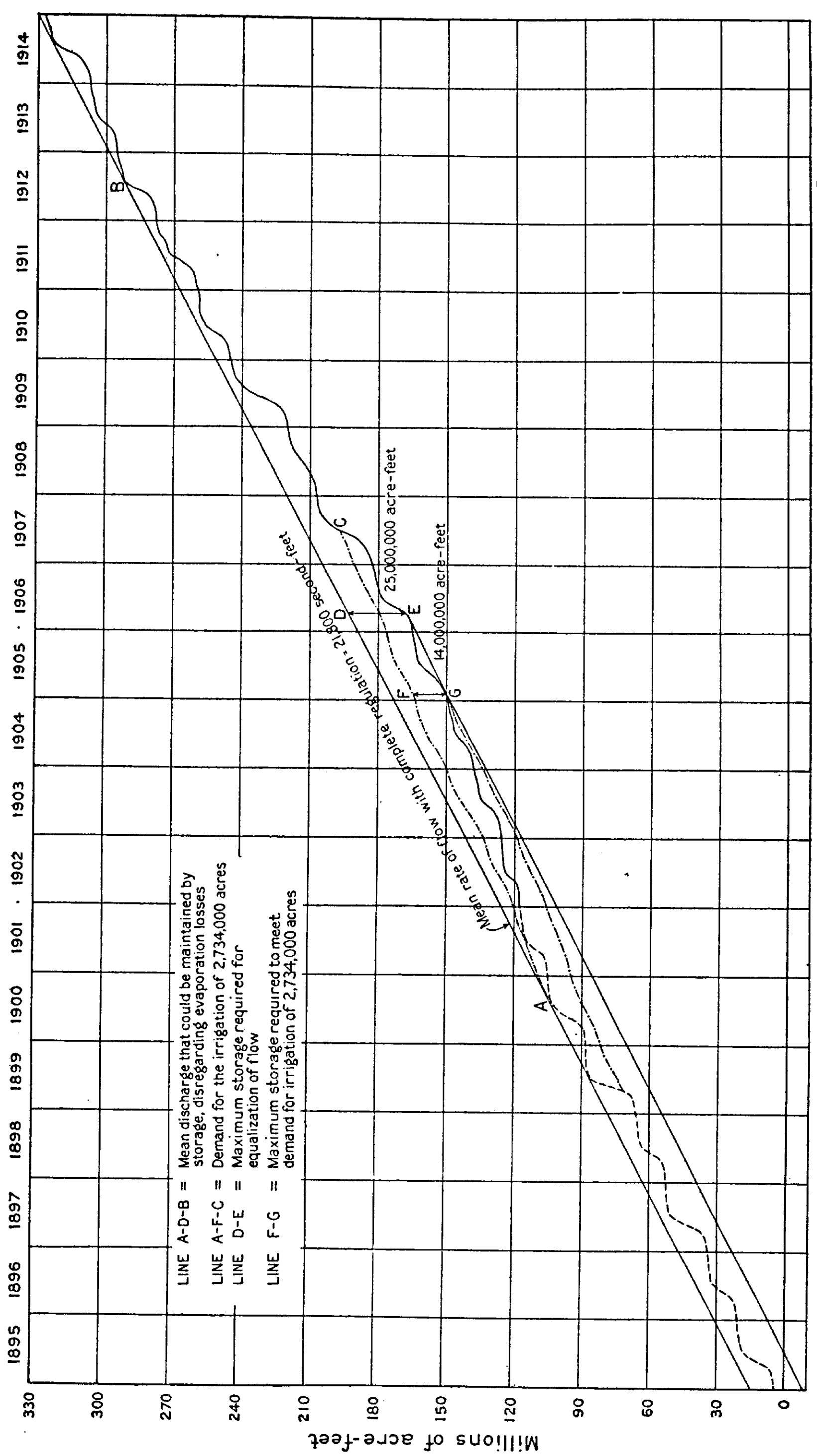
EFFECT OF INCREASE IN IRRIGATED AREA ABOVE VIRGIN RIVER ON THE FLOW OF THE LOWER COLORADO.

The table on page 158 shows that approximately 980,000 acres were irrigated in the Colorado River basin above and including the Virgin in 1913, and that an additional area, roughly estimated at 2,380,000 in 1913, and that an additional area, roughly estimated at 2,380,000 acres, is susceptible of irrigation. During the year 1913, with 980,000 acres irrigated above the Virgin, 11,788,000 acre-feet of water passed the gaging station on the Colorado at Yuma, Ariz. Of this amount 1,693,000 acre-feet was diverted to the Imperial Valley, leaving 10,095,000 acre-feet as the amount of water that wasted into the Gulf of California. If additional areas aggregating 2,380,000 acres are placed under irrigation above and including the Virgin, the discharge of the lower Colorado will be materially reduced, but the estimation of the amount of the reduction presents a problem containing so many factors that no two engineers working independently would be likely to arrive at the same result. It should be remembered that the following discussion represents the opinion of but one engineer.

The situation of the additional areas that may be irrigated is shown by the following table:

Irrigable areas in basin of the Colorado above and including Virgin River.

From—	Acres.
Green River and tributaries in Wyoming	300,000
Henrys Fork in Utah	10,000
Pot and Grouse creeks	100
Brush Creek	4,000
Ashley Creek	15,000
Duchesne River	180,000
Price River	50,000



MASS CURVE SHOWING REGULATION OF COLORADO RIVER AT HARDYVILLE, ARIZ., 1895 TO 1914, INCLUSIVE.

From—

	Acres.
San Rafael River	30,000
Fremont River	40,000
Escalante River	12,000
Paria River	10,000
Kanab Creek	1,500
Virgin River	48,000
Yampa River	260,000
White River	150,000
Grand River	475,000
San Juan River	595,000
Little Colorado River	30,000
Green River direct in Utah	170,000
	2,380,600

The additional areas that may be irrigated near the headwaters of the various tributaries in Utah, Wyoming, and Colorado consist chiefly of hay lands. The irrigation season is short and large quantities of water are used. In many places 10 to 20 acre-feet of water per acre irrigated is turned onto the land, but only a comparatively small amount of water—possibly not more than half an acre-foot per acre irrigated—is actually consumed or lost to the main stream, as a large part of the amount diverted returns to the stream as surface flow or seepage. For the cultivation of the large areas of irrigable lands lower down on the various tributaries the average diversion from the main stream or head-gate duty is about 3.5 acre-feet. The diagram (fig. 3) shows the head-gate duty or diversion in acre-feet per acre irrigated near Grand Junction, Colo., to be 4.16 acre-feet. This diagram was based on a study of the diversions made for the irrigation of 43,000 acres during a dry year with an abundance of water available.

Though the head-gate duty for the additional lands that may be irrigated in Utah, Wyoming, and Colorado may not vary greatly, the quantity of water consumed by the growing crops and the quantity that will return to the stream and finally reach the Colorado depends on the quantity diverted, and on the character of the crops and soil. On some of the streams little of the water diverted for the irrigation of new lands on the upper stretches will be returned to the stream and be available for rediversion lower down. Physical conditions in the upper basin of the Colorado favor a comparatively high return flow from the irrigated areas in this part of the basin. Green, Yampa, White, Grand, San Juan, Price, San Rafael, Fremont, and Escalante rivers occupy deep box canyons for many miles of the lower sections of their drainage areas. For example, none of the water that reaches the Green below the mouth of the San Rafael, the Grand below Westwater, Colo., the San Juan below Shiprock, N. Mex., can be rediverted for irrigation above the mouth of the Virgin, for it finds its way through the canyons of the tributaries to the Grand Canyon of the Colorado, where diversion is not possible.

An interesting comparison may be drawn between the streams of the upper Colorado basin and Arkansas and North and South Platte rivers in Colorado and Wyoming. In the 800 miles of canyons of the lower Green and Grand rivers and the upper Colorado in southern Utah and northern Arizona water can never be diverted for irrigation; whereas diversion of the waters of the Arkansas, for example, is possible at many places between Canon City and the Colorado-Kansas State line. During years of average run-off almost the entire flow is diverted at several points below Canon City, and the return seepage from the irrigated lands is rediverted for irrigation lower down on the

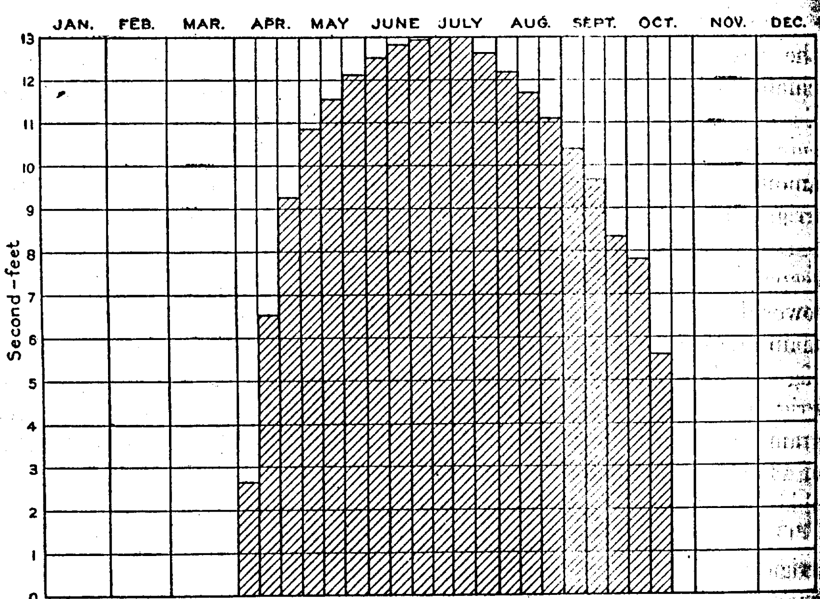


FIGURE 3.—Diagram showing head-gate diversion for irrigation of 1,000 acres near Grand Junction, Colo.

stream. Irrigation in the Arkansas basin in Colorado is so highly developed that little water passes the Colorado-Kansas State line except during periods of sudden floods. Conditions on the North Platte and the South Platte in Wyoming and Colorado are similar to those on the Arkansas in Colorado.

On the assumption that 2,380,000 acres are to be placed under cultivation in the region above and including Virgin River, a large part of the water for these lands would be provided by utilizing small reservoirs. The demand on the water supply of the lower Colorado would extend over the entire year, though most of the water would be stored during the flood period or in May, June, and July. Probably at least 6,000,000 acre-feet would be diverted between May 1 and October 1 each year.

For some of the new projects under consideration in the upper Colorado basin 2 acre-feet storage per acre to be irrigated will be required; for others perhaps less than 1 acre-foot per acre irrigated may suffice. It seems reasonable to assume necessity for at least 1 acre-foot storage per acre to be irrigated, that is, that storage reservoirs will be constructed with an aggregate capacity of 2,380,000 acre-feet. Seepage water from these reservoirs would no doubt find its way to the main streams and be available for irrigation below. Loss due to evaporation should, however, be considered. With a large number of reservoirs, having an aggregate capacity of about 2,380,000 acre-feet, approximately 75,000 acres of water surface would be exposed to evaporation. For a conservative estimate it has been assumed that 50,000 acres of water surface would be exposed six months each year and that the evaporation during this period would be at least 2 feet; on this assumption the loss due to evaporation alone would be 100,000 acre-feet.

It is well known that all the irrigable lands under any canal system are not irrigated each year. For example, one water user may have his entire farm in crops one year but in the following year may cultivate not more than half his farm. For various reasons some of the farms may be idle. It has been assumed that on an average about 70 per cent of the irrigable lands under the various canal systems would be irrigated each year—that is, that about 1,666,000 acres of additional land would actually be irrigated in the region above and including the basin of the Virgin each year. The average head-gate duty for this net area to be irrigated would be about 3.5 acre-feet, which would mean that 5,831,000 acre-feet would be diverted during the irrigation season, or between May 1 and October 1, each year. Concerning the quantity of water actually consumed and lost to the main stream and the quantity returning to the main stream as seepage and surface waste from the irrigated lands little information is available, but the results of some investigations indicate that about 25 per cent of the water diverted may return to the stream. From 5,832,000 acre-feet diverted, therefore, approximately 1,457,000 acre-feet may be returned to the Colorado and its tributaries and become available for irrigation on the lower Colorado. Under these conditions of development above the Virgin the total loss to the flow of the lower Colorado would be about 4,374,000 acre-feet.

SUMMARY.

An attempt has been made to estimate the quantity of water that will be consumed by the future developments, but the results should be considered only roughly approximate. The losses to the flow of the lower Colorado, due to future development above Hardyville, may be classified as follows:

1. Losses due to diversion for irrigation within the Colorado River basin.

2. Losses due to diversions from the Colorado River basin to other drainage basins.

3. Losses due to evaporation from the water surface of reservoirs used for irrigation and river control.

To estimate approximately the loss to the flow of the lower Colorado due to diversions for irrigation of additional areas within the Colorado River basin above Hardyville, the following assumptions have been made: (1) That the area watered each year is 70 per cent of the area irrigable under the various systems; (2) that the head-gate duty for the net area irrigated each year is 3.5 acre-feet; (3) that 25 per cent of the water diverted will return to the streams as seepage from the irrigated lands. The additional area that may be irrigated in the Colorado River basin above and including Virgin River is estimated at 2,380,000 acres. If 70 per cent of this area is irrigated each year sufficient water must be diverted annually to irrigate 1,666,000 acres. If the average head-gate duty is 3.5 acre-feet, 5,832,000 acre-feet will be diverted annually. If 25 per cent of this water returns to the stream and is available for irrigation below, the net loss to the flow of the upper Colorado and its tributaries, due to diversions for irrigation, would be 4,374,000 acre-feet.

Diversions from the Colorado River basin to other drainage basins will also reduce the supply available for use on the lower Colorado. Present diversions are small, but the future loss to the lower Colorado from this cause is roughly estimated at 340,000 acre-feet annually.

The loss due to evaporation from the reservoirs that might be constructed in the Colorado River basin above Hardyville is difficult to predict. Though a fairly accurate estimate might be prepared of the annual loss by evaporation from the water surface of the large reservoirs that may be used in connection with the control of the Colorado, the number of small reservoir sites that will be utilized in connection with future irrigation developments can not be forecast. Ten of the larger reservoir sites in the basin above Lee Ferry afford an aggregate capacity of 30,800,000 acre-feet (see p. 218); with reservoirs full the total area exposed to evaporation would be approximately 313,000 acres. If the Colorado is completely controlled for irrigation it will be necessary to construct some storage dams for the purpose of holding the stored water for perhaps two or three years to augment the flow during a series of years of low run-off. It seems reasonable to believe, therefore, that 75 per cent of the aggregate area exposed to evaporation with the reservoirs full would be exposed throughout the year. The average annual loss due to evaporation from all the reservoirs would probably amount to 3.5 feet in depth, and the total annual loss due to evaporation would be about 822,000 acre-feet. This estimate should be increased to 1,000,000 acre-feet in order to include the losses due to evaporation from the water surface of the hundreds of small reservoirs that will be utilized in connection with future irrigation systems.

On summarizing the data relative to the future reduction in the flow of the lower Colorado, we have:

	Acre-feet.
Estimated loss due to possible future irrigation above Hardyville	4,374,000
Estimated loss due to future diversions from the Colorado River basin	340,000
Estimated loss due to evaporation from the water surface of various reservoirs that may be constructed in connection with future irrigation and for the purpose of river control	1,000,000
	5,714,000

If the mean flow at Hardyville for the years 1902 to 1913, inclusive, estimated at 15,560,000 acre-feet, represents the average flow that might be expected at Hardyville in future years without future development above Hardyville, it may be assumed that the full utilization of the Colorado and its tributaries above Hardyville would reduce the mean annual flow at Hardyville (or below the Virgin) to about 9,900,000 acre-feet. It is estimated that the irrigable area below the Virgin, aggregating 2,730,000 acres, will need for complete development 13,670,000 acre-feet of water annually.

The figures here presented therefore indicate that complete utilization and control of the stream waters in the upper basin will create a shortage of about 3,800,000 acre-feet in the supply available for the lower basin. More complete data would probably indicate a greater shortage in the water supply available for the irrigation of lands on the lower Colorado. Evidently the flow of Colorado River and its tributaries is not sufficient to irrigate all the irrigable lands lying within the basin. If diversion to other drainage basins were prohibited by law about 340,000 acre-feet annually might be saved for use on the lower Colorado, but this quantity is small when compared to the shortage that may be expected. The adoption of a policy or plan of development tending to prevent the unnecessary waste of water can not be too strongly urged.

ACCURACY OF ESTIMATES.

The figures in the foregoing discussion indicate the available water supply and requirements for storage under the most favorable conditions, but their accuracy depends on many factors that may tend to reduce the estimate of discharge of the lower Colorado, so that an area below Virgin River much less than 2,730,000 acres would be irrigated, and a storage capacity of less than 18,000,000 acre-feet would be necessary. Among the factors affecting the problem the following may be mentioned:

1. The discharge of the Colorado at Yuma, Ariz., has been computed from records obtained at that point by the United States Reclamation Service and the United States Geological Survey. The gaging station at Yuma is a short distance below the mouth of Gila River. The water available for the irrigation of lands below the mouth of Virgin River was roughly estimated by deducting the measured flow of the Gila from the measured flow at Yuma. No other correction was made in these records, although water for the reclamation of about 53,000 acres was diverted from the Colorado between Virgin River and the Yuma gaging station in 1913, that is, the discharge estimated by deducting the flow of the Gila from that of the Colorado at Yuma would be somewhat less than the actual flow below the mouth of the Virgin or at Hardyville, Ariz. Probably about 150,000 acre-feet of water was lost to the Colorado by diversion during 1913 between Hardyville and Yuma, Ariz. Furthermore, the Colorado loses some water by evaporation in the 244 miles between Hardyville and Yuma. If the average width of the river is assumed to be about 1,000 feet and the annual evaporation 7 feet the loss from evaporation in this section would be 218,000 acre-feet. The water surface exposed to evaporation is no doubt greatly increased during years of high run-off, when 100,000 to 200,000 acres on the section of the Colorado between Hardyville and Yuma may be inundated. Though the discharge estimated by deducting the flow of the Gila from that of the Colorado below Yuma is apparently less than the actual discharge of the Colorado at Hardyville, Ariz., the small error introduced is probably counterbalanced by the fact that a head-gate duty of 5 acre-feet has been applied to the discharge records at Hardyville, when in reality the head-gate duty should be applied at the respective canal headings after deducting from the actual flow at Hardyville the loss due to evaporation below Hardyville. Therefore the use of the discharge record thus obtained to determine the water available for the irrigation of lands on the lower Colorado seems consistent.

2. Since 1902 the areas irrigated in the Colorado basin above Yuma have been largely increased. In other words, if exactly the same climatic conditions that determined the flow of the Colorado during the 12-year period beginning with the year 1902 were reproduced for a 12-year period beginning with the year 1915, the run-off during the later period would be less than that during the earlier. For example, if the climatic conditions that produced the run-off of 7,959,000 acre-feet at Hardyville, Ariz., in 1902 should be duplicated during the winter of 1914–15 the run-off at Hardyville during 1915 would be considerably less than 7,959,000 acre-feet, for the reason that the use of the water of the Colorado is greater at the present time than it was in 1902. The correction that should be applied to the Yuma records beginning with the year 1902 can not be determined from available information concerning the increase in irrigated areas during this period. It should be noted, however, that these records can not be considered to represent properly the flow of the Colorado at Yuma during future years under climatic conditions in all respects similar.

3. Ultimately little water may be contributed to the Colorado by Gila, Williams, and Virgin rivers, Kanab Creek, and Little Colorado, and Paria rivers. The records used in estimating the discharge of the Colorado at Hardyville include the run-off from all these tributaries except the Gila. The mean annual run-off from the other five ranges from about 350,000 to 750,000 acre-feet. The greater part of this water may eventually be used for irrigation on these tributaries and may thus be lost to the Colorado. If allowance is made for this contingency the estimate of the flow of the Colorado at Hardyville must be reduced by 300,000 to 500,000 acre-feet annually.

4. The water available for irrigable lands below the Virgin may finally be derived almost entirely from the run-off of that part of the Colorado River basin above the mouth of Paria River or above the Grand Canyon (p. 160).

5. The quantity of water available for the irrigation of lands in the basin of Colorado River will probably be reduced by the diversion of water from this basin to other drainage basins.

WATER POWER.

GENERAL CONDITIONS.

The physical conditions in the Colorado River basin are not in general favorable for the development of cheap water power. From Green River at Green River, Wyo., 6,070 feet above sea level, the distance by river to the Gulf of California is 1,487 miles, and the average fall is therefore 4.08 feet per mile. In this distance there are about 1,000 rapids but no sheer drops. In the valleys the fall is between 1 and 2 feet per mile; in a 10-mile section of the canyon it may be as much as 15 feet per mile. The greatest fall per mile is in Ladore, Cataract, Marble, and Grand canyons.

At Kremmling, Colo., Grand River is 7,312 feet above sea level and at its mouth 3,880 feet, the intervening distance being 356 miles and the average fall 9.64 feet per mile. Grand River and its tributaries offer the best inducements for the development of head for power by diversion. The low fall and other unfavorable conditions on the Green and Colorado would render the diversion of these streams to develop head for power unfeasible. However, an enormous amount of power can be developed on these rivers by constructing high dams. An approximate profile of Green, Grand, and Colorado rivers is shown on Plate XVIII.

It is estimated that more than 2,000,000 horsepower may be developed without interfering with the use of the water for irrigation.

There are about 25 hydroelectric plants in the Colorado River basin, many of which develop but a few hundred horsepower. In addition, there are 8 or more small plants where power for milling and for pumping water for irrigation is used direct from the wheel shaft.

The location of the power plants is indicated on the map of the Colorado River basin (Pl. XIII, in pocket) by dots; undeveloped sites are indicated on the map by arrowheads. Dots and arrowheads are numbered to correspond to the numbers used in the following descriptions of the more important plants and sites.

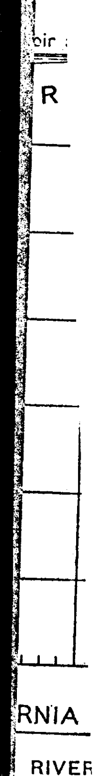
The foundation for dams or cost of development of the unutilized power sites has as a rule not been investigated. Consideration of market for power has also been omitted, as that market will change greatly with increase of population, construction of industrial plants, and use of hydroelectric power for operation of trunk line railroads.

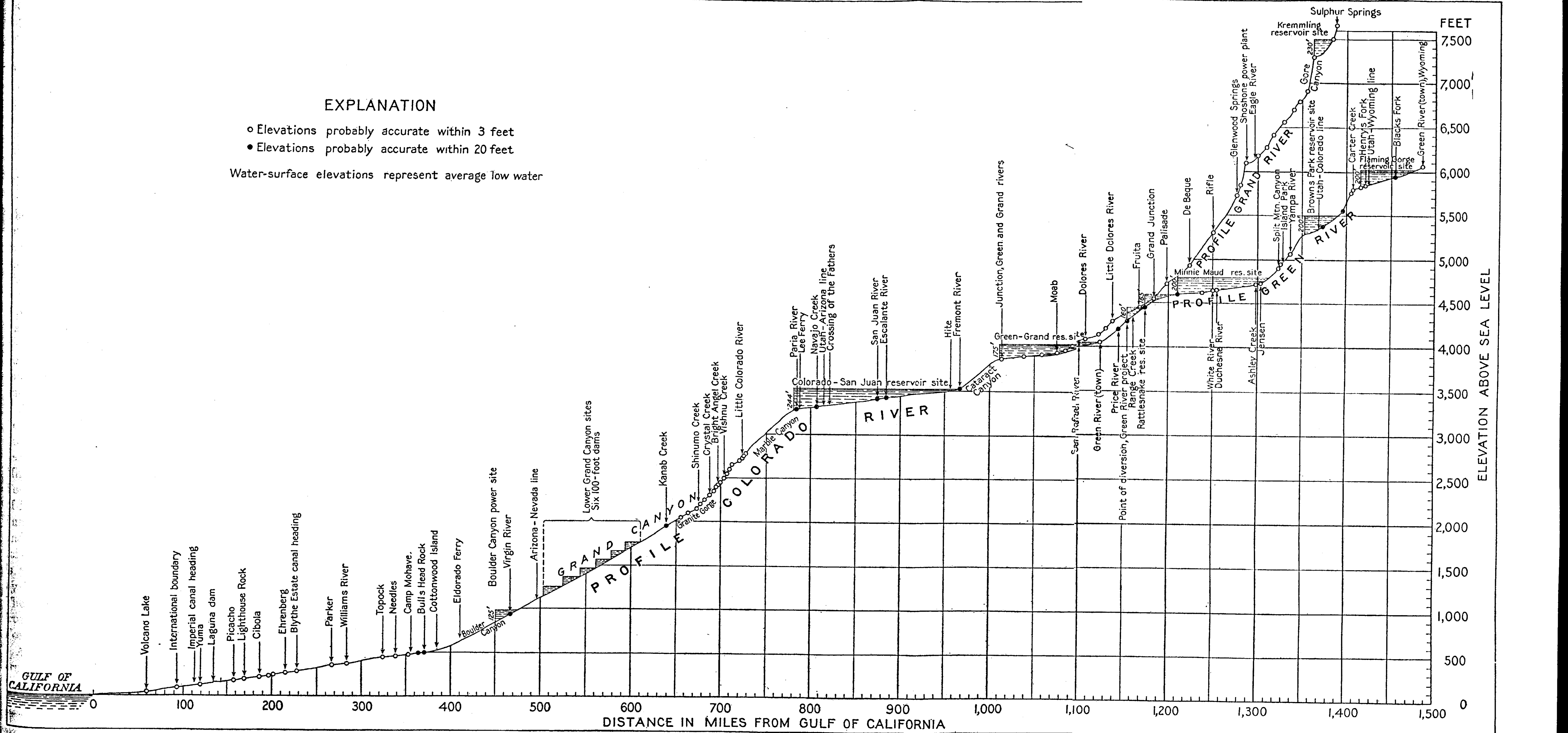
DEVELOPED WATER POWERS.

