DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 9

IRRIGATION NEAR GREELEY, COLORADO.—BOYD

WASHINGTON
GOVERNMENT PRINTING OFFICE
1897

IRRIGATION REPORTS.

The following list contains the titles and brief descriptions of the principal reports relating to water supply and irrigation prepared by the United States Geological Survey since 1890:

1890.

First Annual Report of the United States Irrigation Survey, 1890, octavo, 123 pp.

Printed as Part II, Irrigation, of the Tenth Annual Report of the United States Geological Survey, 1888-89. Contains a statement of the origin of the Irrigation Survey, a preliminary report on the organization and prosecution of the survey of the arid lands for purposes of irrigation, and report of work done during 1890.

1891.

Second Annual Report of the United States Irrigation Survey, 1891, octavo, 395 pp.

Published as Part II, Irrigation, of the Eleventh Annual Report of the United States Geological Survey, 1889-90. Contains a description of the hydrography of the arid region and of the engineering operations carried on by the Irrigation Survey during 1890; also the statement of the Director of the Survey to the House Committee on Irrigation, and other papers, including a bibliography of irrigation literature. Illustrated by 29 plates and 4 figures.

Third Annual Report of the United States Irrigation Survey, 1891, octavo, 576 pp.

Printed as Part II of the Twelfth Annual Report of the United States Geological Survey, 1890-91. Contains a report upon the location and survey of reservoir sites during the fiscal year ending June 30, 1891, by A. H. Thompson; "Hydrography of the arid regions," by F. H. Newell; "Irrigation in India," by Herbert M. Wilson. Illustrated by 93 plates and 190 figures.

Bulletins of the Eleventh Census of the United States upon irrigation, prepared by F. H. Newell, quarto.

No. 35, Irrigation in Arizona; No. 60, Irrigation in New Mexico; No. 85, Irrigation in Utah; No. 107, Irrigation in Wyoming; No. 153, Irrigation in Montana; No. 157, Irrigation in Idaho; No. 163, Irrigation in Nevada; No. 178, Irrigation in Oregon; No. 193, Artesian wells for irrigation; No. 198, Irrigation in Washington.

1892.

Irrigation of western United States, by F. H. Newell; extra census bulletin No. 23, September 9, 1892, quarto, 22 pp.

Contains tabulations showing the total number, average size, etc., of irrigated holdings, the total area and average size of irrigated farms in the subhumid regions, the percentage of number of farms irrigated, character of crops, value of irrigated lands, the average cost of irrigation, the investment and profits, together with a résumé of the water supply and a description of irrigation by artesian wells. Illustrated by colored maps showing the location and relative extent of the irrigated areas.

1893.

Thirteenth Annual Report of the United States Geological Survey, 1891-92, Part III, Irrigation, 1893, octavo, 486 pp.

Consists of three papers: "Water supply for irrigation," by F. H. Newell; "American engineering and engineering results of the Irrigation Survey," by Herbert M. Wilson; "Construction of topographic maps and selection and survey of reservoir sites," by A. H. Thompson. Illustrated by 77 plates and 119 figures.

A geological reconnoissance in central Washington, by Israel Cook Russell, 1893, octavo, 108 pp., 15 plates. Bulletin No. 108 of the United States Geological Survey; price, 15 cents.

Contains a description of the examination of the geologic structure in and adjacent to the drainage basin of Yakima River and the great plains of the Columbia to the east of this area, with special reference to the occurrence of artesian waters.

1894.

Report on agriculture by irrigation in the western part of the United States at the Eleventh Census, 1890, by F. H. Newell, 1894, quarto, 283 pp.

Consists of a general description of the condition of irrigation in the United States, the area irrigated, cost of works, their value and profits; also describes the water supply, the value of water, of artesian wells, reservoirs, and other details; then takes up each State and Territory in order, giving a general description of the condition of agriculture by irrigation, and discusses the physical condition and local peculiarities in each county.

Fourteenth Annual Report of the United States Geological Survey, 1892-93, in two parts, Part II, Accompanying papers, 1894, octavo, 597 pp.