Shoshone plant (*6*).—The Shoshone power plant is on Grand River, 10 miles above Glenwood Springs in Garfield County, Colo. A low diversion dam has been constructed across Grand River, from which the water is carried to the forebay of the plant through a concrete-lined tunnel 2½ miles long with a carrying capacity of 1,250 second-feet. The operating head at the plant is 175 feet. The installation consists of two turbines, two generators, and auxiliary machinery. Each turbine is 54 inches in diameter and is rated at 9,000 horsepower at 400 revolutions per minute. The operation of the wheels is controlled by automatic governors. Each wheel is direct-connected with a General Electric generator of the 3-phase 60-cycle type. The rated capacity of each generator is 5,000 kilowatts. The current is generated at 4,000 volts. The power is transmitted 180 miles to Denver and intermediate points, the line voltage being 100,000.

Castle Creek plant (*8*).[1]—The Castle Creek plant, owned by the Roaring Fork Electric Light & Power Co., is in Pitkin County, Colo., in T. 10 S., R. 84 W., sixth principal meridian. The water is taken from Maroon, Castle, and Hunter creeks, tributaries of Roaring Fork, which flows into Grand River. An operating head of 356 feet is obtained by carrying the water of Maroon Creek through 4,000 feet of 30-inch pipe; the water of Castle Creek, carried to the power house by a 4,000-foot 24-inch pipe line, gives a head of 340 feet; and the water of Hunter Creek, carried to the power house through 2 miles of 14-inch pipe, gives a head of 876 feet. In addition to auxiliary

[1] Colorado State Engineer Sixteenth Bienn. Rept., p. 123, 1913.





APPROXIMATE PROFILE OF GREEN, GRAND, AND COLORADO RIVERS.

machinery, the installation consists of seven wheels with a rated capacity of 2,900 horsepower at 300 revolutions per minute, as follows: Four 57-inch Pelton wheels, each furnishing 250 horsepower; one 84-inch Doble wheel, giving 500 horsepower; and two 60-inch Doble wheels each giving 700 horsepower. There are six generators, four of 200 kilowatt capacity and two of 400 kilowatt capacity, operating at 600 volts.

The plant contains five automatic governors, three of the Lombard and two of the Replogle type. The power is used for mining and milling and for lighting the town of Aspen.

Crystal River plant (*10*).[1]—The Crystal River plant, on Crystal River, a tributary of Roaring Fork, in Gunnison County, Colo., is the property of Colorado Yule Marble Co. Three double-runner De Remer wheels are used. Wheel No. 1 is 48 inches in diameter, runs at 348 revolutions per minute, and is rated at 550 horsepower with two nozzles. It is belted to two General Electric 3-phase 200-kilowatt generators, operating at 2,300 volts. Each of the other wheels is 36 inches in diameter, runs at 360 revolutions per minute, is rated at 600 horsepower with four nozzles, and is direct-connected to a General Electric 3-phase 540-kilowatt generator operating at 2,300 volts. Wheels Nos. 2 and 3 are controlled by long-bar automatic governors. The operating head is 390 feet. No storage is provided. The power is used in the quarry and mill of the Colorado Yule Marble Co. and for lighting the town of Marble. The water supply is insufficient in winter months and a 2,250-horsepower auxiliary steam plant has been installed.

Ames plant (*16*).—The Ames plant is owned in fee by the Western Colorado Power Co. and that company's issued stock is owned by the Utah Power & Light Co. The plant is on San Miguel River in sec. 32, T. 42 N., R. 9 W., New Mexico principal meridian, in San Miguel County, Colo. The water supply is derived from Howards Fork and Lake Fork, tributaries of San Miguel River. The waters of Lake Fork are carried to the plant by a 40-inch by 38-inch timber flume, 12,550 feet long. The penstock is of steel, is 2,620 feet long, and varies in diameter from 30 to 24 inches. The static head obtained by the Lake Fork diversion is 915 feet and the effective head is 835 feet. The water of Howards Fork is carried to the plant by a timber flume, 27 inches by 27 inches, and 4,800 feet long. The penstock is of steel, is 2,000 feet long, and varies in diameter from 28 to 16 inches. The static head obtained by the Howards Fork diversion is 624 feet and the effective head is 580 feet.

At the power house are two water wheels, one generator, governors, and auxiliary machinery. The wheels are of the impulse type manufactured by the Pelton Water Wheel Co. Wheel No. 1 is 84 inches in diameter and is rated at 1,200 horsepower at 225 revo-

[1] Idem, p. 124.

lutions per minute; wheel No. 2 is 120 inches in diameter and is rated at 5,000 horsepower at 225 revolutions per minute. Both wheels are direct-connected to one General Electric generator of the 3-phase type, rated at 3,600 kilowatts. The current is generated at 11,000 volts, and the plant is operated in parallel with the Ilium plant.

Ilium plant (*17*).—The Ilium plant is owned in fee by the Western Colorado Power Co., whose issued securities are owned by the Utah Power & Light Co. The plant is on the South Fork of San Miguel River in sec. 6, T. 42 N., R. 9 W., New Mexico principal meridian, in San Miguel County, Colo. The water used at this plant is diverted direct from the tailrace of the Ames plant, and then through 5 miles of timber flume. The penstock is of steel, 32 inches and 28 inches in diameter and 700 feet long. The static head is 499 feet and the effective head 490 feet. The installation at the power house consists of two water wheels, one generator, and auxiliary machinery. The water wheels are of the impulse type manufactured by the Pelton Water Wheel Co. Each wheel is 72 inches in diameter and rated at 800 horsepower at 200 revolutions per minute. The water wheels are direct-connected to a General Electric generator of the 3-phase type, rated at 1,200 kilowatts, operating at 1,000 volts. The voltage is stepped up to 11,000 and the plant is operated in parallel with the Ames plant.

Tacoma plant (*18*).—The Tacoma plant is owned in fee by the Western Colorado Power Co., and the issued stock of that company is owned by the Utah Power & Light Co. The plant is on Animas River in sec. 31, T. 38 N., R. 8 W., New Mexico principal meridian, in La Plata County, Colo. The water is obtained from Cascade reservoir, which is fed by Cascade and Elbert creeks. The flow into the reservoir is controlled by a system of diverting dams, flumes, and canals. The water is carried to the plant by a timber flume, 56 by 38 inches and 9,000 feet long, and a steel penstock 2,550 feet long, varying in diameter from 44 to 34 inches. The static head is 988 feet and the effective head 963 feet. The installation at the power house consists of two water wheels, two generators, and auxiliary machinery. The water wheels are of the impulse type manufactured by the Pelton Water Wheel Co. Each wheel is 84 inches in diameter, is rated at 3,350 horsepower at 300 revolutions per minute, and is direct-connected to a General Electric generator of the 3-phase type, rated at 2,250 kilowatts. The current is generated at 4,000 volts. The power is used for mining, milling, and lighting.

Roosevelt plant (*21*).—The Roosevelt plant, which is on Salt River at Roosevelt dam, in Maricopa County, Ariz., was built by the United States Reclamation Service. To provide power for use in the construction of the Roosevelt dam and to make possible the development of power with the reservoir empty, a canal was constructed above the flowage line of the reservoir to carry the water of Salt River to the power house. This system consists of a diversion dam on Salt River, 19.33 miles of open canal, 9,535 feet of tunnel, and 3,000 feet of pressure pipe. The operating head is 226 feet. In connection with this development three water wheels and three generators were installed. The wheels are of the turbine type manufactured by S. Morgan Smith & Co. Each is 30 inches in diameter and is rated at 1,680 horsepower. The generators are of the General Electric 3-phase 25-cycle type, rated at 1,060 kilowatts. In addition to the machinery mentioned above, three water wheels and three generators have been installed. The head for these additional units is obtained from the dam itself and varies from 80 feet to 226 feet, the variation depending on the elevation of the water surface in the reservoir. Of the three additional water wheels two are 30¼ inches in diameter and are rated at 1,800 horsepower each; one is 53 inches in diameter and is rated at 6,000 horsepower for a head of 160 feet, although the maximum capacity of the wheel at a head of 226 feet is about 7,000 horsepower. Two of the additional generators are of the General Electric 3-phase 25-cycle type, rated at 1,060 kilowatts each, and a third is rated at 5,000 kilowatts. The total installed wheel capacity is 15,640 horsepower, and the rated capacity of the six generators is 10,300 kilawatts. The current is generated at 2,200 volts.

South Consolidated plant (*22*).—The South Consolidated plant is on the South canal of the Salt River project of the United States Reclamation Service, in sec. 22, T. 2 N., R. 6 E., in Maricopa County, Ariz. The operating head is 29 feet. The installation consists of two water wheels and two generators, with automatic governors and auxiliary machinery. The water wheels are of the turbine type manufactured by S. Morgan Smith & Co. Each wheel is 48 inches in diameter and is rated at 1,400 horsepower. The generators are of the General Electric 3-phase 25-cycle type, rated at 1,000 kilowatts each.

Crosscut plant (*23*).—The Crosscut plant is on the Crosscut canal on the Salt River project, United States Reclamation Service, in sec. 9, T. 1 N., R. 4 E., in Maricopa County, Ariz. The operating head is 116 feet. The installation consists of six water wheels, six generators, and auxiliary machinery. The water wheels are of the impulse type manufactured by the Pelton Water Wheel Co. Each wheel is rated at 1,000 horsepower. The generators are of the Westinghouse 3-phase 25-cycle type, rated at 875 kilowatts each. The current is generated at 11,000 volts.

Arizona Falls plant (*24*).—The Arizona Falls plant is on the Arizona canal of the Salt River project, United States Reclamation Service, in sec. 28, T. 2 N., R. 4 E., in Maricopa County, Ariz. The installation consists of two water wheels and two generators, with auxiliary machinery. The water wheels are of the turbine type manufactured by S. Morgan Smith & Co. Each wheel is rated at 725 horsepower. The generators are of the General Electric 3-phase 25-cycle type, each rated at 525 kilowatts. The current is generated at 11,000 volts.

Childs plant (25).—The Childs plant is on Fossil Creek, a tributary of Verde River, in Yavapai County, Ariz., and is owned by the Arizona Power Co. The water is carried from Fossil Creek to the power house by means of a flume, pressure pipe, and tunnels. The capacity of this system is about 47 second-feet. The effective head is 1,050 feet. The installation consists of three water wheels and three generators with auxiliary machinery. The water wheels are of the impulse type manufactured by the Abner Doble Co. Each wheel is 70 inches in diameter and is rated at 3,000 horsepower at 400 revolutions per minute. The generators are of the General Electric 3-phase 60-cycle type, rated at 1,800 kilowatts each, at a speed of 400 revolutions per minute. The current is generated at 2,300 volts. This plant has an auxiliary steam plant of 240 kilowatts capacity.

Summary of developed powers.—In addition to the 11 plants described above 14 hydroelectric plants are in operation in the Colorado River basin. A list of such plants is given in the following table:

Hydroelectric plants in Colorado River basin.

Green River basin.

Name of plant.	Index No.[a]	Location.			Operating head.	Installed capacity.	
		Stream.	County.	State.	Feet.	Kilowatts.[b]	Horsepower.[c]
Ashley Creek	1	Ashley Creek	Uinta	Utah	84	250	400
Myton	2	Lake Fork	Duchesne	do	......	150	250
Cottonwood	3	Cottonwood Creek	Emery	do	75	50	75
Grand River basin.							
Spruce Creek	4	Spruce Creek	Summit	Colorado	250	450	[d] 700
Summit County	5	Snake Creek	do	do	500	1,000	1,600
Shoshone	6	Grand River	Garfield	do	175	10,000	18,000
Glenwood Springs	7	No Name Creek	do	do	460	248	530
Castle Creek	8	Maroon Creek	Pitkin	do	356	400	2,900
		Castle Creek	do	do	340	400	
		Hunter Creek	do	do	876	800	
Yule Creek	9	Yule Creek	Gunnison	do	90	300	424
Crystal River	10	Crystal River	do	do	390	1,300	1,750
Osgood	11	do	Pitkin	do	......	65	85
Rifle	12	Rifle Creek	Garfield	do	70	150	247
Hinsdale	13	Lake Fork	Hinsdale	do	65	200	160
Hidden Treasure	14	Henson Creek	do	do	90	128	321
Ouray	15	Uncompahgre River	Ouray	do	350	450	800
Ames	16	Howards Fork	San Miguel	do	580	3,600	6,200
		Lake Fork	do	do	835		
Ilium	17	South Fork San Miguel	do	do	490	1,200	1,600

[a] Figures indicate position of plant on Pl. XIII (in pocket).
[b] Figures represent rated capacity of generators.
[c] Figures represent rated capacity of water wheels.
[d] Two plants.

Hydroelectric plants in Colorado River basin—Continued.

Colorado River basin below Grand River.

Name of plant.	Index No.	Location.			Operating head.	Installed capacity.	
		Stream.	County.	State.	Feet.	Kilowatts.	Horsepower.
Tacoma	18	Animas River	La Plata	Colorado	963	4,500	6,700
St. George	19	Cottonwood Creek	Washington	Utah	325	45	60
White River	20	North Fork of White	Navajo	Arizona	12	23	33
Roosevelt	21	Salt River	Maricopa	do	[a] 225	10,300	15,640
South Consolidated	22	do	do	do	29	2,000	2,800
Crosscut	23	Crosscut Canal	do	do	116	5,250	6,000
Arizona Falls	24	Arizona Canal	do	do	18	1,050	1,450
Childs	25	Fossil Creek	Yavapai	do	1,050	5,400	9,000

[a] Head varies from 80 to 225 feet.

UNDEVELOPED POWER SITES.[1]

GREEN RIVER BASIN.

Flaming Gorge reservoir power site (1).—The Flaming Gorge power site is at the dam site for the Flaming Gorge reservoir, in northeastern Utah (pp. 199–201). The elevation of the low-water level of Green River at the dam site in Horseshoe Canyon is 5,825 feet. By constructing a dam to elevation 6,050 for storing to elevation 6,040 feet, the reservoir capacity would be 3,130,000 acre-feet. The storage capacity between the 6,000 and 6,040-foot contour would be 1,210,000 acre-feet, or sufficient to equalize the flow of the river at this point and insure a minimum flow of 2,700 second-feet. By constructing a 3-mile tunnel at elevation 6,000 feet an effective head of about 290 feet could be obtained. With a head of 290 feet and a flow of 2,700 second-feet 71,000 brake horsepower[2] could be developed.

Swallow Canyon power site (2).—Swallow Canyon is near the upper end of Browns Park, in northeastern Utah. This canyon is about 2 miles long. At its upper end, in sec. 31, T. 2 N., R. 25 E., Salt Lake meridian, an outcrop of solid rock extending across the channel of Green River indicates that it would be practicable to construct a high dam. The water level could be raised about 150 feet without interfering with the development of the Flaming Gorge site. By utilizing the Flaming Gorge reservoir site a uniform flow of 2,700 second-feet could be maintained, which, with a head of 150 feet, would make possible the development of 36,800 brake horsepower.

[1] The position of the power sites is shown by the arrowheads on the map (Pl. XIII, in pocket). The number of the arrowhead corresponds to the number used in the text.

[2] In this report brake horsepower represents horsepower on the water-wheel shaft, calculated on the basis of a water-wheel efficiency of 80 per cent.

Cross Mountain Canyon power site (*3*).—The Cross Mountain Canyon site is on Yampa River a few miles above Little Snake River in Moffat County, Colo. The canyon is about 4 miles long, and by constructing a pipe line 3 miles long a head of 165 feet could be obtained; with a pipe line and canal 7¾ miles long a head of 224 feet would be available. Twenty-eight miles above Cross Mountain is the Juniper Mountain reservoir site, where a dam 165 feet high would give a storage capacity of 600,000 acre-feet. The average annual flow of Yampa River at Cross Mountain Canyon is about 1,100,000 acre-feet. By storing 600,000 acre-feet at the Juniper Mountain reservoir site (see p. 203) a uniform flow of 1,100 second-feet could be maintained in this canyon. The low-water flow under normal conditions is between 50 and 100 second-feet. With a uniform flow of 1,100 second-feet and a head of 224 feet 22,400 brake horsepower could be developed.

Blue Mountain Canyon power site (*4*).—Seven miles below the mouth of Little Snake River in Moffat County, Colo., the Yampa enters Blue Mountain Canyon through which it flows to its confluence with Green River. The elevation of Yampa River at the head of this canyon is 5,583 feet; at its mouth, 5,065 feet; the total fall in the canyon is 518 feet. By constructing two or three dams it is probable that an aggregate head of 400 feet could be made available. No investigations of dam sites have been made, and these data are presented as showing possibilities only. By utilizing the Juniper Mountain reservoir site a uniform flow of 1,100 second-feet can be maintained in this canyon, and this flow, with a total head of 400 feet, would make possible a development of 40,000 brake horsepower.

Split Mountain Canyon power site (*5*).—Split Mountain is on Green River, 20 miles above Jensen, Utah, and 2 miles below Island Park. By constructing a tunnel 9,000 feet long, with its upper portal at the lower end of Split Mountain Canyon and its lower portal in the SW. ¼ sec. 36, T. 4 S., R. 23 E., Salt Lake meridian, 9 miles of the river could be intercepted. An 80-foot head could be obtained without a diversion dam. The average annual discharge of Green River at this point for the 20-year period 1895 to 1914 was about 3,980,000 acre-feet, or the equivalent of a uniform flow of 5,500 second-feet. If the Flaming Gorge and Juniper Mountain reservoirs should be built it is probable that a dependable flow of not less than 5,000 second-feet could be maintained at Split Mountain. The dependable low flow under normal conditions is about 600 second-feet. With a flow of 5,000 second-feet and a fall of 80 feet 36,400 brake horsepower could be developed.

Ashley Creek power site (*6*).—Ashley Creek, which has its source in the Uinta Mountains at an elevation of about 12,000 feet, flows in a southeasterly direction and joins Green River 3 miles below Jensen,

Utah. In the 9-mile section immediately north of the south boundary of the Ashley National Forest the creek falls 2,730 feet, or 303 feet per mile; in the 3½-mile section immediately south of the Ashley National Forest boundary the fall of the creek is 360 feet. By constructing three power plants possibly 2,600 feet of fall might be utilized. The dependable minimum flow of the creek under normal conditions is about 30 second-feet. If a dependable minimum flow of 80 second-feet could be obtained by using small storage reservoirs 18,900 brake horsepower could be developed.

Duchesne River power sites (*7*).—The only part of Duchesne River that will be considered is a 23-mile section immediately above the mouth of Strawberry River, which joins the Duchesne at Duchesne, Utah. In the 11-mile section of the river immediately above Rock Creek the fall is 450 feet. The dependable flow is about 70 second-feet and may be increased to 114 second-feet by storage. With a flow of 114 second-feet and a fall of 450 feet 4,660 brake horsepower could be developed.

Between the mouth of Rock Creek and the mouth of Strawberry River the Duchesne falls 510 feet; the length of this section of the river is 12 miles. The minimum flow below Rock Creek is about 140 second-feet, which may be increased to 250 second-feet by storage. However, considerable water from Rock Creek and Duchesne River above Strawberry River will be diverted for irrigation, and it is probable that only about 100 second-feet can safely be used as a basis for estimating the possibilities of power development. If the available head is 450 feet and the flow is 100 second-feet, 4,100 brake horsepower could be developed.

Minnie Maud power site (*8*).—The Minnie Maud site is in Desolation Canyon on Green River, about 1 mile below the mouth of Minnie Maud Creek. A 200-foot dam at this site would form a reservoir having a storage capacity of about 4,000,000 acre-feet. The capacity at the 120-foot level would be approximately 1,440,000 acre-feet, which would indicate that the storage capacity between the 120-foot level and the 200-foot level would be 2,560,000 acre-feet. If the Flaming Gorge and Juniper Mountain reservoirs should be constructed the flow of Green River would be practically under control to Jensen, Utah. The inflow from White and Duchesne rivers could be regulated with a storage capacity of about 2,560,000 acre-feet at the Minnie Maud storage site. It would therefore be possible to utilize the Minnie Maud storage dam to the level of 120 feet to obtain a head for power development. The discharge records obtained at gaging stations in the Green River basin indicate that the average annual run-off available for storage at the Minnie Maud reservoir site for the 20-year period 1895 to 1914 was 5,300,000 acre-feet, or the equivalent of a uniform flow of 7,330 second-feet. Probably a mean low flow of not less than 6,000 second-feet could be maintained by storage, as indicated above. With a head of 120 feet and a flow of 6,000 second-feet 65,400 brake horsepower could be developed.

Rattlesnake power site (*9*).—The Rattlesnake site is on Green River in Desolation Canyon, about 37 miles below the Minnie Maud dam site and about 3 miles above the mouth of Rattlesnake Creek. A dam 175 feet high could be constructed to raise the water level 165 feet, and the backwater would not extend to the Minnie Maud dam site. If the Minnie Maud power site were utilized as discussed in the preceding paragraph, a minimum flow of 6,000 second-feet would be available for power development at the Rattlesnake dam site. With a head of 165 feet and a flow of 6,000 second-feet 90,000 brake horsepower could be developed.

Coal Creek power site (*10*).—The Coal Creek site is on Green River at the mouth of Coal Creek, 29 miles above the town of Green River, Utah. The Green River Co. proposes to construct a dam at this point for the purpose of diverting 2,000 second-feet of the water of Green River to irrigate land in the vicinity of Green River, Utah. Raising the water level at Coal Creek 160 feet would not interfere with the development of power at the Rattlesnake dam site. The dependable minimum flow available at Coal Creek would be the same as that available at the Minnie Maud and Rattlesnake sites, or 6,000 second-feet. Assuming that 2,000 second-feet will be diverted for irrigation, there would remain 4,000 second-feet available for use in power development. With a head of 160 feet and a flow of 4,000 second-feet 58,200 brake horsepower could be developed.

GRAND RIVER BASIN.

Gore Canyon power site (*11*).—Gore Canyon is immediately below the Kremmling reservoir site on upper Grand River, in Grand County, Colo. The canyon proper is about 3½ miles long. In an 8-mile section of the river, beginning at the railroad station at Gore, the fall is 420 feet. The Central Colorado Power Co. has investigated the feasibility of developing power in this canyon. Owing to the precipitous character of the canyon walls the river can not be diverted except by means of a tunnel. By constructing a tunnel 24,000 feet long a head of 411 feet could be obtained. By utilizing the Kremmling reservoir site a mean flow of 1,600 second-feet would be available and about 60,000 brake horsepower could be developed.