Contains papers on "Potable waters of the eastern United States," by W J McGee; "Natural mineral waters of the United States," by A. C. Peale; "Results of stream measurements," by F. H. Newell. Illustrated by maps and diagrams.

(Continued on third page of cover.)

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UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

IRRIGATION NEAR GREELEY, COLORADO

BY

DAVID BOYD

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DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, April 13, 1897.

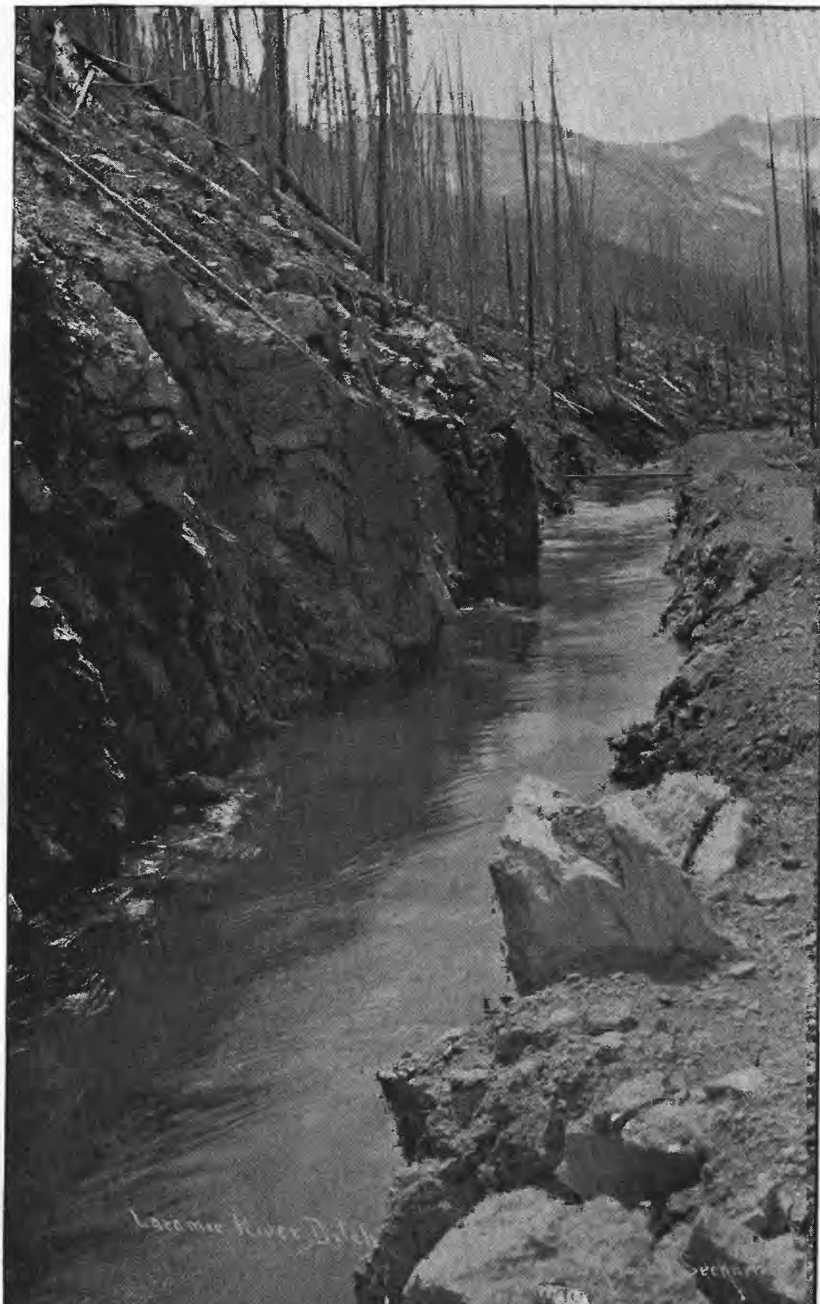
SIR: I have the honor to transmit herewith a manuscript entitled, "Irrigation near Greeley, Colorado," and to recommend that it be published in the series of water-supply and irrigation papers. The statements therein contained have been compiled from a report prepared by Hon. David Boyd, of Greeley, Colorado, one of the early members of Union Colony, which was led by Nathan C. Meeker and given encouragement and prominence by Horace Greeley. In a short paper of this kind it is impossible to go into the details of the struggles of this colony for existence and of the development of agriculture and of a system of water control whose leading features have been widely copied. The attempt has been made, however, to present the more prominent facts and those of most interest and value to the citizens of the West who are now following in similar paths and seeking to lay the foundations for broad and lasting systems of water utilization and control by which the rights of all may be determined and protected.