Westwater power site (*12*).—The Westwater site is on Grand River 10 miles below the railroad station of Westwater, in Grand County, Utah. The water level at the dam site could be raised 140 feet without damage to the roadbed of the Denver & Rio Grande Railroad, and a head of 135 feet could be obtained for the development of power. The dependable minimum flow at the present time is 2,000 second-feet. With increase in irrigation from the Grand and its tributary, Gunnison River, the minimum flow is most likely to occur in August and September. If the flow of the Grand is not regulated by storage it may fall below 500 second-feet at Westwater during those months. If the Kremmling reservoir site is utilized to equalize the flow of Grand River to the mouth of Eagle River, then it is reasonable to expect that the minimum flow of Grand River at Westwater would be about 1,000 second-feet. With a head of 135 feet and a flow of 1,000 second-feet about 12,300 brake horsepower could be developed.

COLORADO RIVER AND TRIBUTARIES BELOW GRAND RIVER.

Junction power site (*13*).—Recent investigations made by the United States Reclamation Service show the conditions at the junction of Green and Grand rivers in Wayne County, Utah, to be unfavorable for the construction of a high masonry dam,[1] and though the construction of a rock-fill dam may be practicable the cost would be high. A dam intended primarily for the development of power will probably never be constructed at this point, but a reservoir to be operated primarily in the interest of irrigation on lower Colorado River may become commercially feasible at some future time when the entire run-off from the Colorado is needed for irrigation below Virgin River, if a 270-foot rock-fill dam can be built here at a cost not exceeding $43,000,000. A 270-foot dam would make possible the storage of 8,600,000 acre-feet of water. The construction of a power plant at the dam would interfere with the free operation of the reservoir for irrigation. It might become necessary to allow a flood to pass through the dam to remove silt deposited in the reservoir basin. To obtain a head of 100 feet for the development of power, 940,000 acre-feet of storage capacity would be lost. If the Green-Grand reservoir were constructed and operated in the interest of irrigation, all reservoirs on Green River could be operated to equalize the flow of Green River for power development, and the Kremmling reservoir site on Grand River could also be operated primarily for the development of power.

Marble Canyon power site (*14*).—Marble Canyon extends from the mouth of Paria River, a few miles south of the Utah-Arizona line, to the mouth of Little Colorado River. The fall in this 60-mile section of the river is about 550 feet, and by constructing three dams a head of 450 feet could probably be developed. Under present conditions the natural dependable low-water flow of Colorado River in Marble

[1] See discussion of Green-Grand reservoir site, pp. 206–210.

Canyon is about 3,500 second-feet. If the flow of the Colorado should be regulated to meet the demands of irrigation the dependable low flow in the canyon would be approximately 10,000 second-feet. With a head of 450 feet 143,000 brake horsepower could be developed without storage and 410,000 brake horsepower with storage.

Upper Grand Canyon power sites (*15*).—The Grand Canyon of the Colorado is in northwestern Arizona. In the 84 miles between the mouth of the Little Colorado and Kanab Creek the fall is 780 feet, the average fall per mile being 9.3 feet. Owing to the precipitous character of the canyon walls it would not be feasible to create a head by diversion, but by constructing four dams it may prove feasible to utilize 600 feet of the fall. At many points the canyon walls are but a few hundred feet apart, and foundations suitable for high masonry dams can probably be found. The dependable minimum flow is about 3,500 second-feet. If the flow of the Colorado should be regulated for irrigation, the dependable minimum flow would be about 10,000 second-feet. Without storage 191,000 brake horsepower could be developed; with storage 545,000 brake horsepower.

Lower Grand Canyon power sites (*16*).—In the lower Grand Canyon, between Kanab Creek and the Nevada-Arizona State line, the Colorado falls about 850 feet in 144 miles, the average fall per mile being 5.9 feet. The physical conditions are similar to those in the upper section of the Grand Canyon. To create a head for the development of power it would be necessary to construct high dams. Private parties are considering plans for the development of power on this section of the river by means of six 100-foot dams, and it seems probable that a total head of 750 feet can be utilized in developing power. With the present minimum flow of 3,500 second-feet 239,000 brake horsepower could be developed; with the river flow regulated to conform to the future demands for irrigation, 10,000 second-feet would be available during the low stage, and this flow, with a head of 750 feet, would make possible the development of 682,000 brake horsepower.

Boulder Canyon power site (*17*).—Three miles below the mouth of Virgin River the Colorado passes into Boulder Canyon. In the half-mile section of this canyon the distance between walls is about 240 feet. The rock is granite in large ledges. Private parties contemplate constructing a dam to a height of 125 feet to obtain an effective head of 110 feet. The dependable minimum flow without storage is about 3,500 second-feet. By providing a small amount of storage above the dam a dependable minimum flow of 5,000 second-feet may be obtained. If the flow of the Colorado is regulated to meet the future irrigation demands, a minimum flow of 10,000 second-feet would be available. With a flow of 5,000 second-feet and a head of 110 feet 50,000 brake horsepower could be developed, and with a flow of 10,000 second-feet obtained by storage 100,000 brake horsepower could be developed.

Verde River power site (*18*).—A private company has investigated the feasibility of developing power on an 18-mile section of Verde River, a tributary of Salt River, in Yavapai County, Ariz., beginning at a point 9 miles above the mouth of Fossil Creek. The tentative plan of development calls for the construction of three power houses, the first to be placed at a storage dam 9 miles above Fossil Creek, the second 2 miles below Fossil Creek, and the third 7 miles below the second. The water would be carried to power houses Nos. 2 and 3 by means of canals, flumes, and tunnels. The total effective head to be utilized in the 18-mile section of the river is 415 feet. By regulating the flow of Verde River it appears that 9,750 brake horsepower may be developed.

SUMMARY.

In the foregoing discussion attention has been called to the points at which large quantities of power can probably be developed. Data regarding the many sites at which small powers can be developed are too meager to warrant their discussion. Some of the larger sites may not be utilized for many years; others will not prove commercially feasible until the flow of the Colorado or its principal tributaries is controlled by storage.

A summary of the possibilities of the undeveloped powers is presented in the following table:

Undeveloped power sites in Colorado River basin.

Name of site.	Index No.[a]	Stream.	State.	Estimate of available power.[b]
				Brake horse-power.
Flaming Gorge	1	Green River	Utah	71,000
Swallow Canyon	2	do	do	36,800
Cross Mountain Canyon	3	Yampa River	Colorado	22,400
Blue Mountain Canyon	4	do	do	40,000
Split Mountain Canyon	5	Green River	Utah	36,400
Ashley Creek	6	Ashley Creek	do	18,900
Duchesne River	7	Duchesne River	do	8,760
Minnie Maud	8	Green River	do	65,400
Rattlesnake	9	do	do	90,000
Coal Creek	10	do	do	58,200
Gore Canyon	11	Grand River	Colorado	60,000
Westwater	12	do	Utah	12,300
Junction	13	Colorado River	do	0
Marble Canyon	14	do	Arizona	410,000
Upper Grand Canyon	15	do	do	545,000
Lower Grand Canyon	16	do	do	682,000
Boulder Canyon	17	do	Arizona-Nevada	100,000
Verde River	18	Verde River	Arizona	9,750
				2,266,910

[a] The numbers in this column correspond to numbers given to arrowheads on map of Colorado River drainage basin (Pl. XIII, in pocket). The arrowhead indicates the location of the power site.
[b] On water-wheel shafts realizing 80 per cent of theoretical power.

MARKET FOR POWER.

DISTANCE TO MARKET CENTERS.

Twenty-five hydroelectric plants, aggregating 77,725 horsepower installed capacity, are operated in the Colorado River basin. In addition there are in operation a number of plants at which power is used direct from the wheel shaft for milling and for pumping water for irrigation. The capacity of the undeveloped power sites is estimated at more than 2,000,000 brake horsepower. Thorough investigations of the Gore Canyon site on Grand River have been made by the Central Colorado Power Co., and preliminary investigations have been made at the Minnie Maud, Rattlesnake, Junction, Upper and Lower Grand Canyon, and Boulder Canyon sites on Green and Colorado rivers by private parties.

As early as 1908 a report was prepared by Guy Sterling, consulting engineer, Salt Lake City, Utah, setting forth a tentative plan for utilizing the Minnie Maud, Rattlesnake, and Junction power sites. A survey was made of the Minnie Maud site and filings were made on the necessary water in accordance with the laws of Utah. Mr. Sterling reported the aggregate capacity of the three sites to be 275,000 horsepower at the plants, or 183,270 horsepower delivered at the customers' switchboards. He estimated the immediate demand at 53,000 horsepower, and the possible demand within a few years after completion of the plant at 100,000 horsepower. The air-line distances to present market centers, as shown by the following table:

Air-line distances from Minnie Maud, Rattlesnake, and Junction power sites to principal cities and mining camps within a radius of 300 miles.

City.	From Minnie Maud power site.	From Rattlesnake power site.	From Junction power site.
	Miles.	*Miles.*	*Miles.*
Salt Lake City, Utah	125	137	205
Park City, Utah	102	115	187
Eureka, Utah	120	120	168
Ogden, Utah	147	162	235
Ely, Nev	275	262	283
Leadville, Colo	204	204	215
Grand Junction, Colo	85	77	93
Silverton, Colo	185	152	126
Telluride, Colo	175	156	115
Cripple Creek, Colo	280	280	263
Creede, Colo	208	195	165
Denver, Colo	270	270	289
Pueblo, Colo	303	303	290

ARTIFICIAL FERTILIZERS.

The manufacture of artificial fertilizers may in the future afford a large market for electrical power in the Colorado River basin. In 1912 it was reported that more than 200,000 horsepower was being used in Norway in the manufacture of calcium or sodium nitrate and other nitrogen compounds for use principally as fertilizers.[1] A part of this product was marketed in California and in the Hawaiian Islands. Plants for the manufacture of cyanamid ($CaCN_2$) have been established in practically every country in Europe. The plant of the American Cyanamid Co., at Niagara Falls, Canada, which was started in 1909 with an annual output of 12,000 tons of cyanamid, was enlarged in 1913 to produce 32,000 tons annually and in 1914 was again enlarged, so that the output is now 64,000 tons.[2] This output requires a continuous use of 30,000 horsepower. Cyanamid is well adapted to the cheap production of ammonium phosphate, a compound which may be used directly in agriculture.

If high dams are built in the Colorado River basin for the purpose of preventing floods and regulating the flow to conform to the irrigation demand, a large amount of cheap power can probably be developed in connection with the storage works. At the Flaming Gorge dam site (pp. 199–201), where power can be developed cheaply if the cost of the storage works is charged to the irrigation interests, all raw materials necessary for the manufacture of ammonium phosphate are available, and it would be necessary to remove phosphate rock in excavating for the spillway. Limestone also is found in the vicinity. The slack water above the dam would afford water transportation to a point a few miles below Green River, Wyo., the nearest railroad point, and a market for the product would be found in the agricultural regions of the adjoining States.

ELECTRIFICATION OF RAILROAD LINES.

GENERAL CONDITIONS.

During recent years many electrical engineers have come out strongly in favor of replacing steam locomotives with electric locomotives in railway service. Heretofore, railways have replaced steam locomotives by electric chiefly to care for heavy suburban traffic or to solve special problems of operation, such as the steam, gas, and smoke produced by steam locomotives in long tunnels. The Butte, Anaconda & Pacific Railway, which operates about 120 miles of track in Montana, now uses electric motive power, and some of the larger railroad systems have recently adopted electric in preference to steam locomotives for main-line freight and passenger service. A division of the Norfolk & Western Railway in the mountains of Virginia was electrified early in 1915. The Chicago, Milwaukee & St. Paul Railway Co. is electrifying its road between Harlowton, Mont., and Avery, Idaho, a distance of 440 miles, in-

[1] Lewis, J. H., The Columbia River power project near The Dalles, Oreg.: Oregon State Engineer. Bull. 1, pp. 52–53, 1912.

[2] Landis, W. S., The fixation of atmospheric nitrogen: Met. and Chem. Eng., vol. 13, p. 218, April, 1915.

volving the use of 650 miles of track, and contemplates the extension of the electrified zone from Avery, Idaho, to Seattle and Tacoma, Wash., 850 miles farther west. The electrification is practically completed from Harlowton to Deer Lodge and will probably be extended to Avery by January 1, 1918.

Six trunk railroad lines now in operation and two that are proposed could, if electrically operated, be supplied with electricity generated at water-power plants in the Colorado River basin. In this connection the following data (pp. 184–190), abstracted from a report prepared by Charles P. Kahler, electrical engineer, Oregon Short Line Railroad Co., Salt Lake City, Utah, will be of interest. The electrification of existing and proposed railroads in the Colorado River basin and adjacent regions would furnish a market for the entire output from water-power plants having a capacity of 525,000 brake horsepower.

RAILROAD LINES CONSIDERED.

The electric power necessary to operate a steam railroad depends on many varying factors, and complete data on which to base a close estimate of the electric power that would be required to operate the steam railroads that traverse the Colorado River basin are not available. The approximate estimate here presented, however, indicates in a general way the probable market for electric power if the railroad lines named in the following list should be electrified:

LINES OPERATED.

Oregon Short Line Railroad:
- (*a*) Montpelier, Idaho, to Granger, Wyo.
- (*b*) Ogden, Utah, to Sandy, Utah.

Union Pacific Railroad:
- (*a*) Ogden, Utah, to Granger, Wyo.
- (*b*) Granger, Wyo., to Cheyenne, Wyo.

San Pedro, Los Angeles & Salt Lake Railroad:
- (*a*) Salt Lake City, Utah, to Daggett, Cal.
- (*b*) Branch lines near Salt Lake City, Utah.

Denver & Rio Grande Railroad:
- Ogden, Utah, to Pueblo, Colo.

Atchison, Topeka & Santa Fe Railway:
- (*a*) Daggett, Cal., to Gallup, N. Mex.
- (*b*) Williams, Ariz., to Grand Canyon, Ariz.
- (*c*) Ash Fork, Ariz., to Phoenix, Ariz.

Southern Pacific Co.:
- (*a*) Yuma, Ariz., to Lordsburg, N. Mex.
- (*b*) Miscellaneous branches.

LINES PROPOSED.

Denver & Salt Lake Railroad:
- Salt Lake City, Utah, to Denver, Colo.

Southwestern Pacific Railroad:
- Grand Junction, Colo., to San Diego, Cal.

A section of the Denver & Salt Lake Railroad is already constructed, but as there is only a remote possibility that this section would be operated electrically until the line is completed to Salt Lake City, the total mileage was included with the proposed lines.

PHYSICAL CONDITIONS ON RAILROADS.

The following table shows the principal physical conditions affecting the railroad lines for which electric-power requirements have been estimated:

Physical conditions on railroad lines.

Railroad.	Miles.	Ascents.		Average grades.		
		West.	East.	West.	East.	Both ways.
		Feet.	*Feet.*	*Per cent.*	*Per cent.*	*Per cent.*
Oregon Short Line Railroad: (a)	115	805	1,145	0.133	0.189	0.164
(b)[a]	49	595	421	.23	.163	.198
Union Pacific Railroad: (a)	146	716	1,694	.09	.219	.154
(b)	338	4,499	5,270	.25	.295	.272
San Pedro, Los Angeles & Salt Lake Railroad: (a)	625	8,006	10,221	.244	.31	.273
(b)[a]	177					
Denver & Rio Grande Railroad	659	10,396	10,843	.299	.312	.305
Atchison, Topeka & Santa Fe Railway: (a)	580	10,146	12,872	.330	.420	.377
(b)	64					
(c)	194					
Southern Pacific Co.: (a)	416	1,640	5,728	.075	.261	.168
(b)	200					
Denver & Salt Lake Railroad	558	9,449	14,061	.32	.477	.40
Southwestern Pacific Railroad (approximate)	1,100	13,000	20,000	.224	.334	.284

[a] Salt Lake to Sandy is considered as operated by San Pedro, Los Angeles & Salt Lake Railroad.

The curvature is not stated in the tables, as complete information was not available, but an allowance for curvature has been made in the estimates of power consumption.

The east and west ascents given in the preceding table were taken from condensed profiles and consequently are less than the exact totals for these lines, but the ascents not taken into consideration generally are on minor or momentum grades and would not materially affect the requirements for electric power.

For ordinary interurban electric railways it is generally assumed that the ascents and descents of grade equalize each other. This assumption can not be made, however, in estimating the power requirements of the trunk-line steam railroads where brakes have to be used on down grades. The possibility of returning to the trolley wires power generated by the locomotive on down grades was not taken into account in the estimate here given. On some sections considerable power might be thus returned, but the total for all the lines was deemed unimportant for the present purpose.

QUANTITY OF TRAFFIC.

The estimated tonnage, including the weight of electric locomotives, equipment, and cars with contents, of the railroads considered is shown in the following table:

Average tons per day per mile of line.

Railroad.	Passenger trains.	Freight and mixed trains.
	Tons.	*Tons.*
Oregon Short Line Railroad: (a)	4,400	8,000
(b)[a]	2,400	6,300
Union Pacific Railroad: (a)	6,600	24,000
(b)	9,000	30,000
San Pedro, Los Angeles & Salt Lake Railroad: (a)	2,400	9,200
Denver & Rio Grande Railroad	4,000	10,000
Atchison, Topeka & Santa Fe Railway: (a)	6,000	14,000
Southern Pacific Co.: (a)	6,000	14,000
Denver & Salt Lake Railroad	4,000	10,000
Southwestern Pacific Railroad	4,000	10,000

[a] Salt Lake to Sandy is considered as operated by San Pedro, Los Angeles & Salt Lake Railroad.

The data are incomplete, but the figures are probably sufficiently accurate to serve the required purpose. The tonnage eastward is not the same as the tonnage westward, but, except on the southern railroads, for which an allowance is made in the estimates, the difference is small.

The average daily passenger and freight traffic, in ton-miles, computed from the tonnage and mileage given in the foregoing table, is shown below:

Average traffic in ton-miles per day.

Railroad.	Passenger traffic.	Freight and mixed traffic.	Total.
Oregon Short Line Railroad: (a)	506,000	920,000	1,426,000
(b)	86,400	226,800	313,200
Union Pacific Railroad: (a)	963,600	3,504,000	4,467,600
(b)	3,042,000	10,140,000	13,182,000
San Pedro, Los Angeles & Salt Lake Railroad	1,500,000	5,750,000	7,250,000
Denver & Rio Grande Railroad	2,636,000	6,590,000	9,226,000
Atchison, Topeka & Santa Fe Railway: (a)	3,480,000	8,120,000	11,600,000
Southern Pacific Co.: (a)	2,496,000	5,824,000	8,320,000
Denver & Salt Lake Railroad	2,232,000	5,580,000	7,812,000
Southwestern Pacific Railroad	4,400,000	11,000,000	15,400,000

BASIS OF ESTIMATE.

Three of the railroad companies operating lines in this drainage area have seriously considered the single-phase system in connection with the proposed electrification of parts of their lines, and that system forms the basis for estimates here presented. It was assumed that the high-tension lines would operate at 150,000 volts and 15 cycles, that the trolley voltage would be 15,000, and that single-phase commutator locomotives would be used. Most of the commercial power

lines in this section would operate at 60 cycles, and the fact that 60 is a multiple of 15 would make it convenient to connect together the 60-cycle and 15-cycle lines.

POWER LOSSES.

No allowance was made for losses in the high-tension lines from the power plants to the railroads, but the losses in the high-tension lines paralleling the railroads were taken into account.

The following table shows the efficiencies of the locomotives, transmission lines, and transformer stations:

	Per cent.
High-tension lines	95
Transformer stations (step down)	97
Trolley feeder wires	92
Locomotives (complete)	80
Over-all efficiency	67.8

In other words, it is estimated that only about two-thirds of the power delivered to the railroad high-tension lines would be utilized in hauling the trains.

CONSUMPTION OF POWER.

The average daily consumption of power, in kilowatt hours, for passenger traffic, and data used in obtaining it, and also for the freight and mixed traffic, are presented in the following table. The train resistance on level track was assumed at 8 pounds per ton for passenger trains and only 6 pounds per ton for freight and mixed trains, which are operated at lower speed than passenger trains. Theoretically the watt hours per ton-mile are equal to nearly two times the total train resistance in pounds per ton. At 66⅔ per cent efficiency the watt-hours per ton-mile would equal three times the total resistance in pounds per ton, and this factor was used in the tables.

Average daily consumption of power for passenger traffic.

Railroad.	Ton-miles per day.	Resistance (pounds per ton).			Watt hours per ton-mile (66⅔ per cent efficiency).	Kilowatt hours per day.
		Friction, etc.	Grade.	Total.		
Oregon Short Line Railroad: (a)	506,000	8	3.2	11.2	33.6	17,002
(b)	86,400	8	4.0	12.0	36.0	3,111
Union Pacific Railroad: (a)	963,000	8	3.1	11.1	33.3	33,088
(b)	3,042,000	8	5.5	13.5	40.5	123,201
San Pedro, Los Angeles & Salt Lake Railroad: (a)	1,500,000	8	5.5	13.5	40.5	60,750
Denver & Rio Grande Railroad	2,636,000	8	6.1	14.1	42.3	111,503
Atchison, Topeka & Santa Fe Railway: (a)	3,480,000	8	7.6	15.6	46.8	162,864
Southern Pacific Co.: (a)	2,496,000	8	3.5	11.5	34.5	86,112
Denver & Salt Lake Railroad	2,232,000	8	8.0	16.0	48.0	107,136
Southwestern Pacific Railroad	4,400,000	8	5.7	13.7	41.1	180,840

Average daily consumption of power for freight and mixed traffic.

Railroad.	Ton-miles per day.	Resistance (pounds per ton).			Watt hours per ton-mile (66⅔ per cent efficiency).	Kilowatt hours per day.
		Friction, etc.	Grade.	Total.		
Oregon Short Line Railroad: (a)	920,000	6	3.2	9.2	27.6	25,392
(b)	226,800	6	4.0	10.0	30	6,804
Union Pacific Railroad: (a)	3,504,000	6	3.1	9.1	27.3	95,660
(b)	10,140,000	6	5.5	11.5	34.5	349,830
San Pedro, Los Angeles & Salt Lake Railroad: (a)	5,750,000	6	5.5	11.5	34.5	198,375
Denver & Rio Grande Railroad	6,590,000	6	6.1	12.1	36.3	239,217
Atchison, Topeka & Santa Fe Railway: (a)	8,120,000	6	7.5	13.5	40.5	328,860
Southern Pacific Co.: (a)	5,824,000	6	3.5	9.5	28.5	165,984
Denver & Salt Lake Railroad	5,580,000	6	8.0	14.0	42.0	234,360
Southwestern Pacific Railroad	11,000,000	6	5.7	11.7	35.1	386,100

The estimates given in the two tables preceding are combined in the following table, which shows the total kilowatt hours per day for each railroad, the average load in kilowatts, and maximum load in kilowatts required to operate the estimated traffic:

Total requirements for power, in kilowatt hours per day, all service.

Railroad.	Passenger.	Freight and mixed.	Switching and miscellaneous.	Total.	Average load.	Annual load factor.	Maximum load.
					Kilowatts.	*Per cent.*	*Kilowatts.*
Oregon Short Line Railroad: (a)	17,002	25,392	8,479	50,873	2,120	25	8,480
(b)	3,111	6,804	2,478	12,393	516	15	3,436
Union Pacific Railroad: (a)	32,008	95,666	19,151	146,825	6,117	60	47,971
(b)	123,201	349,830	70,954	543,985	22,666		
San Pedro, Los Angeles & Salt Lake Railroad: (a)	60,750	198,375	38,870	297,995	12,412	45	28,693
(b)	....	....	....	12,000	500		
Denver & Rio Grande Railroad	111,503	239,217	52,608	403,328	16,805	45	37,340
Atchison, Topeka & Santa Fe Railway: (a)	162,864	328,860	73,758	565,482	23,562	40	60,718
(b)	....	....	....	3,000	125		
(c)	....	....	....	14,400	600		
Southern Pacific Co.: (a)	86,112	165,984	37,814	289,910	12,080	40	31,450
(b)	....	....	....	12,000	500		
Denver & Salt Lake Railroad	107,136	234,360	51,224	392,720	16,364	40	40,910
Southwestern Pacific Railroad	180,840	386,100	85,041	651,981	27,166	45	60,370

The traffic is not usually of uniform intensity, and more power would be required during some times of the day and some seasons of the year than at others. The maximum requirements for power would also be greater at some seasons than at others. Furthermore, during some months there is an empty-car movement which is greater eastward than westward, especially on the southerly railroads, and this movement has to be considered in determining the maximum load in kilowatts that it would be necessary to supply to the secondary transmission lines which parallel the railroads. On long lines the daily peaks would be relatively less than on short lines, and where the traffic is dense the load would usually be more uniform. The

average load divided by the maximum requirements gives what is known as the "load factor," and the probable load factor for the various railroad lines herein considered is given in the preceding table.

On the Southern Pacific Co.'s lines and the Atchison, Topeka & Santa Fe Railway some correction should be made to allow for the heavier westbound freight trains. For the Southern Pacific lines this correction may be of considerable magnitude, although the ascents west are much less than the ascents east. On the Atchison, Topeka & Santa Fe Railway the east and west ascents are, however, not very different. If the above factors are taken into account the maximum amount of power in kilowatts that it would be necessary to supply to the secondary transmission lines which parallel the respective railroads is shown in the following table:

Maximum demand for power for railroads.

	Kilowatts.
OPERATED RAILROADS.	
Oregon Short Line Railroad	12,000
Union Pacific Railroad	47,000
San Pedro, Los Angeles & Salt Lake Railroad	29,000
Denver & Rio Grande Railroad	37,000
Atchison, Topeka & Santa Fe Railway	65,000
Southern Pacific Co	35,000
	225,000
PROPOSED RAILROADS.	
Denver & Salt Lake Railroad	40,000
Southwestern Pacific Railroad	60,000
	100,000
	325,000

If the railroad companies are to purchase the electric power from a power company that company must be prepared to deliver to the high-tension transmission lines which parallel the railroad a maximum of 325,000 kilowatts. By assuming a generator efficiency of 95 per cent, step-up transformer efficiency of 97 per cent, and a loss of 10 per cent in the primary transmission system, it is estimated that the power company's plants must have a capacity of 525,000 brake horsepower.

The consumption of power depends of course on the traffic, and the estimate of tonnage for the proposed railroad lines is roughly approximate.

The traffic on the existing lines will no doubt increase, but the capacity of the power plants need not be increased proportionally, for as a rule the load factor increases as the traffic increases.

If the high-tension transmission lines and power plants were operated as a single unit the load factor for railroad operation alone would be higher than for the average of the individual roads, and consequently the required power-plant capacity and the cost of power generation would be less. Also, if the same power plants and transmission system served the whole territory for lighting, power, and all other purposes, the load factor would be greater and capacity of the plants required to handle the railroad load would be somewhat less than indicated by the table.

RIVER CONTROL.

GENERAL PROBLEM.

The elevation of the water surface of Colorado River at Bulls Head Rock is 500 feet above sea level. The distance by river between Bulls Head Rock and the Gulf of California is 370 miles; the average fall in this section of the river, therefore, is 1.35 feet per mile. Between Bulls Head and Yuma, Ariz., approximately 200,000 acres of irrigable land are subject to overflow during periods of high run-off. From Yuma to the Gulf the river flows through its delta, which is made up of silt brought down and deposited during past centuries and which extends southward to the Gulf, westward to the San Jacinto Mountains, and merges on the north with Salton Basin (pp. 140–141). At low stages the river winds through the delta in a channel fairly well defined by banks 10 to 12 feet in average height; at high stages it overflows its banks at many points.

After the river has flowed in one channel for a number of years its bed and banks are built up by silt deposits until the stream itself occupies a ridge on the delta. The manner in which the bed and banks are built up by the silt deposits is described by Gilbert as follows:[1]

> Alluvial streams tend to broaden their channels by eroding one or both banks. The influence of vegetation opposes this tendency. Often the erosion of the bank exposes roots, and some trees extend rootless into the water. At low stages the bared parts of the flood channel are occupied by young plants. In these ways vegetation creates obstacles which retard the current at its contact with the bank and thus oppose erosion. If the current is strong erosion is merely retarded, not prevented; if the current is weak deposition may be induced. * * *
>
> Some streams aggrade so rapidly that vegetation does not secure a foothold. By erosion of its banks such a stream broadens its channel and reduces its depth until the slackened current clogs itself by deposition of its load. The built-up bed becomes higher than the adjacent alluvial plain, and the stream takes a new course. Before the assumption of the new course the banks are overtopped by shallow distributaries which deposit their loads on the banks, thus building them up, until the stream is made to flow on a sort of elevated conduit, and when the main body of water at last leaves this pathway it is apt to start its new course with a steepened slope and scour for itself a relatively narrow channel.
>
> The building up of the bank by deposition from overflow is more pronounced in the presence of vegetation. The ridge thus created is called a natural levee.

[1] Gilbert, G. K., The transportation of débris by running water: U. S. Geol. Survey Prof. Paper 86, p. 222, 1914.

As the slope of the delta is greatest toward the north and west, the river during flood periods is continually seeking a new channel to Salton Sea. Several million dollars have been expended by private interests and the Federal Government in constructing levees and bank protective works, that are more or less temporary in nature, to prevent the overflow of the Colorado into Salton Basin.[1] The value of the property in Imperial Valley subject to injury by overflow has been variously estimated at $30,000,000 to $50,000,000, and between Bulls Head Rock and the international boundary are properties valued at $10,000,000 to $15,000,000 which also need protection from the floods of the Colorado.

Obviously no amount of levee construction and bank revetment will prevent high-water stages on the lower Colorado, and if floods are not prevented thousands of dollars must be expended annually in maintaining protective works on the river below Bulls Head Rock. For the prevention of the extremely high stages only one method is available—the construction of properly located storage reservoirs of sufficient capacity to hold back the flood-making waters. If by this means all or the greater part of the overflow is prevented, the lands along the lower river can probably be adequately protected by bank revetment and the cost of maintaining the protective works will have been reduced to a minimum.

If no lands below Virgin River were irrigable from the Colorado, there would be to-day in this region railroad stations only at the Santa Fe crossings at Parker and Needles and at the Southern Pacific crossing at Yuma, Ariz., and, excluding railroad properties, land here would be practically valueless. The region, however, contains irrigable lands of great value. About 367,000 acres were irrigated below Virgin River in 1913 directly from the Colorado, and additional areas aggregating approximately 2,367,000 acres are classed as irrigable. The present value of the irrigated lands and related industries below Virgin River is between $40,000,000 and $60,000,000. If all additional irrigable lands are supplied with water, the value of the property in the irrigated area would probably exceed $300,000,000. To protect the property from the ravages of floods and to increase the irrigated area the flow of the Colorado must be regulated. The control of the river, if obtained by the use of storage reservoirs, will therefore serve a double purpose—it will protect the irrigated area from overflow and bank encroachment and it will increase the water

[1] For detailed accounts of the causes that led to the formation of Salton Sea and of the various attempts and final successful effort to shut the flood flow of Colorado River from the Salton Sink, see the following reports:

Grunsky, C. E., The lower Colorado River and the Salton Basin: Am. Soc. Civil Eng. Trans., vol. 59, pp. 1-51; discussion, pp. 52-62, December, 1907.

Cory, H. T., Irrigation and river control in the Colorado River delta: Am. Soc. Civil Eng. Trans., vol. 76, pp. 1204-1453; discussion, pp. 1454-1571, December, 1913.

supply available for the irrigation of new lands. The ideal end to be sought is the modification of the natural flow of the Colorado to conform to the demand for water for irrigation below Virgin River.

The diagram (fig. 4) shows clearly the necessity for river regulation. The shaded part shows the natural flow of the Colorado at Yuma for the years 1911 and 1912. The demand for the irrigation of 2,730,000 acres below Virgin River is shown by the heavy line. The volume of the discharge in excess of the irrigation demand should be stored for release when the natural flow is less than the demand.

MAGNITUDE AND FREQUENCY OF FLOODS.

To regulate the flow and prevent the floods on the lower Colorado, reservoirs properly located and with sufficient capacity to hold back the water that would otherwise make up a flood must be utilized. The source of the water that produces the annual floods at Yuma, Ariz., is shown by the following table and also in the diagram (Pl. XIX):

Annual discharge, in acre-feet, of Green, Grand, and Colorado rivers, 1895–1914.

Year.	Green River.					Grand River.	Colorado River.	
	At Green River, Wyo.	At Bridgeport, Utah.	At Ouray, Utah.	At Green River, Utah.	At mouth.	At mouth.	At junction of Green and Grand.	At Hardyville or at Laguna dam.
1895	1,260,000	1,860,000	3,210,000	4,350,000	4,520,000	6,360,000	10,900,000	[a]16,600,000
1896	1,460,000	2,140,000	3,690,000	4,170,000	4,320,000	6,790,000	11,100,000	[a]13,400,000
1897	1,680,000	2,510,000	4,330,000	6,250,000	6,460,000	8,260,000	14,700,000	[a]18,400,000
1898	1,500,000	2,240,000	3,860,000	5,300,000	5,430,000	4,850,000	10,300,000	[a]13,200,000
1899	2,650,000	3,880,000	6,700,000	8,120,000	8,480,000	8,900,000	17,400,000	[a]22,900,000
1900	1,080,000	1,550,000	2,670,000	3,720,000	3,820,000	6,880,000	10,700,000	[a]16,500,000
1901	1,280,000	1,880,000	3,240,000	4,420,000	4,600,000	7,010,000	11,600,000	[a]14,900,000
1902	1,010,000	1,480,000	2,550,000	3,490,000	3,600,000	4,280,000	7,880,000	7,960,000
1903	1,400,000	2,060,000	3,550,000	4,830,000	4,960,000	5,650,000	10,600,000	11,300,000
1904	1,830,000	2,690,000	4,570,000	5,200,000	5,320,000	5,070,000	10,400,000	9,890,000
1905	976,000	1,440,000	2,480,000	4,000,000	4,120,000	6,490,000	10,600,000	15,900,000
1906	1,520,000	2,240,000	3,860,000	6,450,000	6,670,000	7,690,000	14,400,000	[b]19,200,000
1907	2,580,000	3,790,000	6,520,000	8,890,000	9,250,000	7,900,000	17,200,000	24,800,000
1908	1,220,000	1,790,000	3,080,000	4,220,000	4,390,000	4,660,000	9,050,000	12,600,000
1909	2,520,000	3,710,000	6,400,000	8,680,000	9,040,000	8,470,000	17,500,000	25,300,000
1910	1,350,000	1,990,000	3,430,000	4,640,000	4,900,000	5,830,000	10,700,000	14,100,000
1911	1,220,000	1,790,000	3,080,000	4,200,000	4,370,000	6,800,000	11,200,000	17,600,000
1912	1,450,000	2,130,000	3,670,000	6,220,000	6,430,000	8,500,000	14,900,000	18,100,000
1913	1,670,000	2,460,000	3,850,000	5,360,000	5,490,000	5,370,000	10,900,000	11,700,000
1914	1,710,000	2,520,000	4,770,000	7,080,000	7,350,000	8,660,000	16,000,000	20,100,000
Twenty-year average	1,570,000	2,310,000	3,980,000	5,480,000	5,680,000	6,720,000	12,400,000	16,200,000

[a] Mean obtained by comparing the annual run-off of Colorado River at junction of Green and Grand rivers, with record showing the run-off of Colorado River at Hardyville and by comparing the run-off of Arkansas River at Canon City, Colo., with the run-off of Colorado River at Hardyville.
[b] Record obtained at Hardyville gaging station.

The relative importance of the tributaries of the Colorado is shown by the map of the basin (Pl. XX, in pocket), on which the width of the lines representing the streams is proportional to the volume of discharge. This map shows graphically the small volume of run-off above

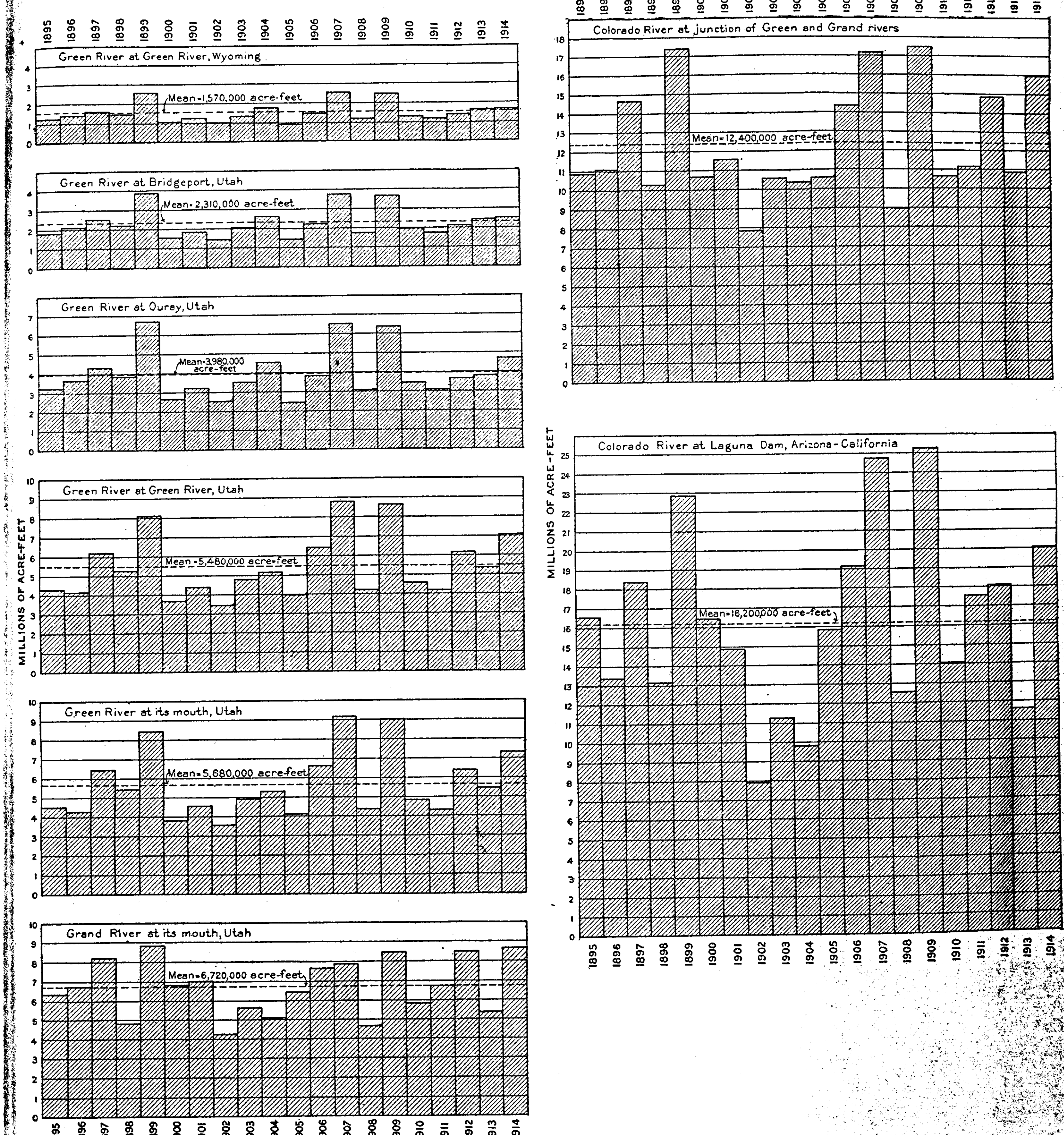


CHART SHOWING ANNUAL DISCHARGE OF GREEN, GRAND, AND COLORADO RIVERS 1895 TO 1914, INCLUSIVE.

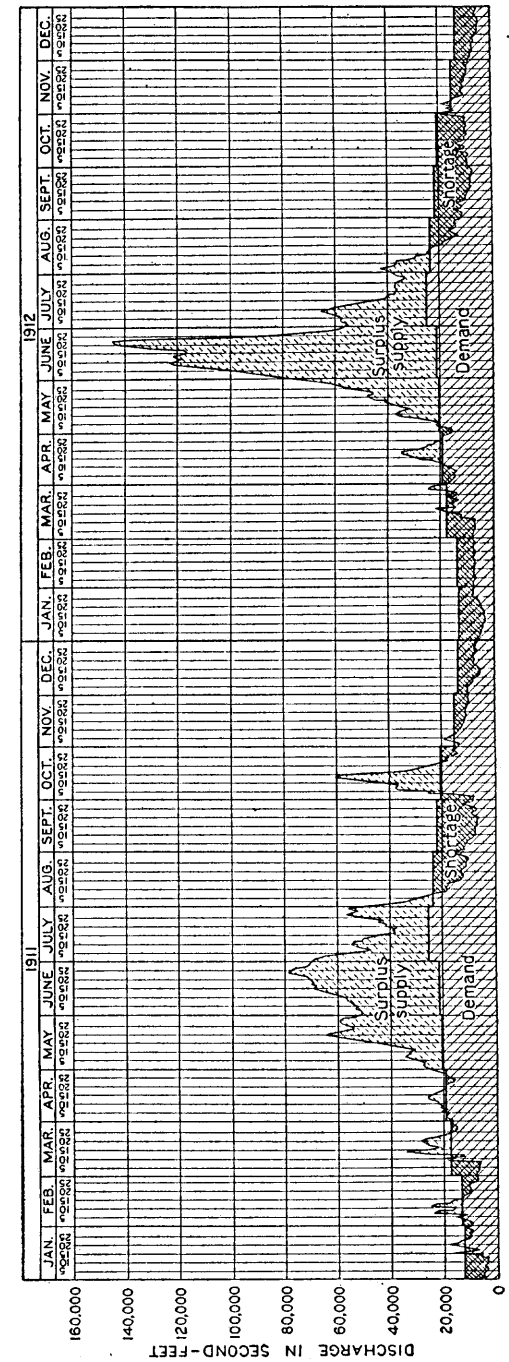


FIGURE 4.—Diagram showing daily discharge of Colorado River for 1911 and 1912 and regulation of flow required to make the supply conform to the demand for the irrigation of 2,730,000 acres below Virgin River; head-gate duty, 5 acre-feet.

Flaming Gorge and Kremmling and the large run-off at the junction of Green and Grand rivers, and indicates the futility of constructing reservoirs on small tributaries or near the head of Green and Grand rivers for the purpose of controlling the flood flow of the Colorado at Yuma. In the following table the relation of run-off of Green, Grand, San Juan, and other rivers is expressed in per cent of flow at Laguna dam.

Relative run-off of Colorado River and its tributaries.

	Per cent of flow at Laguna dam.
Green River at Flaming Gorge, Utah	14. 3
Grand River at Kremmling, Colo	7. 4
Green River at mouth, Utah	35. 0
Grand River at mouth, Utah	41. 5
Colorado River at junction of Green and Grand rivers, Utah	76. 5
San Juan River at Bluff, Utah	14. 2
Colorado River at mouth of Paria River, Ariz	92. 5
Colorado River at Laguna dam, Ariz.-Cal	100. 0

The diagram (fig. 5) shows the annual variation in the flow of Colorado River for the 20-year period 1895 to 1914, inclusive. The mean annual run-off at Hardyville or at Laguna dam during this period was 16,200,000 acre-feet. The least run-off recorded is that of 1902—7,960,000 acre-feet, or 51 per cent below normal. The highest run-off recorded is that of the year 1909—25,300,000 acre-feet, or 56 per cent above normal. From 1901 to 1905, inclusive, the run-off was below normal, as is indicated not only by the large tributaries of the Colorado above Virgin River but by many of the larger streams in the Great Basin.

The rise and fall of Great Salt Lake, for example, shows roughly the variation of the flow of the streams in the Great Basin that are tributary to the lake. The lake levels for the 65-year period 1850 to 1914, inclusive, are shown in Plate XXI. During this period the lake level was lowest in 1902. Estimates have been made of the quantity of water that has flowed into the lake annually during this period. (See Pl. XXII.) In making these estimates an area curve of the lake surface for various levels was prepared from surveys made in 1850 and 1869. The earlier survey was made by Capt. Howard Stansbury, of the United States topographical engineers, April 1 to June 26, 1850, when the mean level of the lake was at an elevation represented by 3.4 feet on the present midlake gage, and its area was 1,120,000 acres. A similar survey made in the spring of 1869 by Clarence King, United States geologist, showed the mean level of the lake to be about 12.8 feet, and its area 1,386,240 acres.

The quantity of water received by the lake annually, including the rainfall on the lake as well as the inflow, was estimated from the records of the annual variation in lake level and the surveys showing

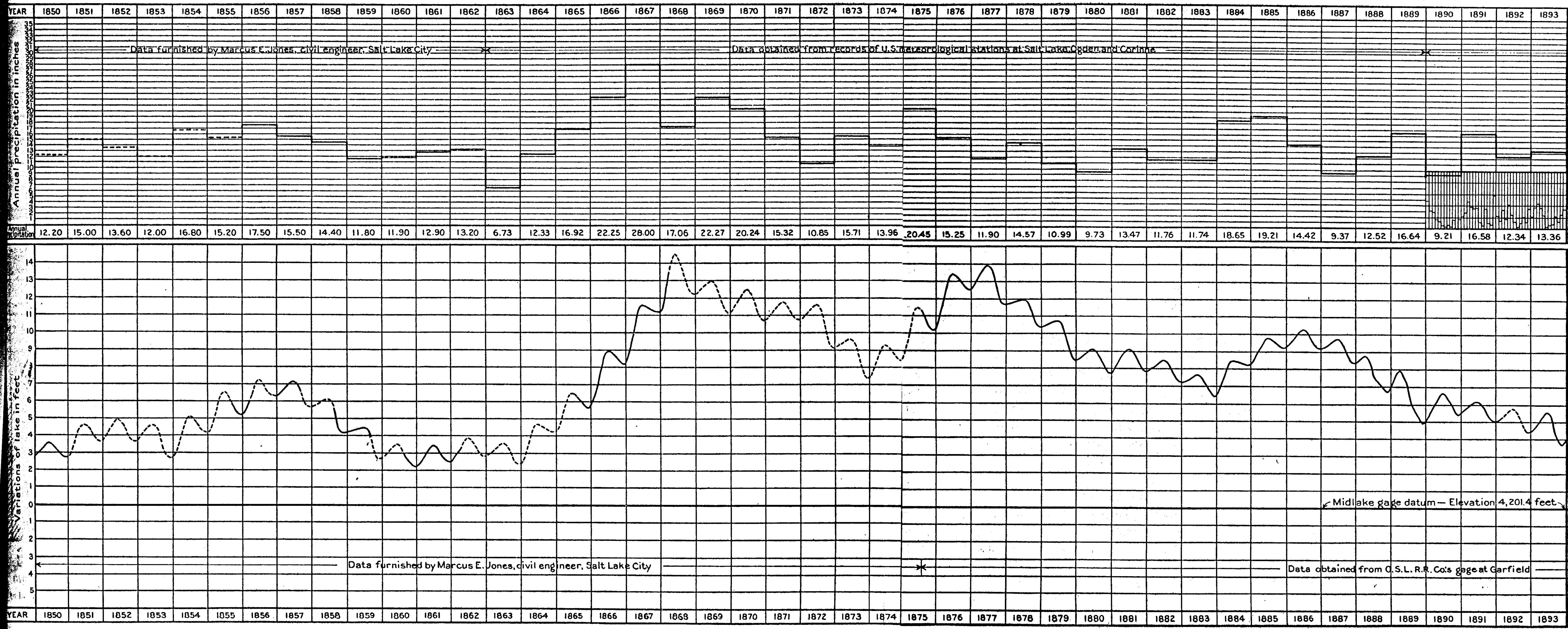
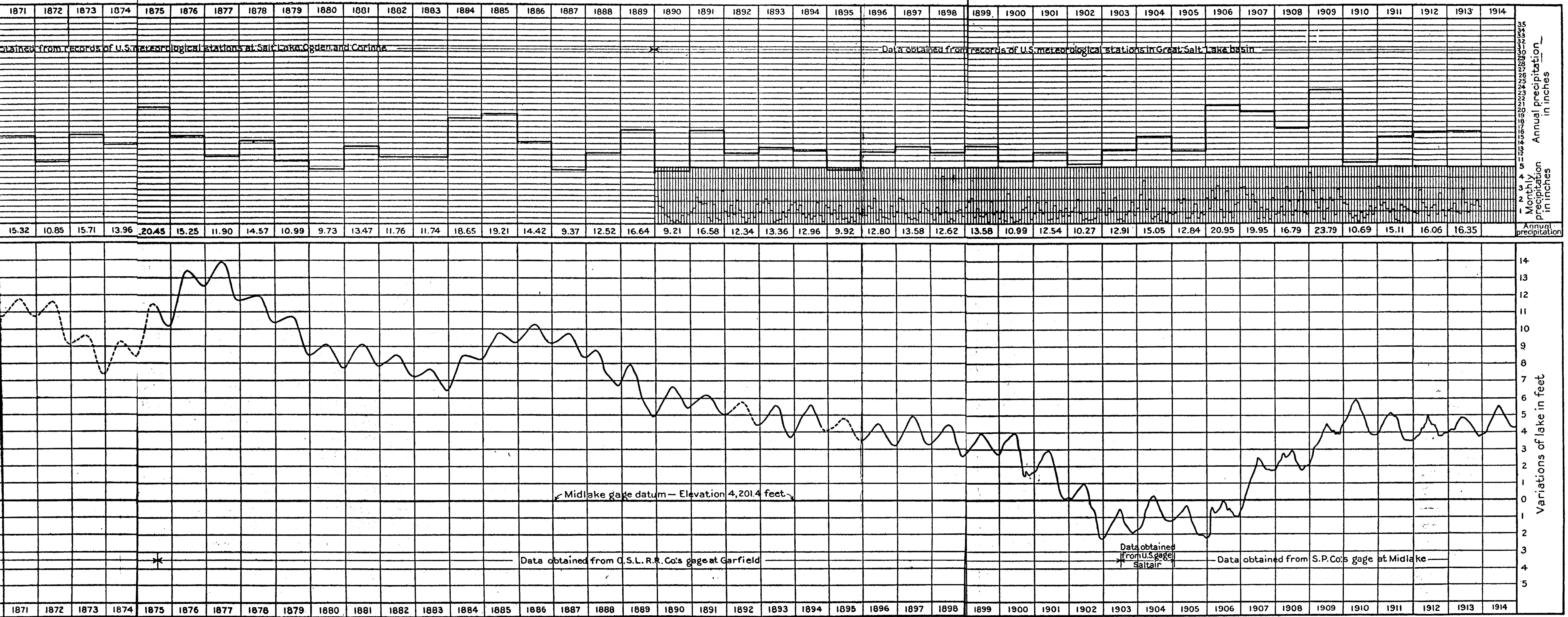


CHART SHOWING VARIATON IN LEVEL OF GREAT SALT LAKE AND IN MONTHLY AND ANNUAL PRECIPITATION IN GREAT SALT LAKE BA

From chart prepared in the office of the chief engineer of the Oregon Short Line Railroad Co.