The paper by Mr. Boyd is prefaced by an introduction, compiled from the records of this division and from other sources, to illustrate the climatic and topographic conditions of Cache la Poudre Valley, in which Greeley is situated, and also the limitations of water supply, since it is upon the latter that the question of growth and development must rest. The evolution of systems for obtaining and applying water to the agricultural lands and of the complicated laws and regulations are in striking contrast to the quiet, almost imperceptible development of irrigation in southern New Mexico, to be described in the next paper of this series. A comparison of the two illustrates the great differences existing between various portions of our Western country and the impossibility of transferring local practices from one point to another irrespective of natural conditions.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.



VIEW OF SKY LINE CANAL.

Taking water from the upper sources of the Big Laramie River and diverting it into the Poudre above Chambers Lake at the height or 8,000 feet.

IRRIGATION NEAR GREELEY, COLORADO.

BY DAVID BOYD.

INTRODUCTION.

BY F. H. NEWELL.

In the following paper by Mr. Boyd, a description is given of the growth and development of irrigation in the valley of Cache la Poudre Creek, in the northern part of Colorado. In this valley the best known town is Greeley, and hence this paper has been entitled "Irrigation near Greeley," as being most expressive of the location and character of the irrigation system and methods described.

Omitting the great Pacific Coast State of California, which lies for the most part outside of the strictly arid region, it may be safely claimed that Colorado stands preeminent in the extent and high degree of development of agriculture by irrigation. Here what may be termed American methods and devices for diverting and applying water to the fields have grown up, and the success attained has stimulated attempts elsewhere throughout the Western third of the United States. The same relation that Colorado holds to the rest of the arid region is borne by the Cache la Poudre Valley to the State of Colorado. It has for many years led in the construction and extension of irrigation systems, and its history may be said to epitomize the record of struggles and successes throughout the State.

The development of irrigation is not merely the result of a succession of victories over physical or material obstacles. In our country these form but a part—and, unfortunately, often a relatively small part—of the difficulties encountered by the irrigator. By far the most vexatious and expensive impediments to be removed have been those arising from the inapplicability of our laws and customs to the conditions prevailing within the arid region. Every instinct acquired through generations of life in a humid country seems to rebel against the methods of the irrigator, and every tradition of law is in direct opposition to the proper employment of the natural waters. These instincts and traditions have had to be laboriously demolished, usually after severe struggle, and the series of contests appears a never-ending one. There is little doubt that if it were possible to sum up in one column the total expense incurred in the irrigation and reclamation of the West, and in another column the costs due to defective legislation, and especially to controversies over conflicting water rights, the latter would prove to be far the larger.

As in the development of her water resources Colorado has led the greater part of the West, so in the attempts to effect a suitable judicial and executive system having to do with water has this State been the pioneer. It can not be said that Colorado has been the most successful, for newer States, notably Wyoming, profiting by her experience, have achieved what seem to be more perfect systems; but their happiness in this regard is due largely to exertions of citizens of Colorado.

In the same way that Colorado has led in improvements in legislation have the citizens of Greeley and vicinity been the leaders in Colorado. First to experience the necessities, they have been at the front in urging needed reforms, and in these they have been notably successful. Thus it is appropriate in a series of papers devoted mainly to irrigation to review at some length the conditions near Greeley, for from here have come many initiatives to a proper state of affairs.

Considerable space is devoted in this paper to matter which at first sight may seem to be more peculiar to the lawyer than to the farmer, but, as above stated, the irrigator is called upon probably more than any other agriculturist to consider his legal environment. Although a beginning has been made, yet many years must elapse before the laws relating to irrigation, both State and national, fully recognize the necessities of the irrigator or permit such a development that the greatest good shall come to the greatest number. In a government by the people and for the people it is essential that every man become to a certain extent familiar with such defects before they can be remedied, as well as with the physical possibilities and limitations of his country.

There is no way in which these matters can be brought more clearly to the attention of the voter and farmer than by relating the experiences of other men in their struggles for existence. In nearly every State there are still to be made great and even fundamental changes in the laws relating to the control of water before the water resources can be fully utilized. The perplexities and even the mistakes of the pioneers teach most valuable lessons, for in many other States these conditions are not yet outgrown. Happy will their citizens be if they can utilize the costly experience of others without paying the high price.

LOCATION AND TOPOGRAPHY.

The State of Colorado comprises within its limits the headwaters of both the North and South Platte, the Arkansas, Rio Grande, San Juan, Grand, and White rivers. For convenience of water administration, the State has been divided, as described on a later page, into six great divisions, corresponding to these large drainage basins indicated on the map (fig. 1) by roman numerals. These in turn have been divided into districts, and numbers have been arbitrarily assigned to these, as shown by the map. Of these districts, the one discussed in this paper is numbered 3, and includes Cache la Poudre Creek, one of the principal tributaries of South Platte River.

On the map the outlines of the water districts are indicated by light broken lines and those of the large divisions by heavy dotted lines. These latter follow the mountain summits or main divides, the line between divisions Nos. I and II and those to the west being

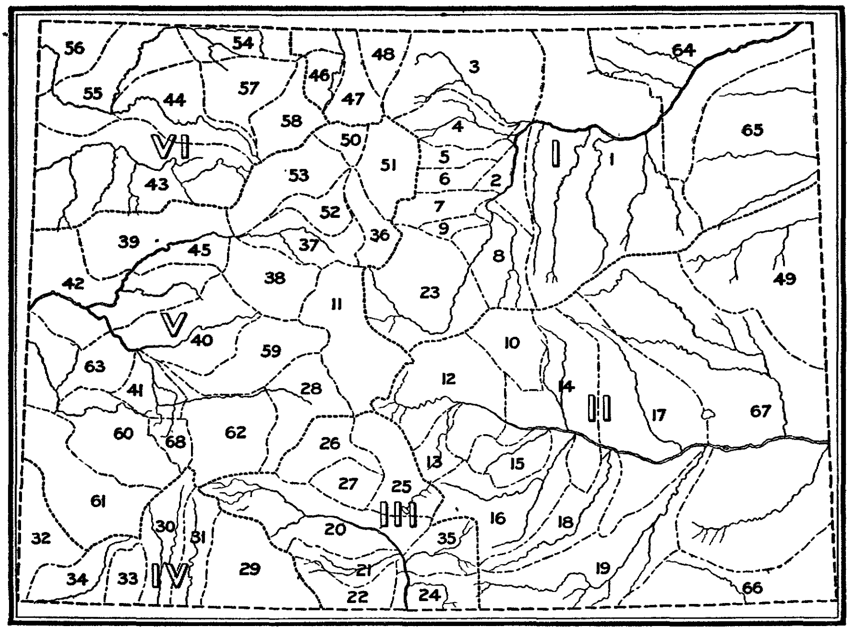


FIG. 1.—Map of water divisions and districts of Colorado.

along the continental watershed. This line thus marks the higher mountain ranges, which rise to altitudes of from 9,000 to over 13,000 feet. From these high crests the streams flow in all directions, those upon the east uniting to form the Arkansas, or, north of this, the South Platte. The latter stream, after debouching from its canyon some 12 miles south of Denver, pursues a nearly northerly course until it reaches Cache la Poudre Creek, some 52 miles by rail north of Denver and 4 miles east of Greeley. Near Denver it receives, from the mountains to the west, Clear Creek; 30 miles farther down, the St. Vrain; and 10 miles still farther, the Big Thompson. Cache la Poudre Creek is the last perennial tributary received by South Platte River before it joins the North Platte in Nebraska. The name, originally Cache a la Poudre, signifies hiding place for the powder. In local usage it is often still further shortened to Poudre Creek.