[C]HART SHOWING VARIATION IN LEVEL OF GREAT SALT LAKE AND IN MONTHLY AND ANNUAL PRECIPITATION IN GREAT SALT LAKE BASIN.

From chart prepared in the office of the chief engineer of the Oregon Short Line Railroad Co.

the area of the lake, by assuming the annual evaporation to be 48 inches. There is little doubt that these estimates are sufficiently accurate to show conclusively the periods of high, low, and average run-off. The periods of low run-off thus shown were 1857–1860, 1872–73, 1877–1880, 1887–1889, and 1900–1902. In the 65-year period 1902 was the year of lowest run-off. During the last 20 years the inflow has been reduced somewhat by the use of water for irrigation. The years of high run-off were 1854–1856, 1864–1868, 1874–1876, 1884–85, and 1907–8. If the variation in the water level of Great Salt Lake does indicate the variation in run-off, then it is reasonable to assume that the period of low run-off on the Colorado,

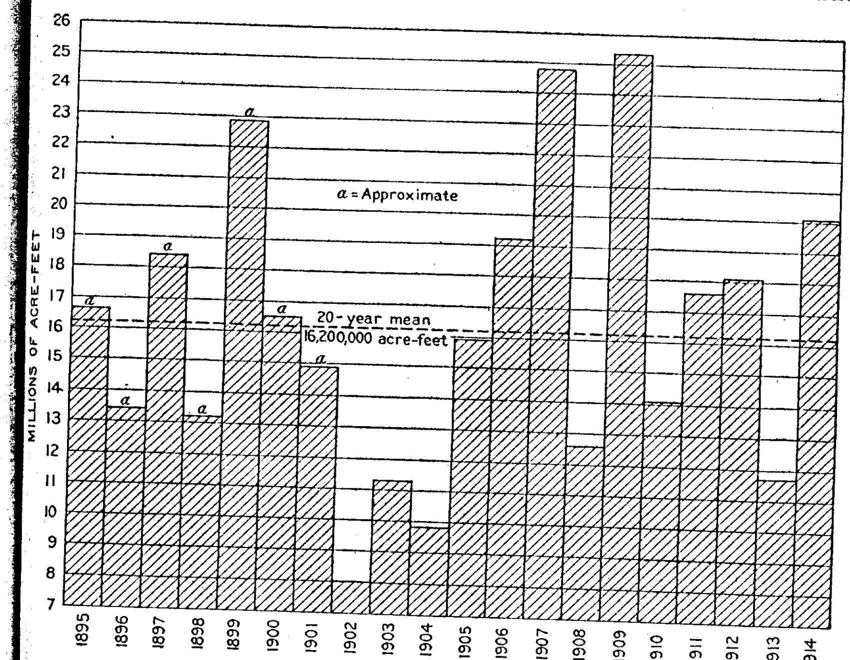


FIGURE 5.—Diagram showing annual discharge of Colorado River above Gila River, 1895–1914.

901 to 1905, inclusive, may not occur on an average oftener than nce in 50 or 60 years.

The accuracy of the records showing the run-off of the Colorado at uma, Ariz., for the year 1902 has been questioned; but the gage as read daily as usual; 36 discharge measurements were made during e year; changes in the cross section of the river channel were due scour and were probably small, as the average discharge was small; the run-off for 1902 is the lowest recorded for Green and Grand ers, the two largest tributaries of the Colorado. It therefore seems t the run-off records for the Yuma station for 1902 are not only stent but of an accuracy comparable with that of the records ng the run-off at that station during later years.

Daily gage readings have been taken showing the stage of the Colorado at Yuma since April 1, 1878, to date, but systematic discharge measurements were not begun until 1902, and no method has been devised whereby the early gage heights can be used to determine the discharge. Owing to the fact that the river bed is eroded during high water and silted up during low the section of the river channel that determines the elevation of the water surface at the Yuma gage is not permanent and the usual method of defining the relation between gage height and discharge by means of a rating curve is not practicable. Estimates of the annual run-off in acre-feet, based on the run-off of Green, Grand, and Arkansas rivers have been made for the period 1895 to 1901, inclusive, and are probably accurate within 20 per cent.

The gage-height records are of value, however, in that they show the river stage and dates of all floods since 1878. At Yuma the river overflows its banks at gage height 25 feet and above, regardless of the actual discharge. Plate XXIII shows a 38-year record of the river stage obtained by plotting the gage heights from 1878 to 1915, inclusive. The gage height 25 feet, at which overflow occurs, is shown by the heavy dotted line. It will be noted that overflow occurred in 1884, 1886, 1890, 1891, 1892, 1893, 1895, 1897, 1899, 1900, 1901, 1903, 1904, 1905, 1906, 1907, 1908, 1909, 1911, 1912, and 1914. In the 21-year period, 1878–1898, overflow occurred during 8 years; in the 17-year period, 1899–1915, overflow occurred during 13 years. There is no reason for concluding that the average annual discharge for the period 1878–1898 was less than that for the period 1899–1915. The gage records show that the average low-water plane has gradually risen, and as a result the river channel is more obstructed by silt deposits; the average annual flood that now causes overflow would, in the eighties, have remained in the river channel.

The gage-height chart (Pl. XXIII) shows also the occurrence of sudden floods aside from the annual rise due to melting snow. Nearly all these sudden floods come from Gila River, which joins the Colorado 1½ miles above Yuma. The magnitude of these Gila floods has been lessened somewhat by the construction of the Roosevelt dam on Salt River, but violent floods still reach the Colorado from this source, and these floods will continue to menace irrigation development below Yuma unless they are controlled by storage reservoirs.

CAPACITY OF CHANNEL.

When the river rises above the 25-foot stage on the gage at Yuma overflow occurs within the limits of the irrigation works of the United States Reclamation Service at that place. If the flow of the river to be regulated in such a way that levees will not be required discharge at Yuma must be kept below the carrying capacity of

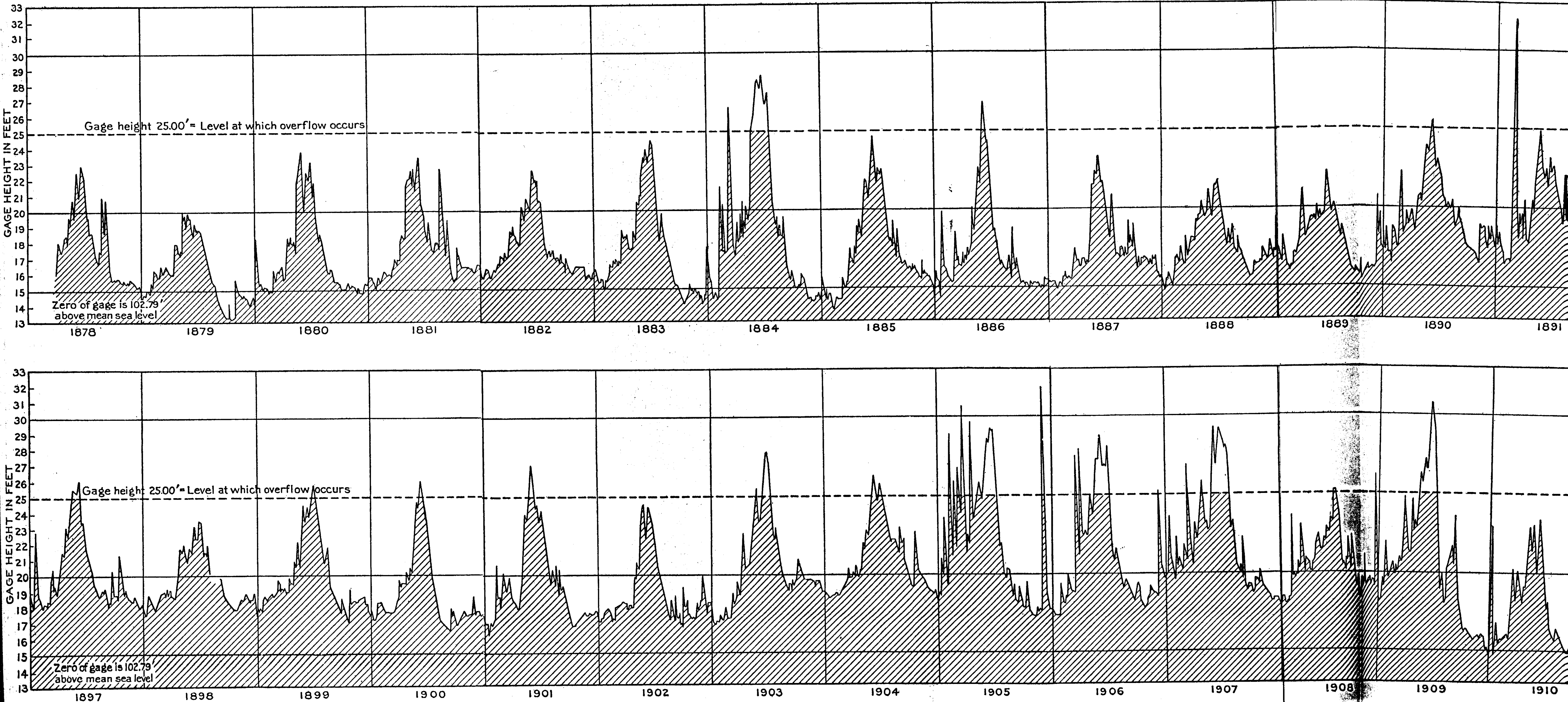
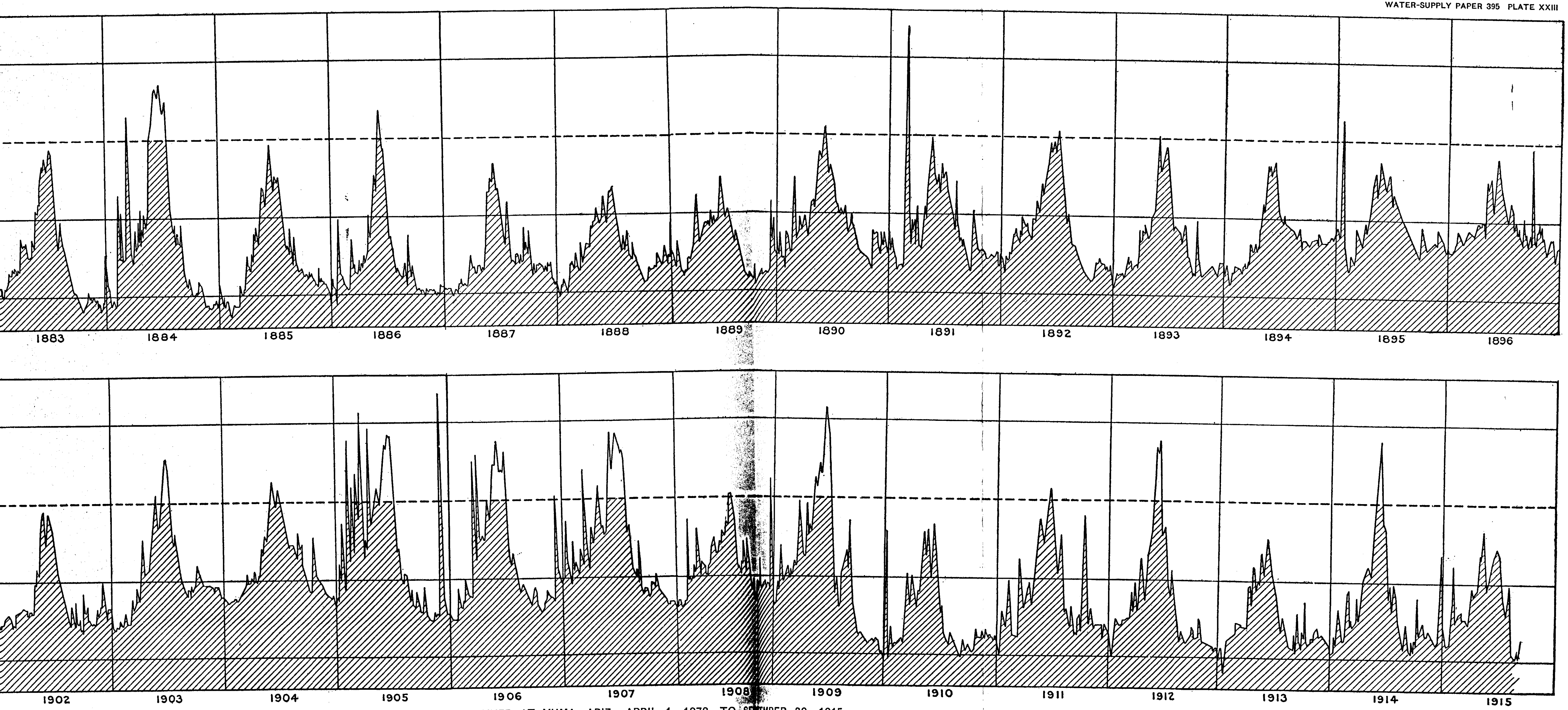


CHART SHOWING DAILY GAGE HEIGHT OF COLORADO RIVER AT YUMA, ARIZ., APRIL 1, 1878, TO SEPTEMBER 30, 1915.

Gage readings from 1878 to 1902 taken by Southern Pacific Co., from 1902 to 1915 by the United States Reclamation Service.



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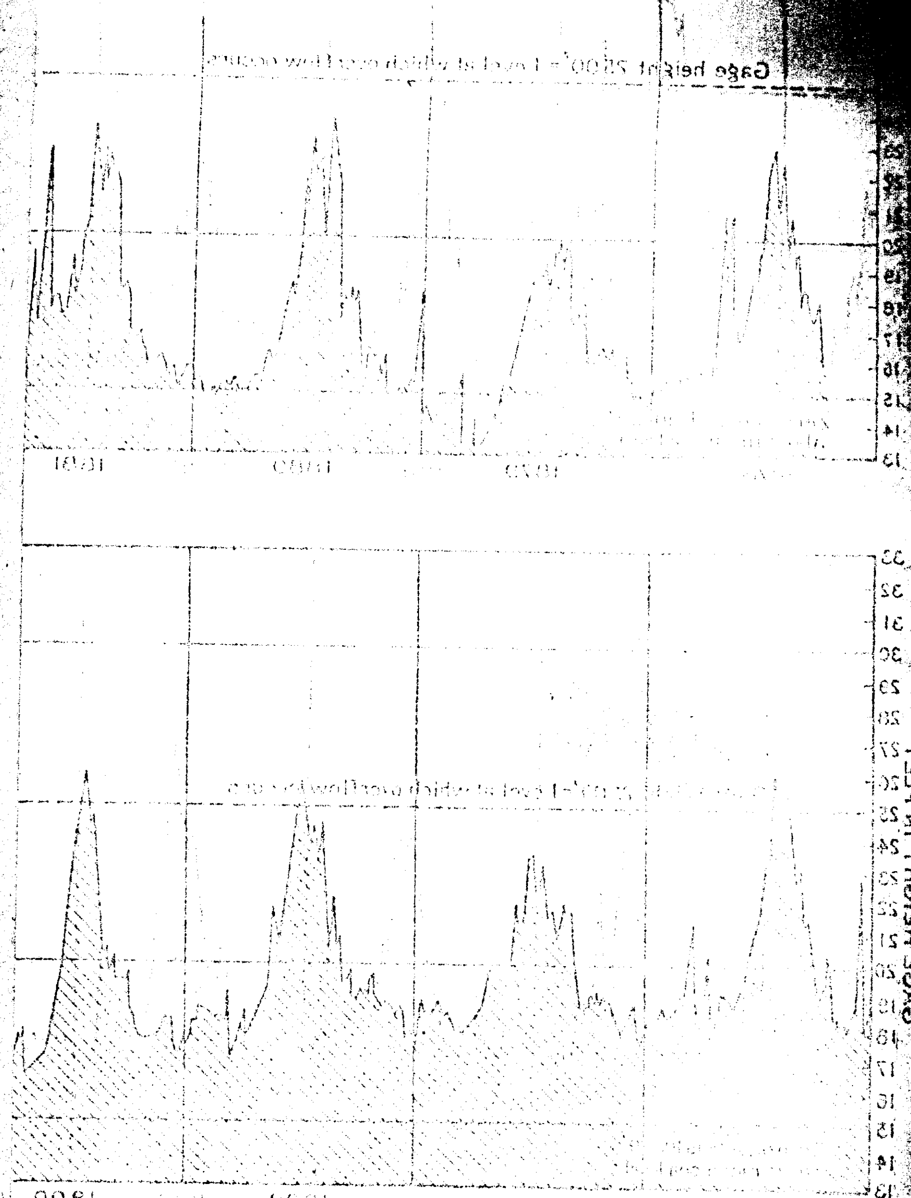


nel for gage height 25 feet. The following table shows the car- capacity of the river channel at Yuma for stages approximat- 25 feet on the gage, and the dates on which that stage has been ..ed.

..charge of Colorado River at Yuma, Ariz., at 25-foot (approximate) gage height.

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
	Feet.	*Sec.-ft.*		*Feet.*	*Sec.-ft.*
..y 26, 1902	24.5	59,200	May 15, 1906	24.9	46,500
..y 23, 1903	25.2	48,980	Dec. 7, 1906	25.3	60,000
..ne 10, 1903	24.8	49,050	Apr. 20, 1907	24.8	41,500
..ly 9, 1903	25.2	44,430	July 24, 1907	24.85	82,400
..ne 17, 1904	24.8	38,192	June 21, 1908	24.75	51,700
..ne 20, 1904	25.1	40,350	June 22, 1908	25.00	55,100
..b. 20, 1905	24.9	47,000	June 28, 1908	24.80	50,700
..r. 2, 1905	25.05	39,260	May 16, 1909	24.9	55,500
..r. 6, 1905	24.8	44,310	July 14, 1909	25.05	80,800
..r. 19, 1905	24.9	45,050	May 24, 1910	23.0	70,300
May 1, 1905	25.0	41,520	June 19, 1911	24.75	68,500
May 8, 1905	25.1	40,050	June 29, 1911	24.80	70,500
May 16, 1905	25.0	37,320	May 30, 1912	25.05	69,100
May 23, 1905	24.95	38,390	June 26, 1912	24.35	78,000
Mar. 17, 1906	25.5	42,300	June 11, 1913	22.80	62,300
Mar. 30, 1906	25.0	47,500	May 24, 1914	25.00	74,500
May 2, 1906	25.1	50,800	June 20, 1914	24.20	106,300

The above table brings out the following facts: At a stage of 25 feet on the Yuma gage the carrying capacity of the channel in 1902 was about 60,000 second-feet; in 1903, about 50,000 second-feet; in 1904, about 40,000 second-feet. In 1905 the carrying capacity of the channel was still further reduced by silt brought down by the spring floods from Gila River. On May 16, 1905, with a gage height of 25 feet the discharge was 37,320 second-feet. During 1906 the safe carrying capacity was 48,000 second-feet. In 1907, 1909, 1912, and 1914 unusually high floods occurred. During these years at the 25-foot stage the discharge ranged from 41,000 to 106,000 second-feet. Under natural conditions during the period 1902 to 1914 the carrying capacity of the river channel at Yuma for the 25-foot stage varied between 37,320 and 106,000 second-feet. If the river were regulated the high floods would be prevented and the low-water flow would be considerably increased. These changes would tend to eliminate the scour that occurs during high floods and the silting up during periods of low flow. It therefore seems reasonable to assume that with the river under control and a flow more equalized the carrying capacity of the channel at Yuma for the 25-foot stage could be maintained at 50,000 second-feet.

STORAGE REQUIRED.

To determine how much storage would be required to prevent the floods exceeding 50,000 second-feet the daily discharge at Yuma for the period 1902 to 1915 has been plotted (Pl. XXIV, in pocket). The volume of discharge above 50,000 second-feet must be stored. From this chart the following table has been prepared showing the annual storage required to maintain a flow at Yuma not exceeding 50,000 second-feet.

Storage required to maintain a flow at Yuma not exceeding 50,000 second-feet.

	Acre-feet.		*Acre-feet.*		*Acre-feet.*
1902	176,000	1907	5,750,000	1912	3,820,000
1903	654,000	1908	155,000	1913	164,000
1904	2,320	1909	6,330,000	1914	4,700,000
1905	2,690,000	1910	792,000		
1906	2,770,000	1911	1,300,000		

The table indicates that during 1909 it would have been necessary to store 6,330,000 acre-feet to maintain a flow at Yuma of 50,000 second-feet or less.

A mass curve of the discharge of Colorado River at Hardyville has been prepared for the period 1895 to 1914, inclusive (Pl. XVII, p. 162), by means of which various storage problems can be solved approximately. Disregarding evaporation and the effect of development of irrigation, it is estimated that for the 20-year period 1895 to 1914 a mean discharge of 15,750,000 acre-feet or 21,800 second-feet could have been maintained at Hardyville by utilizing storage reservoirs with an aggregate capacity of 25,000,000 acre-feet. Such regulation would increase the navigability of the stream and make possible the maximum use of the waters of the Colorado for power development. It has been conclusively shown by engineers that it is not commercially feasible to maintain a channel on the lower Colorado suitable for navigation; it is also apparent that the regulation of the river for the benefit of power development would result in a waste of water. Without going into further detail it may be said that the regulation of the Colorado to produce a uniform flow is not desirable. The problem of greatest importance is that of regulating the river to conform to the demand for water for irrigation and of protecting the irrigated area from overflow. The storage required to regulate the flow to meet the demand for irrigation of the 2,730,000 acres of land below Virgin River could be estimated with a fair degree of accuracy if there were to be no increase in the use of water on the upper reaches of the Colorado. A diagram indicating the storage required under this hypothetic condition is shown in Plate XVII. On the diagram the line AFC represents the demand for the irrigation of 2,730,000 acres with head-gate duty of 5 acre-feet. To augment the low-water flow during the years 1902 to 1906, inclusive, 14,000,000 acre-feet of storage would have been required. If the demand-line is extended back from G, it intersects the mass curve near A, thus showing that the reservoirs would fill.