These tributary streams above named head some 75 or 100 miles back of the foothills among mountain peaks many of which are over 14,000 feet high. Their flow is small during the seven months of the year commencing with September and ending with March. The discharge of the larger ones during these months rarely exceeds 100 second-feet or falls much below 50.

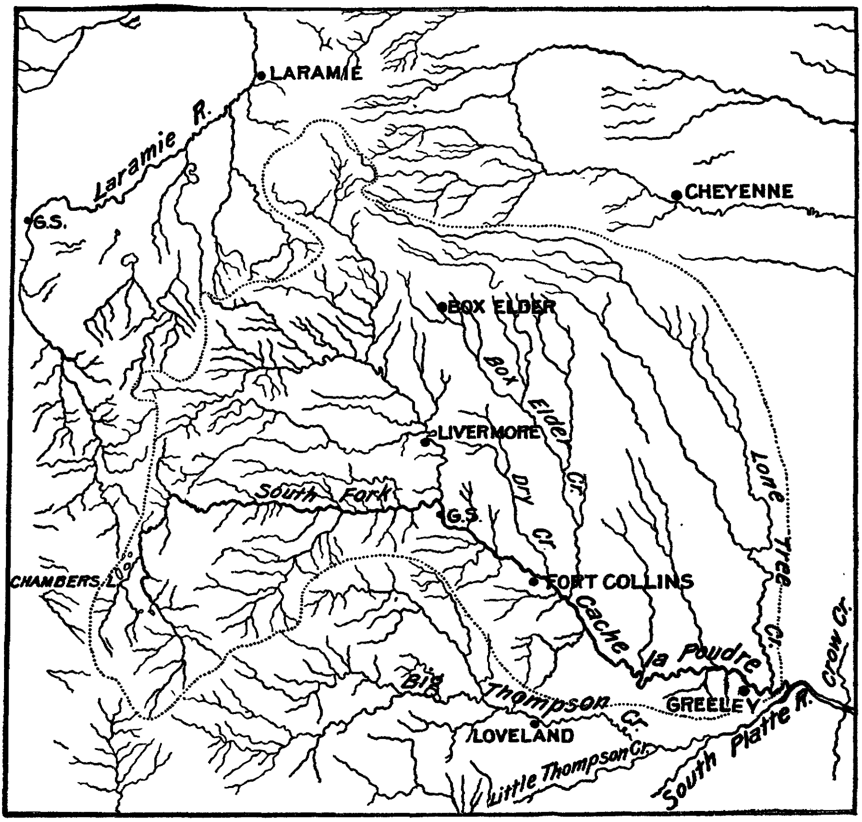


FIG. 2.—Map of Cache la Poudre Valley.

A small map, fig. 2, shows the principal streams and drainage channels tributary to Cache la Poudre Creek, and also exhibits the relative position of the towns. On the west the drainage basin extends well into the high mountains, from which a considerable proportion of the rain and snow falling upon the steeper slopes escapes to the stream. In the center of the basin is the belt of foothill region, and in the eastern third the undulating area, neither plain nor foothill. From this come a considerable number of drainage lines, the principal of which are Boxelder and Lone Tree creeks. These and other channels rarely receive water. For the greater part of the year their beds, though well-marked features, are dry; but after heavy rains or unusual rain storms—locally known as "cloud-bursts"—they become filled with raging torrents, which destroy everything in their paths. The configuration of the country is such that the canals from the perennial streams must cross these, necessitating considerable expenditure in the construction of flumes or in annual outlay for repairs. A glance at the map of these channels and of the canal lines crossing them shows the well-marked trend toward the southeast and indicates that any excess or seepage water brought by the canals or by torrents, whether flowing above ground or percolating beneath, must ultimately reach Cache la Poudre Creek at points not far from its mouth.

The streams on the western side of the basin flow with rapid fall through narrow valleys. At the point marked on the small map (fig. 2) with a dot and the initials G. S. (gaging station) the river leaves the canyon and enters upon a comparatively broad valley. To the north of the stream the lands below this point are low, the bottoms varying in width from half a mile to 2 miles. Above these are in succession two or three well-defined terraces or benches, as they are sometimes called. The soil and subsoil of these are, as a rule, coarse and pervious, being composed largely of sands and gravels. On the south of the river the valley lands are narrow and restricted, comparatively small areas being available for agriculture.