To make up the losses due to evaporation and other causes it is probable that a storage of 18,000,000 acre-feet would be required. This may be considered a maximum storage requirement, for it

would not be possible to bring about this enormous development on the lower Colorado within a short period of years. The development will be gradual and will be paralleled by increase in the irrigated area in the Colorado River basin above Virgin River. In another part of this report (p. 158) it has been shown that 980,000 acres were irrigated above and including Virgin River in 1913, and that an additional area of 2,380,000 acres can be irrigated if storage reservoirs with an aggregate capacity of 2,000,000 or 3,000,000 acre-feet are provided. There will be losses due to evaporation from the reservoirs and to diversions for irrigation, and there will be comparatively uniform return flow from the irrigated lands. These factors will not only reduce the annual run-off available for irrigation on the lower Colorado but will cause marked changes in the rate of run-off. The flood peaks will be reduced and the return flow from the irrigated areas will tend to increase the low flow on the lower Colorado during the winter months.

STORAGE SITES.

GREEN RIVER BASIN.

FLAMING GORGE RESERVOIR SITE.

General conditions.—From Green River, Wyo., the Green flows southward through an open country for about 75 miles. Four miles south of the Utah-Wyoming line it passes into a canyon known as Flaming Gorge, 1 mile below which is the upper end of Horseshoe Canyon. The dam site for the Flaming Gorge reservoir is near the lower end of Horseshoe Canyon (Pl. XXV, *A*), about 3 miles by river below Flaming Gorge and about 4 miles below the mouth of Henrys Fork.

During the fall and winter of 1914 the United States Reclamation Service made detailed surveys of this site. Investigations to determine the character of the foundation at the dam site are not completed, but recent reports from the engineer in charge indicate that bedrock lies between 60 and 70 feet below the water surface. The elevation of low water at the dam site is 5,825 feet. A dam 210 feet high would be 200 feet long on the bottom and 550 feet on the top and would form a reservoir capable of storing 3,000,000 acre-feet.

Area and capacity of Flaming Gorge reservoir site, Utah-Wyoming.

Contour.	Area.	Capacity.	Contour.	Area.	Capacity.
Feet.	*Acres.*	*Acre-feet.*		*Acres.*	*Acre-feet.*
5,825 [a]			5,980	21,600	1,450,000
5,860	3,500	60,000	6,000	25,600	1,920,000
5,880	5,900	150,000	6,020	29,700	2,490,000
5,900	7,800	280,000	6,040	34,400	3,130,000
5,920	11,100	470,000	6,060	40,300	3,860,000
5,940	14,600	730,000	6,080	46,700	4,720,000
5,960	18,000	1,050,000			

[a] Elevation above sea level of water surface at dam site during low stage.

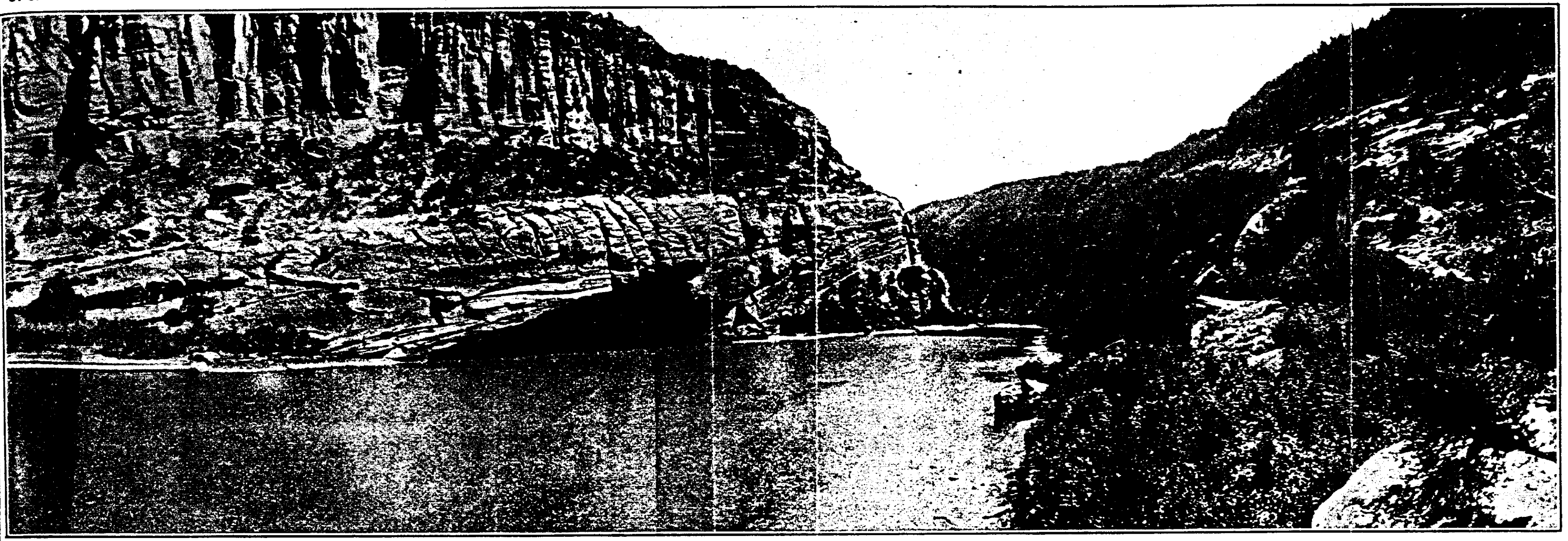
Run-off available for storage.—The drainage area tributary to the Flaming Gorge reservoir site is about 15,000 square miles. From records showing the run-off from Green River at Green River, Wyo., and Bridgeport, Utah, and also from Blacks Fork below Hams Fork, near Granger, Wyo., a fairly accurate estimate of the run-off available for storage at the Flaming Gorge reservoir site can be made. Between this reservoir site and station on Green River at Bridgeport, Utah, about 34 miles downstream, only very small tributaries enter the Green, the intervening drainage area being about 650 square miles. The record for the Bridgeport station should therefore show with fair accuracy the run-off available for storage at Flaming Gorge. The drainage area above the gaging station on Blacks Fork and that on Green River at Green River, Wyo., is about 70 per cent of the area tributary to the Flaming Gorge reservoir site; the 30 per cent of the drainage area below these stations and above the dam site for the Flaming Gorge reservoir furnishes proportionally much less of the run-off than the drainage area above the stations; it will therefore be assumed that the combined run-off at the two gaging stations is 85 per cent of the quantity of water available for storage in the Flaming Gorge reservoir site.

Annual discharge of Green River at Bridgeport, Utah.[1]

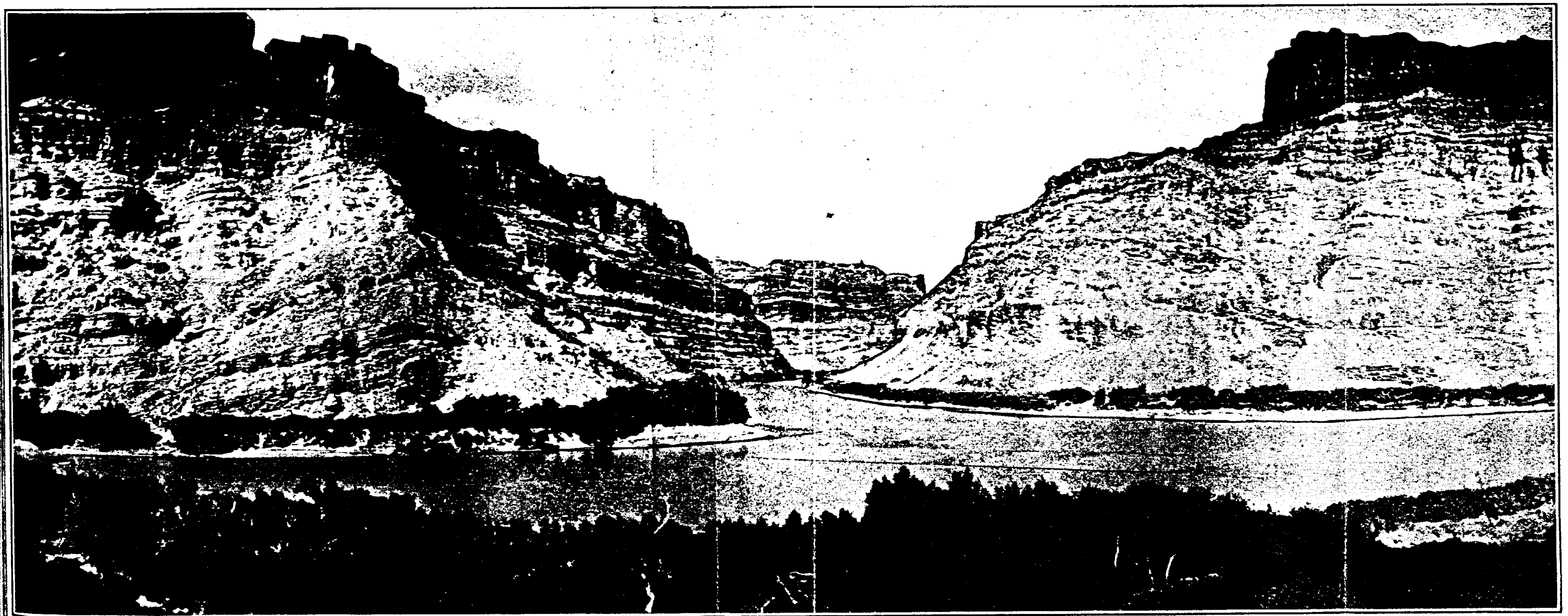
	Acre-feet.		Acre-feet.		Acre-feet.
1895	1,860,000	1903	2,060,000	1911	1,790,000
1896	2,140,000	1904	2,690,000	1912	2,130,000
1897	2,510,000	1905	1,440,000	1913	2,460,000
1898	2,240,000	1906	2,240,000	1914	2,520,000
1899	3,880,000	1907	3,790,000		
1900	1,550,000	1908	1,790,000		46,150,000
1901	1,880,000	1909	3,710,000	Mean	2,310,000
1902	1,480,000	1910	1,990,000		

The mean annual run-off available for storage in the Flaming Gorge reservoir site is 2,310,000 acre-feet, the variation in the annual run-off during the 20-year period 1895 to 1914 being 1,440,000 to 3,880,000 acre-feet. Practically the entire flow could be stored without interfering with prior rights below, as there are few irrigation rights affecting Green River between Flaming Gorge and Gunnison Valley. Storage of the entire flow would interfere with the operation of ferries in the vicinity of Browns Park, although suitable fording places could no doubt be found.

[1] The record for the years 1895 to 1911, inclusive, is based on the discharge records showing the run-off of Green River at Green River, Wyo., and of Blacks Fork, below Hams Fork, near Granger, Wyo. The sum of the flow at these stations was assumed to be 85 per cent of the flow at Bridgeport, Utah. Breaks in the record for the two stations in Wyoming were filled in by noting the run-off at other stations in the Green River basin. The records for the years 1912 to 1914 were obtained at Bridgeport, Utah. The mean for the 20-year period is probably accurate within 5 per cent.



A. DAM SITE AT LOWER END OF HORSESHOE CANYON, GREEN RIVER, UTAH.



B. JUNCTION OF GREEN AND GRAND RIVERS.

Green River at left, Grand River in center, and Colorado River at right.

Value of site.—The Flaming Gorge reservoir site is near the headwaters of Green River, where the stream is comparatively clear. The capacity of the reservoir would probably not be seriously reduced by the deposition of silt. Bedrock has been found at the dam site 60 or 70 feet below low-water level. There is a natural spillway site at a low saddle a mile above the dam site. The area that would be submerged is mostly vacant public land, and little agricultural land would be flooded.[1]

Of the smaller reservoir sites the Flaming Gorge appears to be the most valuable in the Colorado River basin. Its chief value would come from its operation to increase the low-water flow for irrigation on the lower Colorado and to equalize the flow of Green River in the interests of power development. Its use would not reduce materially the floods on the lower Colorado.

BROWNS PARK RESERVOIR SITE.

General conditions.—Browns Park is a small valley on Green River in northeastern Utah and northwestern Colorado. The valley is about 35 miles long and more than a mile wide. The Green, after passing Browns Park, flows into Ladore Canyon. Investigations made by the United States Reclamation Service show that 2,520,000 acre-feet of water could be stored by raising the water level 200 feet at the upper end of Ladore Canyon.[2] At the dam site the bedrock lies 160 feet below the mean low water. A plane-table survey of the reservoir site was made from which the following data were obtained:

Area and capacity of Browns Park reservoir site.

Height of dam (feet).	Elevation of water surface above sea level.	Area.	Total capacity.	Height of dam (feet).	Elevation of water surface above sea level.	Area.	Total capacity.
	Feet.	*Acres.*	*Acre-feet.*		*Feet.*	*Acres.*	*Acre-feet.*
0	5,180	....	....	110	5,290	13,403	835,980
10	5,190	312	1,560	120	5,300	14,573	975,860
20	5,200	2,549	15,860	130	5,310	15,619	1,126,820
30	5,210	5,993	58,570	120	5,320	16,803	1,288,930
40	5,220	7,447	125,770	150	5,330	18,157	1,463,730
50	5,230	8,161	203,810	160	5,340	19,315	1,651,000
60	5,240	8,839	288,810	170	5,350	20,515	1,850,240
70	5,250	9,657	381,290	180	5,360	21,773	2,061,680
80	5,260	10,413	461,640	190	5,370	22,927	2,285,180
90	5,270	11,2[illegible]7	589,940	200	5,380	....	[a]2,520,000
100	5,280	12,279	707,570				

[a] Approximate.

Run-off available for storage.—Records obtained at the Bridgeport gaging station on Green River, at the upper end of the Browns Park reservoir site, show all the run-off available for storage except

[1] See discussion of artificial fertilizers, pp. 182–183.

[2] Newell, F. H., Colorado River projects: U. S. Recl. Service Seventh Ann. Rept., p. 58, 1908.

a small flow from Vermilion Creek, which joins Green River above Ladore Canyon. Records obtained at Bridgeport, Utah, Green River, Wyo., and Granger, Wyo., indicate that the minimum annual run-off available for storage at the Flaming Gorge reservoir site is 1,440,000 acre-feet, the maximum 3,880,000 acre-feet, and the mean 2,310,000 acre-feet. Adding to these results 2 per cent gives a fairly accurate estimate of the storable run-off at Browns Park, or a mean annual run-off of 2,360,000 acre-feet.

Value of site.—The Browns Park reservoir site is about 60 miles below the Flaming Gorge site. Its use in connection with the control of Green and Colorado rivers would be no more effective than the use of the Flaming Gorge site. The dam site in Horseshoe Canyon is better than the dam site in Ladore Canyon. For a given height of dam the Flaming Gorge site gives greater storage capacity; Vermilion Creek would carry considerable silt into the Browns Park reservoir, whereas the river at Flaming Gorge is comparatively free from silt. There are other reservoir sites lower on Green River which can be utilized when complete regulation of the flow of Green River is desired.

In view of these facts the Browns Park reservoir site may be considered of no value in connection with the problem of regulating the flow of Green and Colorado rivers.

CROSS MOUNTAIN RESERVOIR SITE.

General conditions.—The Cross Mountain reservoir site is in Maybell Valley on Yampa River in Moffat County, Colo. The dam site is at Cross Mountain, 7 miles above the mouth of Little Snake River. A 200-foot dam at this point would probably give a reservoir capacity of 4,000,000 acre-feet, which is four times the average annual run-off of Yampa River at the site. If this reservoir site were utilized about 20,000 acres of agricultural land would be submerged and the village of Maybell would be flooded.

Run-off available for storage.—By using the records showing the run-off of Yampa River at Craig and Maybell, Colo., and of Williams Fork at Hamilton, Colo., the mean annual run-off of Yampa River at Maybell has been estimated at 1,100,000 acre-feet, the range in the annual run-off being from 940,000 to 1,400,000 acre-feet. A reservoir having storage capacity of 600,000 acre-feet would be sufficient to control the flow of Yampa River at Cross Mountain Canyon.

Value of site.—Although the capacity of the Cross Mountain reservoir is very large the run-off available for storage is comparatively small, and the damage to property by the flooding of the town of Maybell and about 20,000 acres of agricultural lands would be considerable. The route of the proposed Denver & Salt Lake Railroad, now completed from Denver to Craig, is through Maybell Valley and Cross Mountain Canyon and would have to be changed if this reservoir site should be developed.

In view of the above data and of the fact that there is another reservoir site immediately above the Cross Mountain site, it may be concluded that the Cross Mountain site should not be considered in connection with projects to control the Colorado.

JUNIPER MOUNTAIN RESERVOIR SITE.

General conditions.—The Juniper Mountain reservoir site is on Yampa River in Moffat County, Colo., the dam site being in Juniper Canyon, about 6 miles above Maybell. This reservoir site has been investigated by the Kindred Power & Irrigation Co. A dam 175 feet high would form a reservoir having a storage capacity of about 600,000 acre-feet or sufficient to equalize the flow of Yampa River to the mouth of Little Snake River. The capacity of a reservoir formed by a 200-foot dam would probably exceed 1,400,000 acre-feet.

Run-off available for storage.—As the Juniper Mountain reservoir site is immediately above the Cross Mountain site the estimate of run-off available for storage at Cross Mountain is applicable at Juniper Mountain. The mean annual run-off for the period 1901 to 1910 was about 1,100,000 acre-feet.

Value of site.—A reservoir at the Juniper Mountain site would submerge a comparatively small area of agricultural land and would not interfere with the proposed extension of the Denver & Salt Lake Railroad from Craig, Colo., to Salt Lake City, Utah. In view of the possibility that at some future date it may be found desirable to equalize the flow of Yampa River in the interests of power development in Cross Mountain Canyon, the feasibility of constructing a dam in Juniper Mountain Canyon should be determined by a thorough investigation.

ISLAND PARK RESERVOIR SITE.

General conditions.—The Island Park reservoir site is on Green River in Utah, about 6 miles below the mouth of Yampa River and immediately above Split Mountain Canyon. Investigations[1] made by the United States Reclamation Service indicate that a dam 100 feet high in Split Mountain Canyon would create a reservoir having a storage capacity between 130,000 and 150,000 acre-feet.

Run-off available for storage.—Fragmentary records summarized in the following table show that run-off of Green River at Jensen and Ouray, Utah, which is about the same as at Split Mountain Canyon.

[1] Colorado River projects: U. S. Recl. Service Seventh Ann. Rept., p. 58, 1908.

Discharge of Green River at Ouray, Utah, 1895 to 1914.[1]

	Acre-feet.		Acre-feet.		Acre-feet.
1895	3,210,000	1903	3,550,000	1911	3,080,000
1896	3,690,000	1904	4,570,000	1912	3,670,000
1897	4,330,000	1905	2,480,000	1913	3,850,000
1898	3,860,000	1906	3,860,000	1914	4,770,000
1899	6,700,000	1907	6,520,000		
1900	2,670,000	1908	3,080,000		79,510,000
1901	3,240,000	1909	6,400,000	Average	3,980,000
1902	2,550,000	1910	3,430,000		

Value of site.—The capacity of the Island Park reservoir site is small, and in view of the fact that larger sites are available both above and below it seems evident that Island Park is valueless for use as a reservoir.

MINNIE MAUD RESERVOIR SITE.

General conditions.—The Minnie Maud reservoir site is on Green River in the upper end of Desolation Canyon, the dam site being 1 mile below the mouth of Minnie Maud Creek. A topographic survey was made of this site in 1908 by Guy Sterling, consulting engineer, of Salt Lake City, Utah, whose investigations were made in connection with a power project. A dam 120 feet high would be 600 feet long on bottom and 1,200 feet long on top and would give a storage capacity above the 90-foot level of 1,000,000 acre-feet. With these data the writer has estimated that a reservoir capable of storing 4,000,000 acre-feet could be made by constructing a dam 200 feet high. The backwater would extend up Green River to Jensen, up Duchesne River 20 miles, and up White River 17 miles.

Run-off available for storage.—The storable run-off at the Minnie Maud reservoir site has been computed by deducting the flow of Price River from that shown by the records of run-off for Green River at Green River, Utah.

Discharge of Green River at Green River, Utah, 1895–1914.[2]

	Acre-feet.		Acre-feet.		Acre-feet.
1895	4,350,000	1903	4,830,000	1911	4,200,000
1896	4,170,000	1904	5,200,000	1912	6,220,000
1897	6,250,000	1905	4,000,000	1913	5,360,000
1898	5,300,000	1906	6,450,000	1914	7,080,000
1899	8,120,000	1907	8,890,000		
1900	3,720,000	1908	4,220,000		109,600,000
1901	4,420,000	1909	8,680,000	Average	5,480,000
1902	3,490,000	1910	4,640,000		

[1] The record for 1904 was obtained at the Jensen gaging station; that for 1913 and 1914 was obtained at the stations at Ouray and Jensen. Estimates for the remaining years are based on the flow at other gaging stations in the Green River basin.

[2] The run-off for the years 1898 to 1904, inclusive, is estimated from records obtained at other stations in the Green River basin; that for the remaining years is estimated from data obtained at the gaging stations on Green River at Green River and Little Valley, Utah.

The mean annual run-off for the 20-year period 1895–1914 was 5,480,000 acre-feet, the minimum being 3,490,000 acre-feet, in 1902, and the maximum 8,890,000 acre-feet, in 1907. The average annual run-off from Price River was about 180,000 acre-feet. This quantity deducted from the mean flow of the Green at Green River, Utah, gives the mean annual run-off available for storage at the Minnie Maud reservoir site, or 5,300,000 acre-feet. As the irrigated area above the reservoir is increased the storable run-off will be reduced. The storage capacity at this site is about 4,000,000 acre-feet, which, with the utilization of other storage sites above, would be more than sufficient to control the flow of Green River to its mouth.

Value of site.—The Minnie Maud reservoir site appears to be second in size in the Colorado River basin. The tributary drainage area is about 38,100 square miles. The maximum floods which pass the site exceed 60,000 second-feet. Owing to the location and capacity of this site its utilization would have an appreciable effect on the flow of the lower Colorado. If the conditions at the dam site are favorable for the construction of a 200-foot dam, it would seem certain that the Minnie Maud reservoir site will be of value in connection with any plan for the control of water for the lower Colorado basin.

RATTLESNAKE RESERVOIR SITE.

General conditions.—The Rattlesnake reservoir site is on Green River, in Desolation Canyon, immediately below the Minnie Maud site. A reconnaissance examination was made by Guy Sterling, consulting engineer, Salt Lake City, Utah. The dam site is about 3 miles above the mouth of Rattlesnake Creek and about the same distance above the effect of backwater from the proposed diversion dam for the Green River irrigation project at the mouth of Coal Creek. A dam 165 feet high would be about 1,200 feet long on top and about 750 feet on the bottom. The capacity of the reservoir above the 90-foot level was estimated at 800,000 acre-feet. The total capacity of a reservoir formed by a dam 165 feet high would be about 1,250,000 acre-feet.

Run-off available for storage.—The mean annual storable run-off at the Rattlesnake reservoir site is the same as that at the Minnie Maud site, or 5,300,000 acre-feet.

Value of site.—The flow of Green River can be controlled to its mouth by means of reservoirs at the Flaming Gorge and Minnie Maud sites. The capacity of the Rattlesnake reservoir site is comparatively small and the cost of storage at this point would probably be high. The site may therefore prove to be of little value in connection with the control of the Colorado; it has, however, possible value for the development of power, and for this purpose is worthy of thorough investigation.

GREEN-GRAND RESERVOIR SITE.

General conditions.—The Green-Grand reservoir site is at the junction of Green and Grand rivers, in southeastern Utah. A view of the junction is shown in Plate XXV, *B* (p. 200). By constructing a dam in the canyon of Colorado River just below this junction a reservoir of enormous storage capacity could be created. During the summer of 1914 the United States Reclamation Service made a plane-table survey of Green River from Gunnison Butte to its mouth, and in 1912 the topographic branch of the United States Geological Survey made a survey of Grand River. The following table is based on the data furnished by these surveys:

Area and capacity of Green-Grand reservoir site, Utah.

Contour (feet).	Area.	Capacity.	Contour (feet).	Area.	Capacity.
	Acres.	*Acre-feet.*		*Acres.*	*Acre-feet.*
3,880 [a]			4,040	33,100	2,600,000
3,900	320	3,000	4,060	39,000	3,330,000
3,920	7,000	80,000	4,080	49,200	4,250,000
3,940	11,100	250,000	4,100	57,000	5,250,000
3,960	16,200	550,000	4,120	64,600	6,460,000
3,980	22,500	940,000	4,140	72,500	7,880,000
4,000	25,800	1,420,000	4,150	76,500	8,600,000
4,020	29,200	1,960,000			

[a] Elevation above sea level of water surface at dam site during low stage.

By raising the water level 270 feet at the junction of Green and Grand rivers a reservoir having a storage capacity of 8,600,000 acre-feet could be created. The backwater would extend up Green River 127 miles and up Grand River 110 miles, and would submerge the towns of Moab and Green River, Utah. If the water level at the junction were raised 170 feet the backwater would extend to the Denver & Rio Grande Railroad bridge at Green River, but the town of Moab would be flooded. The reservoir formed by a dam 170 feet high would have a storage capacity of 2,900,000 acre-feet.

During the fall of 1914 the character of the foundation at the dam site was investigated by engineers of the United States Reclamation Service. Diamond-drill holes bored at four points showed the conditions to be unfavorable for the construction of a high masonry dam. It may be found feasible, however, to construct a rock-fill dam, the spillway to be through tunnels from Green River to Colorado River, where the distance between the rivers is 2,600 feet. A dam 270 feet high would be 1,260 feet long on top and 620 feet on the bottom.

Run-off available for storage.—The drainage area tributary to the Green-Grand reservoir site comprises the area drained by Green and Grand rivers, 44,400 and 25,900 square miles, respectively, the combined area, 70,300 square miles, being 28.8 per cent of the total

area of the Colorado River basin. The average annual run-off at the junction of the Green and Grand is 76 per cent of that of Colorado River at Laguna dam. The discharge of the Colorado below this junction has been measured only at Hardyville and Yuma, Ariz. A fair estimate, however, can be made by using the records showing the run-off at Green River, Utah, San Rafael River near its mouth, and of Grand River and its lower tributaries. The run-off of Green River at Green River, Utah, for the period 1895 to 1914 is tabulated on page 204 in connection with the discussion of the Minnie Maud reservoir site. To determine the run-off of the Green at its mouth it is necessary to add the flow from San Rafael River. Records showing the run-off of the San Rafael near its mouth for the years 1909 to 1914, inclusive, have been used to determine the relation between the run-off of San Rafael River and that of Green River at Green River, Utah. The annual run-off of Grand River at its mouth was estimated by using the discharge records of the Grand at Moab, Utah, and Fruita and Palisades, Colo., of Gunnison River at Whitewater and Grand Junction, Colo., and the run-off records for Dolores River at Dolores, Colo., and for San Miguel River, a tributary of the Dolores, at Fall Creek and Placerville, Colo. The figures in the following table are sufficiently accurate to indicate the annual run-off available for storage at the Green-Grand reservoir site:

Annual discharge of Green, Grand, and Colorado rivers at the junction of the Green and Grand.

Year.	Green River.	Grand River.	Colorado River.	Year.	Green River.	Grand River.	Colorado River.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*		*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1895	4,520,000	6,360,000	10,900,000	1907	9,250,000	7,900,000	17,200,000
1896	4,320,000	6,790,000	11,100,000	1908	4,390,000	4,660,000	9,050,000
1897	6,460,000	8,260,000	14,700,000	1909	9,040,000	8,470,000	17,500,000
1898	5,430,000	4,850,000	10,300,000	1910	4,900,000	5,830,000	10,700,000
1899	8,480,000	8,900,000	17,400,000	1911	4,370,000	6,800,000	11,200,000
1900	3,820,000	6,880,000	10,700,000	1912	6,430,000	8,500,000	14,900,000
1901	4,600,000	7,010,000	11,600,000	1913	5,490,000	5,370,000	10,900,000
1902	3,600,000	4,280,000	7,880,000	1914	7,350,000	8,660,000	16,000,000
1903	4,960,000	5,650,000	10,600,000				
1904	5,320,000	5,070,000	10,400,000	20-year average.	5,680,000	6,720,000	12,400,000
1905	4,120,000	6,490,000	10,600,000				
1906	6,670,000	7,690,000	14,400,000				

The table shows that the mean annual run-off available for storage at the Green-Grand reservoir site for the 20-year period 1895–1914 was 12,400,000 acre-feet. The minimum flow, 7,880,000 acre-feet, occurred in 1902, and the maximum, 17,500,000 acre-feet, in 1909. The monthly mean flow of the Colorado at the junction of the Green and the Grand for the period October 1, 1913, to December 31, 1914, is shown by the following table:

Monthly discharge of Colorado River at junction of Green and Grand rivers for the period Oct. 1, 1913, to Dec. 31, 1914.[a]

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
1913-14.				
October	8,810	6,730	7,680	472,000
November	8,150	6,140	7,010	417,000
December	5,860	2,740	4,060	250,000
January	8,620	3,380	4,940	304,000
February	11,500	4,180	5,440	302,000
March	17,600	5,990	10,200	627,000
April	32,400	11,400	22,700	1,350,000
May	101,000	27,900	63,900	3,930,000
June	120,000	52,700	84,600	5,030,000
July	52,300	20,100	32,300	1,990,000
August	19,900	7,890	12,800	787,000
September	10,300	6,160	7,110	423,000
The year				15,900,000
1914.				
October	17,400	7,050	10,300	633,000
November	8,380	5,120	6,440	383,000
December	5,280	3,710	4,150	255,000

[a] This table is based on records showing the discharge of Green River at Little Valley, San Rafael River near its mouth, and Grand River at Moab, Utah.

The maximum discharge in the period covered by the foregoing table—120,000 second-feet—occurred in June, 1914, and though the floods of that year were unusually high, more excessive stages have been recorded on both rivers, which are usually in flood about the same time. A rough estimate indicates that the flow immediately below the junction of the rivers during the heavy floods in May, 1897, exceeded 130,000 second-feet.

Value of site.—By utilizing the Green-Grand reservoir site the flow of Colorado River at Yuma could be regulated in such a way that the maximum flood would not exceed 50,000 second-feet. Rarely would there be sufficient flow from San Juan River and other tributaries to create a discharge at Yuma exceeding this amount if the entire flow at the junction of Green and Grand rivers was cut off. For example, the mean discharge at Yuma for the month of June, 1914, was 110,000 second-feet. The peak of this flood, which occurred June 14, was 137,000 second-feet. The mean discharge of the Colorado at the junction of Green and Grand rivers was 94,100 second-feet during the 30-day period beginning May 22, and the peak flood, which occurred June 3, was 120,000 second-feet or 88 per cent of the peak flood at Yuma. The mean flow at the junction for the 30-day period was 86 per cent of that at Yuma during June. By cutting off the entire flow at the junction of the Green and Grand the flood of 137,000 second-feet at Yuma could have been reduced to about 17,000 second-feet and the mean flow to 16,000 second-feet. During the same 30-day period 5,600,000 acre-feet of water would have been available for storage at the Green-Grand reservoir site.

These data are submitted to show that this site is not only properly located but that its capacity would be sufficient to make possible a fairly complete regulation of the flow of Colorado River at Yuma, Ariz. The utilization of the site in conjunction with the proposed reservoir on San Juan River at Bluff, Utah, would make it possible to regulate the flow at Yuma in such a way as to prevent all overflow below Bulls Head Rock and to increase the low-water flow sufficiently to irrigate nearly 2,000,000 acres of land not now reclaimed.

If reservoirs at Flaming Gorge on Green River and at Kremmling on Grand River had been in operation during 1914, the peak flood flow at Yuma in June could have been reduced from 137,000 to 105,000 second-feet. It is apparent that the high floods on the lower Colorado can not be completely controlled by means of these two sites. If these floods are to be prevented the dams must be placed at or below the junction of Green and Grand rivers and on lower San Juan River.

Although the conditions at the junction of the Green and Grand are unfavorable for the construction of a high masonry dam, another type of dam, possibly a rock fill or combination of rock fill and masonry dam, might be practicable. With the data available at the present time it appears that excessively high stages on the lower Colorado can not be prevented without using the Green-Grand reservoir site, and therefore before it is abandoned every phase of the project should be investigated. The value of an acre-foot of stored water must be known before anyone can properly pass on the feasibility of completing a dam at the junction. For example, assuming that each acre of new land on the lower Colorado will require 5 acre-feet of stored water and will stand a charge of $25 for storage works, without considering the enormous value of storage at the junction for flood prevention, a reservoir operated to increase the low-water flow for irrigation alone would warrant an expenditure of $5 an acre-foot, or $43,000,000.

At present only meager data are available showing the amount of silt carried by Green and Grand rivers.[1] If the silt brought down annually by the Green and Grand is equivalent to 10,000 acre-feet of submerged mud, then the Green-Grand reservoir site, with a capacity of 8,600,000 acre-feet, would be completely filled with silt in 860 years, if all of the silt were to be retained. All this 10,000 acre-feet of mud would, however, not remain in the reservoir, for the 10,000,000 to 14,000,000 acre-feet of water that would pass through the reservoir annually would undoubtedly carry from the reservoir considerable silt. It seems probable that the reservoir could be operated 500 years before its capacity would be reduced 50 per cent.

If the vast irrigation interests on the lower Colorado are to be protected and if the river is to be regulated in such a way as to make pos-

[1] See discussion of silt below junction of Green and Grand rivers, pp. 223-226.

sible the maximum development of irrigation, then the Green-Grand reservoir or its equivalent must be utilized. It is probable that if it is physically possible to build a safe dam on the Colorado at the junction of these rivers with an expenditure of $43,000,000 or less the undertaking will prove commercially feasible at some future date. On account of its location and capacity, the Green-Grand site is the most valuable in the Colorado River basin.

GRAND RIVER BASIN.

KREMMLING RESERVOIR SITE.

General conditions.—The Kremmling reservoir site is near the headwaters of Grand River in Grand County, Colo. By constructing a dam in Gore Canyon 180 feet high more than a million acre-feet of water can be stored, and with a 230-foot dam the capacity of the reservoir would be nearly 2,200,000 acre-feet.

During the summer of 1905 the Kremmling reservoir site was investigated by the United States Reclamation Service.[1] A plane-table survey was made of the basin and borings with a diamond drill outfit were made at the dam site. Conditions are favorable for the construction of a high masonry dam. The canyon at the dam site measures about 170 feet between walls at the water level and about 350 feet at the crest of the dam.

Area and capacity of the Kremmling reservoir site.

Contour (feet).	Area.	Capacity.	Contour (feet).	Area.	Capacity.
	Acres.	*Acre-feet.*		*Acres.*	*Acre-feet.*
7,300	14	140	7,400	12,811	811,615
7,320	2,111	21,390	7,440	14,739	1,087,120
7,340	5,155	94,050	7,450	15,805	1,239,840
7,386	6,998	215,585	7,460	17,103	1,404,380
7,300	8,948	375,050	7,480	19,737	1,772,785
7,400	10,948	574,015	7,500	22,920	2,199,350

Run-off available for storage.—The run-off per square mile from the 2,380 square miles of drainage area tributary to the Kremmling reservoir site is very high. From records obtained at a gaging station established in Gore Canyon near Kremmling, Colo., in July, 1904, a mass curve was prepared for the years 1905 to 1913, from which it was found that theoretically a uniform flow of 1,670 second-feet could be maintained in Gore Canyon with a storage of 1,100,000 acre-feet. After allowing for losses due to evaporation from the water surface in the reservoir, it appears that a uniform flow of 1,600 second-feet could be maintained to the mouth of Eagle River.

Value of site.—The Kremmling is the only large storage reservoir site in the Grand River basin. The possibilities of irrigation in this

[1] U. S. Recl. Service Fourth Ann. Rept., pp. 121-124, 1906.

basin are small, and though no large amount of storage will be required to regulate the flow to conform to the demand for irrigation the construction of the Kremmling reservoir would materially benefit several proposed schemes. About 60,000 brake horsepower could be developed in Gore Canyon; the low-water flow at the Shoshone power plant on Grand River near Glenwood Springs, Colo., could be considerably increased; there would be no danger of a shortage in the water supply for irrigation in the vicinity of Grand Junction; and any shortage on the lower Grand that might be due to diversion from the Grand River basin to the eastern slope through the Continental Divide would be cared for. It is believed that the Kremmling reservoir could be operated in the interests of power development without interfering with the demand for water for irrigation in the vicinity of Grand Junction. Although the floods on lower Grand River would be reduced only from 60,000 to about 40,000 second-feet, the operation of the Kremmling reservoir would tend to equalize the flow of the lower Grand, and slightly less regulation would therefore be needed on the lower Colorado River. Unfortunately, the Denver & Salt Lake Railroad was constructed through the Kremmling reservoir site, and if this site is utilized the position of the railroad must be changed.

In view of the above facts the Kremmling reservoir site appears to have considerable value, its chief importance being in relation to proposed developments in the State of Colorado.

DOLORES RESERVOIR SITE.

General conditions.—The Dolores reservoir site is near the headwaters of Dolores River, near Dolores, Colo. It was examined by the United States Reclamation Service during the summer of 1914. By constructing a 230-foot dam on Dolores River 2 miles below the mouth of Beaver Creek a reservoir having storage capacity of 315,000 acre-feet could be obtained. The backwater would extend to the Montezuma Valley dam and flood 3,680 acres. The average annual run-off available for storage is about 300,000 acre-feet.

Value of site.—The storage site may be of value at some future date in connection with the regulation of the flow of Dolores River for the development of power, but its value for the development of irrigation is doubtful, as the cost per acre-foot of water stored would probably be excessive. In connection with the control of Colorado River the site is practically valueless.

BEDROCK RESERVOIR SITE.

General conditions.—The Bedrock reservoir site is on Dolores River at the town of Bedrock, Colo., the dam site being about 3 miles below Paradox Wash and about 4 miles below Bedrock. An investigation made by the United States Reclamation Service during the summer of 1914 indicates that a dam 235 feet high would form a reservoir having a storage capacity of 1,330,000 acre-feet and flooding about 12,700 acres. The average annual run-off available for storage is a little more than 300,000 acre-feet. The entire run-off of Dolores River for a period of four years would be required to fill the reservoir.

Value of site.—The Bedrock reservoir site is of no value in connection with the control of Colorado River and probably has no value for any feasible irrigation development. It may, however, be utilized in connection with power projects on lower Dolores River, but such use is remote.

MISCELLANEOUS RESERVOIR SITES.

In the Grand River basin are hundreds of small reservoir sites, many of which will be utilized in future developments of irrigation and power. In water district No. 42, for example, which embraces only a small part of the Grand River basin in Colorado, filings have been made on 261 reservoir sites ranging in capacity from one-third of an acre-foot to 40,000 acre-feet. The aggregate capacity of all the sites is 235,000 acre-feet.

Only the more important of the small sites are here described.

Grand Lake reservoir site.—At Grand Lake, near the headwaters of Grand River in Grand County, Colo., a dam 20 feet high would create a reservoir that could store 140,000 acre-feet of water.

Lehman reservoir site.—The Lehman reservoir site is at the junction of the North and South forks of Grand River. With a dam 165 feet high the capacity of a reservoir at this site would be 230,000 acre-feet.

Williams Fork reservoir site.—A 200-foot dam on Williams Fork, a tributary of Grand River, would give a storage capacity of 80,000 acre-feet.

Windy Gap reservoir site.—The Windy Gap reservoir site is at the confluence of Fraser River with Grand River. A dam 135 feet high would create a reservoir whose capacity would be about 100,000 acre-feet.

Taylor Park reservoir site.—The Taylor Park reservoir site is on Taylor River, a tributary of Gunnison River, 24 miles northeast of Gunnison, Colo. The storage capacity of a reservoir formed by a dam 160 feet high would be 106,000 acre feet. This site has been investigated by the United States Reclamation Service and may be utilized to increase the low-water flow available for the Uncompahgre project.

SAN JUAN RIVER BASIN.

BLUFF RESERVOIR SITE.

General conditions.—The Bluff reservoir site is on San Juan River near Bluff, Utah. A plane-table survey of this basin made by the United States Reclamation Service in the summer of 1914 shows

that by constructing a dam 214 feet high on San Juan River about 1 mile below the mouth of Chinle Creek a reservoir capable of storing 1,600,000 acre-feet would be created and about 20,000 acres would be flooded. The canyon walls at the dam site are precipitous, and the construction of a dam 264 feet high, giving a reservoir having a storage capacity of 2,600,000 acre-feet, might be feasible. The small village of Bluff would be submerged if this site were used, but only a small area of agricultural land would be flooded.

Run-off available for storage.—A gaging station was established near Bluff, Utah, October 30, 1914, to obtain data concerning the storable run-off at the Bluff reservoir site. A rough estimate prepared by using the records showing the discharge of the San Juan at Farmington and Shiprock, N. Mex., La Plata at La Plata, N. Mex., and Mancos River at Mancos, Colo., indicates that the average annual run-off of San Juan River at Bluff is about 2,300,000 acre-feet. During years of low flow the run-off may be as little as 1,500,000 acre-feet. The maximum annual run-off appears to be in excess of 3,000,000 acre-feet.

Aside from the annual rise due to melting snow, the San Juan is subject to violent floods during the fall months. On September 5 and 6, 1909, heavy and continuous rains in the San Juan drainage basin caused the river to rise from 1,500 second-feet to more than 40,000 second-feet in 48 hours; and a heavy rain during the period September 25 to October 6, 1911, caused the highest flood ever recorded on the lower San Juan. At Shiprock, N. Mex., during the later flood, the river rose to over 22 feet on the gage, or 18 to 20 feet above low-water stage. The gage was washed out, but engineers of the Survey estimated the discharge to be 150,000 second-feet. The data available were meager, and it is probable that this estimate is too high.

Value of site.—If the flow of the lower Colorado is to be regulated to meet the demand for water for irrigation, or if the floods at Yuma are to be reduced to 50,000 second-feet or less, a reservoir on lower San Juan River must be utilized.

If the construction of a reservoir at the junction of Green and Grand rivers proves feasible, the operation of this reservoir in conjunction with other reservoirs on Green and Grand rivers would effect the desired regulation at Yuma without storage on San Juan River during the years of average run-off. For example, during 1914, the maximum flood on San Juan River was about 21,000 second-feet and occurred June 2. During that year the regulation desired at Yuma could have been obtained without storage on San Juan River. However, this river is subject to occasional violent floods which might cause enormous damage on the lower Colorado. The sudden floods could probably be prevented from reaching the Colorado by constructing the Bluff reservoir to a capacity of 600,000 acre-feet. The flow of the San Juan could no doubt be passed through the reservoir for a period of 9 to 12 months each year. If only the peak floods were stored and all flows of 25,000 second-feet or less were allowed to pass the reservoir the amount of silt that would be deposited in the reservoir would be small. The life of the reservoir would therefore not be endangered by the large amount of silt carried by the river. Unquestionably the Bluff reservoir site on lower San Juan River will prove of value in connection with the control of Colorado River.

TURLEY RESERVOIR SITE.

General conditions.—In connection with his project for the reclamation of 1,225,000 acres on San Juan River in New Mexico, Mr. J. Turley filed on a reservoir site on this river below its junction with Los Pinos River. According to the papers filed by him, a dam 200 feet high would be 6,800 feet long on top, 2,070 feet on the bottom, and the reservoir formed would have a storage capacity of 1,640,000 acre-feet. The average annual run-off available for storage at this site is in excess of 1,000,000 acre-feet.

Value of site.—Although there are thousands of acres of good land susceptible of irrigation from San Juan River the cost of constructing the Turley dam may render the project unfeasible.

DURANGO RESERVOIR SITE.

The Durango reservoir site is on Animas River about 3 miles above Durango, Colo. A dam 100 feet high would create a storage reservoir having a capacity of 500,000 acre-feet. The run-off available for storage ranges from about 500,000 to more than 1,000,000 acre-feet annually. This site may prove valuable for the purpose of regulating the flow of Animas River in the interest of future development of irrigation.

COLORADO RIVER.

COLORADO-SAN JUAN RESERVOIR SITE.

General conditions.—The Colorado-San Juan reservoir site is in Glen Canyon on Colorado River in northern Arizona and southern Utah. By constructing a dam at the head of Marble Canyon, a few miles below the mouth of Paria River, to a height of 244 feet, a reservoir capable of storing 3,000,000 or 4,000,000 acre-feet would be formed. The profile of this section of the river indicates that the backwater would extend up the Colorado 186 miles, or to the mouth of Fremont River, and up the San Juan 14 miles; in other words, 200 miles of canyon would be occupied by the reservoir. No field examination has been made and the site is mentioned here only as a possibility.

Run-off available for storage.—The average annual run-off available for storage at the Colorado-San Juan reservoir site is about 15,000,000 acre-feet, or 92.6 per cent of the mean annual run-off of Colorado River at Laguna dam.

Value of site.—The position of the Colorado-San Juan reservoir site is good. The water which passes it, with the exception of the Gila floods, is identical with that which goes to make up the floods on the lower Colorado, but the capacity of the reservoir might be seriously reduced in 50 years by the deposition of silt. Should the Green-Grand reservoir site prove unfeasible the Colorado-San Juan site should be thoroughly investigated.

BULLS HEAD RESERVOIR SITE.

General conditions.—The dam site for the Bulls Head reservoir, at Bulls Head Rock, about 31 miles above Needles, Cal., and 18 miles above Camp Mohave, Ariz., has been investigated by the United States Reclamation Service.[1] Borings taken at the dam site show that conditions are unfavorable for the construction of a high overflow dam. Bedrock was not reached in holes carried to a depth of 100 feet, the material penetrated by the drill being mostly gravel and bowlders. Conditions are favorable for the construction of a spillway on solid rock on the Arizona side. The reservoir formed by a dam raising the water level 100 feet would have a capacity of 841,000 acre-feet.

Capacity of the Bulls Head reservoir.

Height above low water.	Area.	Total capacity.	Height above low water.	Area.	Total capacity.
Feet.	*Acres.*	*Acre-feet.*	*Feet.*	*Acres.*	*Acre-feet.*
10	806	4,030	60	12,100	259,000
20	1,570	16,000	70	13,600	395,000
30	2,460	35,900	80	14,600	529,000
40	6,210	74,700	90	15,500	687,000
50	9,220	158,000	100	16,700	841,000

Run-off available for storage.—The storable run-off at the Bulls Head reservoir site is given in the table showing the annual discharge of Colorado River at Hardyville, Ariz., on page 192. The mean annual run-off for the period 1895 to 1914 was 16,200,000 acre-feet.

Value of site.—The capacity of the reservoir site is small and would be reduced by the deposition of silt within a few years after the building of the dam. The site is therefore of no value for water storage except for emergency use.

By constructing a dam 20 feet above low water at Bulls Head Rock water can be diverted to irrigate 56,000 acres. The feasibility of constructing such a dam is not questioned.

[1] U. S. Recl. Service Second Ann. Rept., 1902-3, 1904.

During the period extending from the summer of 1905 to February 1, 1907, the Colorado flowed into Salton Sea. (See pp. 141–142.) The cost incident to closing the break and the damage to property in Imperial Valley amounted to several million dollars. If it had been possible to shut off the flow of the river at Bulls Head Rock the break could doubtless have been closed in two weeks, if a railroad trestle had been constructed across the crevasse and cars loaded with rock had been in readiness. It is probable that there could be constructed at Bulls Head a dam designed primarily for the diversion of the river for irrigation at the 20-foot level but carried high enough to store water to the 60-foot level, the spillway to be through tunnels so as to provide no storage when the dam is operated as a diversion dam. The storage capacity at Bulls Head between the 20-foot and 60-foot levels is 243,000 acre-feet. If a break in the levee should occur below the heading of the Imperial canal during the summer floods, preparation for closing it could be made while the river was still flowing into Salton Sea, and when the discharge had fallen to 10,000 second-feet the spillway and canal headgates at Bulls Head could be closed. The Palo Verde, Imperial, and Yuma canals could take care of 5,000 second-feet, and the remaining 5,000 second-feet could be stored for 24 days, during which the river channel at the break would be dry, and the break could no doubt be effectively repaired. The river might flow to Salton Sea for two or three months during the flood stage but not for two years. The capacity of the reservoir above the 20-foot level would not be impaired by the deposition of silt, for it would be used as a storage reservoir only in an emergency and for a short period.

With their lands and homes below sea level, and the Colorado flowing on a ridge in the delta above them, the settlers in Imperial Valley can not feel secure until every precaution has been taken to prevent overflow and to keep the river in the channel leading to the Gulf of California. A sudden and violent flood from Gila River may overtop the levees at any time.

The value of the Bulls Head site for a combination diversion and emergency storage dam should be determined by a thorough investigation.

SUMMARY.

1. By disregarding losses by evaporation, it is estimated that a uniform flow of about 21,800 second-feet could be maintained at Hardyville or at Laguna dam with a storage of 25,000,000 acre-feet. Such regulation of the flow is neither desired nor commercially feasible.

2. During the period 1902 to 1914, inclusive, properly located storage reservoirs having an aggregate capacity of 6,300,000 acre-feet would have been sufficient to maintain a flow at Yuma not exceeding 50,000 second-feet. Such regulation, which would materially reduce the necessity for levee construction and minimize the cost and operation of other protective works, may prove desirable.

3. The flow of the Gila is intermittent. The sudden and violent floods and their enormous loads of silt menace irrigation developments below Yuma and might cause breaks in the levees even if the Colorado proper were controlled by storage reservoirs. Until the flow of the Gila below the Hassayampa is controlled the floods from the Gila will be dangerous.

4. On the assumption of no further increase in the irrigated area above and including Virgin River, all lands susceptible of irrigation below Virgin River could be irrigated if properly located reservoirs with an aggregate capacity of 18,000,000 acre-feet were constructed, even if the excessively dry period from 1902 to 1905 were to be repeated. The irrigated area above and including Virgin River will increase, however, and eventually there will not be sufficient water in the lower Colorado to supply the demand for the reclamation of all the irrigable lands. This increase in the irrigated area on the headwaters will tend to equalize the flow on the lower Colorado, and finally a storage of 3,000,000 or 4,000,000 acre-feet may prove sufficient to maintain a flow of 50,000 second-feet or less at gage height of 25 feet at Yuma.

It is not possible to estimate accurately the effect of the increase of irrigation in the basin of the upper Colorado on the flow of the lower Colorado. The most urgent problem to be solved at the present time is that of protecting the irrigation works below Virgin River from the ravages of the annual floods. The solution of this problem may lie in the construction of storage reservoirs and a permanent system of bank revetments. Obviously storage reservoirs will be required in the future for the purpose of regulating the flow to meet the demand for irrigation. In view of these facts it seems apparent that investigations should be continued to provide base data for plans for construction work. Every effort should be made to find below the junction of Green and Grand rivers and on San Juan River feasible reservoir sites aggregating in capacity not less than 6,000,000 acre-feet.

The large reservoir sites worthy of consideration in connection with the regulation of the flow of Colorado River and its tributaries in the interest of irrigation and the development of water power are listed in the following table. The sites are named in downstream order as they appear on the map of the Colorado River basin (Pl. XIII, in pocket).

Storage reservoir sites in the Colorado River Basin.

Name of reservoir.	Stream.	Height of dam.[a]	Capacity.
		Feet.	*Acre-feet.*
Flaming Gorge	Green River, Utah and Wyo	255	4,720,000
Browns Park	Green River, Utah	200	2,520,000
Juniper Mountain	Yampa River, Colo	200	1,400,000
Minnie Maud	Green River, Utah	200	4,000,000
Rattlesnake	Green River, Utah	165	1,250,000
Kremmling	Grand River, Colo	230	2,200,000
Green-Grand	Junction of Green and Grand rivers, Utah	270	8,600,000
Durango	Animas River, Colo	100	500,000
Bluff	San Juan River, Utah	264	2,600,000
Colorado-San Juan	Colorado River, Ariz., Utah	244	3,000,000
			30,790,000

[a] The figures in this column indicate the elevation of spillway above average low water.

Information now available indicates that there are in the basin reservoir sites of sufficient capacity and properly located to make it possible to regulate the flow of the lower Colorado as desired. To be effective, however, the reservoir system must include the Green-Grand, Bluff, and other sites on upper Green and Grand rivers, or the Colorado-San Juan reservoir site must be utilized in conjunction with the reservoirs on Green and Grand rivers.

SILT IN COLORADO RIVER.[1]

DETERMINATIONS OF SILT IN COLORADO RIVER AT YUMA, ARIZ.

Prof. C. B. Collingwood, of the University of Arizona Agricultural Experiment Station, determined the content of silt in the water of Colorado River at Yuma for a period of seven months beginning with August, 1892. One pint of water was taken each day and evaporated, and the daily residues for each month were then weighed and analyzed. The results ranged from 1,631 parts per million of suspended matter in January, 1893, to 10,309 parts per million in October, 1892, and averaged 2,577 parts per million.[2]

From January 10, 1900, to January 24, 1901, samples of water were collected daily under the direction of R. H. Forbes, director and chemist, University of Arizona Agricultural Experiment Station, from Colorado River at Yuma, Ariz., and united in sets of six consecutive samples.

The samples were taken from the east side of the Colorado, at Yuma, 1 mile below the entrance of Gila River and 14 miles below Laguna dam. The average of the entire series of 61 determinations of silt is 2,776 parts per million. A fairer average, 2,814 parts per million, for the year 1900 has been obtained, however, by interpolating values of suspended matter for the short periods during which no

[1] Extracts from a discussion, unpublished, prepared by R. B. Dole, chemist, U. S. Geol. Survey.
[2] Cory, H. T., Irrigation and river control in the Colorado delta: Am. Soc. Civil Eng. Trans., vol. 76, p. 1217, 1913. For Prof. Collingwood's article see Arizona Agr. Exper. Sta. Bull. 6.

samples were taken and weighting each figure of the series by the number of days covered by it.

Unfortunately no reliable estimates of daily discharge for 1900 are available, and it is therefore impossible to compute the six-day loads of suspended matter. If the mean annual discharge is assumed to have been 22,800 second-feet and the mean load of suspended matter to have been 2,814 parts per million, the total load of silt during 1900 may be computed as 63,200,000 tons, a quantity in agreement with the estimate, 61,000,000 tons, given by Forbes in discussing his data.[1]

The second annual report of the United States Reclamation Service[2] contains a table of determinations of silt from February 3 to June 16, 1903, inclusive. Daily samples evidently were united in sets of three and the silt was determined in the composite thus obtained. It is not known who made the analyses, no comments on the figures being included in the original text. The load of suspended matter in tons during each sample period has been computed by multiplying together suspended matter in parts per million, the discharge in second-feet, the factor 0.00269, and the number of days in each period. According to this method of computation the total load carried past Yuma from February 13 to June 16, 1903, inclusive, was 58,300,000 tons, and the average content of suspended matter during that period was 8,002 parts per million. The discharge from March to June, 1903, was comparable with that during the same months in 1902 and 1904 but was much less than that during those months in 1905, 1906, and 1907.[3] As the series in 1903 covers only four months and does not include October, which is usually the month of high turbidity, it does not constitute a reliable basis for an estimate of the annual load of silt. It covers the period of spring floods and shows that there were large loads of silt during the last part of March and all of April. Graphic comparison of the content of suspended matter with discharge indicates a fairly regular increase of suspended matter with discharge during March and April. The much greater discharge during May and June, however, was not accompanied by proportionate increase in suspended matter.

During 1904 Prof. Forbes continued his study of silt in Colorado River, apparently taking daily samples and uniting these in composites of three or more consecutive samples, on which he made determinations of the suspended matter by weight. He states[4] that

[1] Forbes, R. H., The river irrigating waters of Arizona: Univ. Arizona Agr. Exper. Sta. Bull. 44, p. 202, 1902.
[2] Lippincott, J. B., Investigations in California [on Colorado River]: U. S. Recl. Service Second Ann. Rept., pp. 153-154, 1904.
[3] McGlashan, H. D., and Dean, H. J., Water resources of California, pt. 3: U. S. Geol. Survey Water-Supply Paper 300, pp. 449-450, 1913.
[4] Forbes, R. H., Irrigating sediments and their effects upon crops: Univ. Arizona Agr. Exper. Sta. Bull. 53, p. 60, 1906.

from January 1 to December 31, 1904, Colorado River carried 840 to 32,630 parts per million of suspended matter, and that the total load of silt during that year was 120,961,000 tons. Neither his individual analyses nor a description of his method of computations is available, but Cory [1] observes that "the investigations were carried out in such detail that it was possible to compute the quantity of solid material from the discharge at the time." It may therefore be assumed that Prof. Forbes calculated the total load of silt by adding together the weighted mean loads corresponding to his sampling periods. As the mean discharge during 1904 was 13,980 second-feet,[2] Forbes's estimate is equivalent to an average content of suspended matter of 8,784 parts per million.

Samples of water were taken daily from the Colorado at Yuma by the Reclamation Service between January 1 and December 31, 1905. The samples, which were taken at the railroad bridge below the mouth of the Gila, were analyzed in composites of three or four under the direction of T. H. Means at Berkeley, Cal. Though the dates indicate that the series is not absolutely complete, the errors due to that source have been practically eliminated by assuming reasonable loads of silt for the omitted days, and the total load of silt in 1905 has been computed as 312,000,000 tons. The average of the entire series of 106 determinations is 9,938 parts per million, which, combined with the mean discharge during 1905, 27,200 second-feet, gives the total load of silt for 1905 as 266,000,000 tons. As an estimate of the load of silt during 1905 this figure is not so nearly correct as the preceding one, but it has been computed for comparison with similar figures for other years. The greatest loads of silt in 1905 were carried between February and June, the maximum daily loads having been carried from March 19 to 24, inclusive; the content of silt during the first half of the year corresponds more regularly with the discharge than the content during the last half but bears no mathematical relation to it for any appreciable length of time. Similar lack of mathematical regularity is shown by comparison of the content of silt with the mean velocity during each sampling period; the most definite deduction that can be made from this comparison is that great loads of silt were not carried while the velocity was less than 3 feet per second; on the other hand, relatively small loads were carried many times while the velocity was between 4 and 5 feet per second.

Since May, 1909, the United States Reclamation Service has made observations of the sediment in Colorado River at Yuma, Ariz. Eight observations were made in 1909, 22 in 1910, 52 in 1911, and

[1] Cory, H. T., Irrigation and river control in the Colorado delta: Am. Soc. Civil Eng. Trans., vol. 76, p. 1217, 1913.
[2] U. S. Geol. Survey Water-Supply Paper 300, p. 450, 1913.

64 in 1912. The annual mean content of silt has been reported [1] as 6,500 parts per million in 1909, 5,000 in 1910, 11,500 in 1911, and 7,560 parts in 1912. From these data and the mean annual discharge, the amount of sediment carried by Colorado River during the years 1909 to 1912, inclusive, has been computed as follows:

Tons of sediment carried annually by Colorado River at Yuma, Ariz., 1909–1912.

Year.	Mean discharge.[a]	Mean content of silt.[b]	Load of silt.[c]
	Second-feet.	*Parts per million.*	*Tons.*
1909	36,200	6,500	232,000,000
1910	19,800	5,000	98,000,000
1911	24,600	11,500	278,000,000
1912	25,400	7,560	189,000,000

[a] McGlashan, H. D., and Dean, H. J., Water resources of California: U. S. Geol. Survey Water-Supply Paper 300, p. 451, 1913.
[b] Determined by the U. S. Reclamation Service.
[c] Tons=Mean annual content of silt in parts per million×mean annual discharge in second-feet×0.985.

The foregoing estimates of the annual loads of silt carried by Colorado River at Yuma just below the mouth of the Gila are summarized as follows:

Summary of estimates of silt carried by Colorado River at Yuma, Ariz.

Year.	Mean discharge.	Average content of suspended matter.	Total load of silt.
	Second-feet.	*Parts per million.*	*Tons.*
1892		2,577	
1900	22,800	2,814	[a] 63,200,000 [b] 61,000,000
1903	15,600	[c] 8,002	
1904	13,980	[d] 8,784	120,961,000
1905	27,200	9,938	[e] 312,000,000 [f] 266,000,000
1909	36,200	6,500	[f] 232,000,000
1910	19,800	5,000	[f] 98,000,000
1911	24,600	11,500	[f] 278,000,000
1912	25,400	7,560	[f] 189,000,000

[a] Estimate by Dole.
[b] Estimate by Forbes.
[c] Feb. 13 to June 16 only.
[d] Calculated from total load of silt.
[e] Sum of daily loads.
[f] Calculated from average content of silt.

These data are complete enough to indicate clearly (1) that the average content of silt varies widely from year to year; (2) that the average discharge varies widely from year to year; (3) that the average annual content of silt is not proportional to the average annual discharge; and therefore (4) that the total annual load of silt is not proportional to the total annual discharge. It has already been shown that the content of silt is not a function of the discharge or the velocity of Colorado River. The annual content of suspended matter

[1] Sellew, F. L., Discussion on irrigation and river control [Colorado River]: Am. Soc. Civil Eng., Trans., vol. 76, p. 1479, 1913.

may be said to vary in round numbers from year to year from 2,400 to 12,000 parts per million and to average 7,000 parts per million. The numerical average of the eight annual estimates of suspended matter in the accompanying table is 6,834. It is of course an open question how much weight should be given to the two low contents in 1892 and 1900.

In view of all the irregularities due to normal conditions it seems that an estimate of the average annual load of silt based on the average annual discharge and the average content of 7,000 parts per million is likely to give a fair idea of the magnitude of this quantity. The average annual discharge from 1895 to 1914, inclusive, is 23,560 second-feet, which, combined with the figure for suspended matter, 7,000 parts per million, gives 162,500,000 tons as a fair estimate for the average annual load of silt carried past Yuma by Colorado River. The probable error of this estimate is such that it may be called roundly 160,000,000 tons. The specific gravity of the silt is given by Forbes [1] as 2.65, which is practically the average specific gravity of the earth's crust [2] and corresponds to a weight of 165 pounds per cubic foot. The weight of dry soil is given by Forbes [1] as 93 pounds per cubic foot. On these bases the average annual load is equivalent to 80,000 acre-feet of dry soil or 45,200 acre-feet of rock. The equivalent as dry soil is a fair estimate of the dry mud or compacted silt on the bottom of a reservoir. This annual deposit in a reservoir 1 mile square is equivalent to a depth of 125 feet. Such complete deposition could not be attained, however, unless absolute stagnation existed for a month, for the finer particles of suspended matter are removed very slowly by sedimentation.

INFLUENCE OF GILA RIVER.

One of the chief sources of the silt in Colorado River at Yuma is the enormous amount of suspended matter discharged by the Gila, which has been characterized by Forbes the muddiest river in the world. The silt in this stream above the head of Florence canal ranged in 1899–1900 from 80 to 94,060 parts per million [1] and averaged 19.23 tons per acre-foot of water. At the Survey gaging station near San Carlos, Ariz., the silt content ranged from 120 to 24,700 parts per million and averaged 3,730 parts per million [3] between April 9, 1905, and January 2, 1906.

[1] Forbes, R. H., Irrigating sediments and their effects upon crops: Univ. Arizona Agr. Exper. Sta. Bull. 53, p. 60, 1906.

[2] Gannett, Henry, and others, Papers on the conservation of water resources: U. S. Geol. Survey Water-Supply Paper 234, p. 80, 1909.

[3] Stabler, Herman, Some stream waters of the western United States, with chapters on sediment carried by the Rio Grande and the industrial application of water analyses: U. S. Geol. Survey Water-Supply Paper 274, p. 41, 1911.

The rise and fall of the Gila between January and May, 1905, are closely followed by the content of suspended matter in the Colorado at Yuma. In June, in spite of the high discharge of the Colorado, its content of silt was small, and the average discharge of the Gila during that month was only 725 second-feet. During July, August, and September the discharge of the Gila was practically nothing and the content of suspended matter at Yuma was small. During October, with a small discharge from Gila River and a somewhat greater discharge from Colorado River, the content of silt increased. The increase of discharge from the Gila in November and December was accompanied by an increased content of silt in the Colorado, but this increase was not proportional because the silt content of the Gila was less in December than in November. A similar but not so close relation may be traced, so far as data are available, between the silt content of the Colorado and the discharge of the Gila during 1903. Comparison of data from 1903 to 1912 indicates that the silt content of the Colorado at Yuma varies chiefly with the discharge of Gila River. If the silt content of the water of Gila River, the discharge of that stream, and the proportion of that discharge to the discharge of the Colorado were all taken into consideration, the influence of the Gila could doubtless be more definitely indicated.

As the data regarding the silt content and the discharge of Gila River are incomplete, it is not safe to attempt to correct the figures for the silt content of the Colorado at Yuma in order to make them applicable to the Colorado at Laguna dam. It is possible that the average silt content above the Gila is less than half that of the stream below; indeed it is less than that at times.

FLUCTUATION OF SILT CONTENT.

The general fluctuations of the silt content of the Colorado at Yuma and their relations to discharge have already been outlined. The discharge of the Colorado usually is greatest in June and least from November to February, with floods in March or April and in September or October. The floods in spring and autumn usually are accompanied by marked increases in silt, but the June flood apparently is not.

SILT BELOW THE JUNCTION OF GREEN AND GRAND RIVERS.

During 1905 and 1906 samples of water were collected daily by the Reclamation Service from Grand River near Kremmling, Colo., and near Palisades, Colo., from Gunnison River, a tributary of the Grand, near Whitewater, Colo., and from Green River, near Green River, Wyo., and near Jensen, Utah. The daily samples were analyzed after being united in sets, usually of 3 to 6 consecutive samples, and the results, with computations of the discharge of silt by Stabler have been published in Water-Supply Paper 274.

The measurements of silt at Jensen, Palisades, and Whitewater represent an area of 43,800 square miles in a total of 70,300 square miles. The observations were not conducted over periods long enough to make estimates of the mean load of silt based on them entirely dependable, but they give some idea of the magnitude of the load. It would be distinctly advisable to make collections during a period of three or four years at these and other points in the basins of both the Grand and the Green in order to obtain data from which thoroughly reliable conclusions regarding the mean silt content of the streams might be drawn.

Samples were collected from Grand River near Palisades, Colo., from March 15 to October 31, 1905, and from April 1 to May 5, 1906, but not during the winter of 1905–6. The average daily content of suspended matter between March 15 and October 31, 1905, computed by weighting the determinations by the number of days that each approximately represents, is 281 parts per million. During the period of 134 days from November 1 to March 14, with low water and ice prevailing much of the time, it is probable that 80 parts per million would represent a generous estimate of the average daily content of suspended matter. If this estimate is included with proper weighting, the average daily content of suspended matter for the year would be 207 parts per million. A similarly computed average, including the determinations made in April, 1906, is 404 parts per million, the difference being caused by the great loads of silt carried during April, 1906. Consequently, if the average daily load of silt is taken as 300 parts per million the estimated annual tonnage may be greatly in error; nevertheless there seems to be no fairer method of estimating this quantity from the data at hand. This figure, combined with the average discharge, 5,320 second-feet, gives a total annual load of 1,570,000 tons of silt.

According to the observations the river carried 1,196,000 tons of silt between April 1 and October 31, 1905, and 871,500 tons between April 1 and May 5, 1906. If the mean daily content of suspended matter is assumed to be 80 parts per million and the mean discharge to be 1,600 second-feet [1] the load between April 1, 1905, and March 31, 1906, may be calculated to have been 1,200,000 tons and that between May 6, 1905, and May 5, 1906, to have been 1,900,000 tons. The discharge was much greater during April, 1906, than during April, 1905, and the mean discharge from April to October in 1906 was greater and that in 1905 was less than the average. Conse-

[1] Estimate by Stabler, Herman, Some stream waters of the western United States, with chapters on sediment carried by the Rio Grande and the industrial application of water analyses: U. S. Geol. Survey Water-Supply Paper 274, p. 46, 1911.

quently it seems fair to estimate the total load of silt carried past Palisades at about 1,600,000 tons a year.

Samples of the water of Green River near Jensen, Utah, were collected regularly from March 24, 1905, to May 11, 1906, inclusive, but as discharge measurements made at that point cover only part of that period it has been possible to compute the daily loads of silt for only part of the series. The weighted average daily content of silt between March 24, 1905, and March 28, 1906, is 1,104 parts per million and that between May 14, 1905, and May 11, 1906, is 1,056 parts per million. According to measurements at Green River, Utah, the discharge between March, 1905, and March, 1906, was much less, and that between May, 1905, and May, 1906, somewhat less than the average; consequently it seems reasonable to estimate the mean annual content of suspended matter at Jensen, Utah, at 1,200 parts per million. Combined with the mean discharge, 5,500 second-feet, this estimate gives the average annual load of silt carried past Jensen by Green River as 6,500,000 tons.

Mean discharge in second-feet of Green River at Green River, Utah, during certain periods.[a]

Period.	Mean discharge March to March, inclusive.	Mean discharge May to May, inclusive.
	Second-feet.	*Second-feet.*
1905–1906	5,530	7,650
1906–1907	9,170	9,040
1907–1908	11,200	9,130
1908–1909	5,250	6,820
1909–1910	11,900	10,600
1910–1911	[b] 6,400	[c] 5,500

[a] Water-Supply Papers 269 and 289.
[b] Discharge for January, February, and March, 1911, estimated.
[c] Discharge January to May, 1911, estimated.

Gunnison River enters Grand River at Grand Junction, Colo., about 15 miles below Palisades, Colo. Determinations were made of the silt content of the water of Gunnison River near Whitewater, Colo., a short distance above Grand Junction, from April to October, 1905. If the average content of suspended matter during the low-water period from November to March is estimated at 80 parts per million the weighted average content of suspended matter for the year may be calculated as 565 parts per million; and if the mean discharge during the winter is assumed to have been 700 second-feet [1] the load of silt carried between April 1, 1905, and March 31, 1906, may be calculated as 2,070,000 tons. The average content of suspended matter, 565 parts per million, combined with the average annual

[1] Based on estimate by Stabler, Herman, op. cit., p. 51.

discharge for 14 years, 2,830 second-feet, gives the average load of silt as 1,600,000 tons a year. The difference between this figure and the former is explainable because the discharge during 1905 was higher than the mean.

The foregoing estimates of total silt load are summarized in the accompanying table:

Mean annual discharge and load of silt of Green, Grand, and Gunnison rivers.

River.	Station.	Annual load of silt.	Drainage area above station.	Mean discharge at station.
		Tons.	*Square miles.*	*Second-feet.*
Grand	Palisades, Colo	1,600,000	8,550	5,320
Gunnison	Whitewater, Colo	1,600,000	8,250	2,830
Green	Jensen, Utah	6,500,000	27,000	5,500
		9,700,000	43,800	13,650

The total area of the drainage basins of the Green and the Grand is 70,300 square miles and the mean discharge of both streams is 17,130 second-feet. Because of the nature of the basins below Grand Junction and Jensen the load of silt below the junction of the Green and the Grand would probably be more nearly proportional to the discharge than to the area of the respective basins. On this assumption the total annual load of silt carried by these two streams below their junction would be in round numbers 12,000,000 tons, equivalent to about 6,000 acre-feet of dry soil weighing 93 pounds per cubic foot. This estimate is based on silt determinations covering little more than half the entire basin and extending over a period of less than a year, and it should therefore be considered roughly approximate. In comparison with the load at Yuma, Ariz.—about 160,000,000 tons, equivalent to 80,000 acre-feet of dry soil—it shows that lower Colorado River derives most of its enormous load of silt from the drainage area tributary to Colorado River below the junction of the Green and the Grand, which includes San Juan, Paria, Little Colorado, Virgin, and Gila rivers. How the silt in Gila River affects the Colorado has already been shown. That the Little Colorado also brings in notable loads of silt is indicated by the results of determinations in 1905–6, by which it was found that the weighted average content of suspended matter of Little Colorado River at Woodruff, Ariz., was 7,440 parts per million between April 15, 1905, and April 3, 1906, and individual determinations ranged from 32 to 20,700 parts per million.[1]

[1] Stabler, Herman, op. cit., p. 56.

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