The distance from La Porte, where Cache la Poudre Creek enters the foothills, to its junction with the Platte is about 32 miles as the railroad runs. It is some 8 miles from La Porte to the gaging station at the mouth of the canyon. From the canyon to Chambers Lake it is about 70 miles by the road as it winds among the mountains. This lake is near the head of the Middle Fork and is fed by a number of small streams, the altitude of the lake being about 9,000 feet.

RAINFALL.

The soils of the valley lands are, as a rule, fertile and adapted to the production of crops of the temperate zone; but the rainfall is usually deficient in amount, and can not be relied upon to supply sufficient moisture to the fields. Agriculture is therefore possible only by means of irrigation, which has been developed to a high degree of efficiency, although falling far short of ideal conditions. The amount of rainfall within the basin of Cache la Poudre Creek has been measured for only a comparatively short time and at a few places, these being at the towns in the lower part of the valley. To the northeast of the basin a series of measurements have been carried on at Cheyenne, Wyoming, and to the south observations have been had at a considerable number of points, these being mainly at the foothill towns.

The principal rainfall stations in geographic order from north to south are as follows: Cheyenne, Wyoming; and Boxelder, Livermore, Fort Collins, and Loveland, Colorado. To the east of these latter is Greeley, at the lowest point in the valley. The locations of these places are shown on the small map (fig. 2). The mean annual rainfall at Cheyenne, the elevation of which is about 6,100 feet, has been from 1870 to 1896 a trifle over 12½ inches; the minimum rainfall, that of 1876, was 5.03 inches, and the maximum, that for 1883, was 19.24 inches. The distribution by years is shown on the accompanying diagram (fig. 3), which exhibits by the height of the black columns the quantity of rain for each year from 1870 to 1895, inclusive.

The record of precipitation at Boxelder is comparatively short, extending only from 1890. The average annual precipitation since that time has been a little less than 16 inches. At Livermore the record is fragmentary, the average from 1889 to 1893 being about 14 inches. At Fort Collins the record is longer, beginning in 1872, but

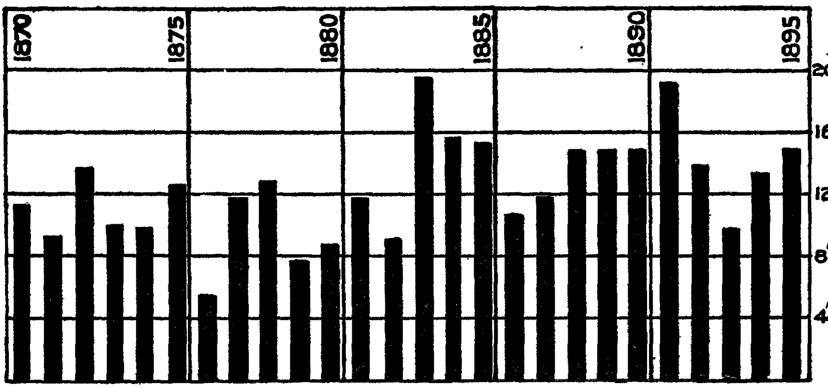


FIG. 3.—Diagram showing annual rainfall at Cheyenne, Wyoming.

is greatly broken until about 1887. The annual average has been 14 inches. The irregularity of distribution of the precipitation is well illustrated by the diagram in Pl. II, showing the monthly precipitation for the years 1887 to 1896, inclusive. This exhibits, by the height of each column, the total amount of rain occurring during the month, shown by the lettering at the top of the diagram. The greatest rainfall in any one month was that of May, 1892—4.83 inches. This diagram exhibits the usually heavy rainfall during the early summer and the prevailing winter drouths.

The record of rainfall at Loveland begins in 1887, being fragmentary until 1891. The average annual precipitation has been about 12 inches. At Greeley a less amount of rain is indicated, the average from 1887 being under 11 inches.

The following table allows a comparison since 1887 of the annual rainfall at the five points where the record is longest. The figures included in parentheses are those for which an interpolated value has

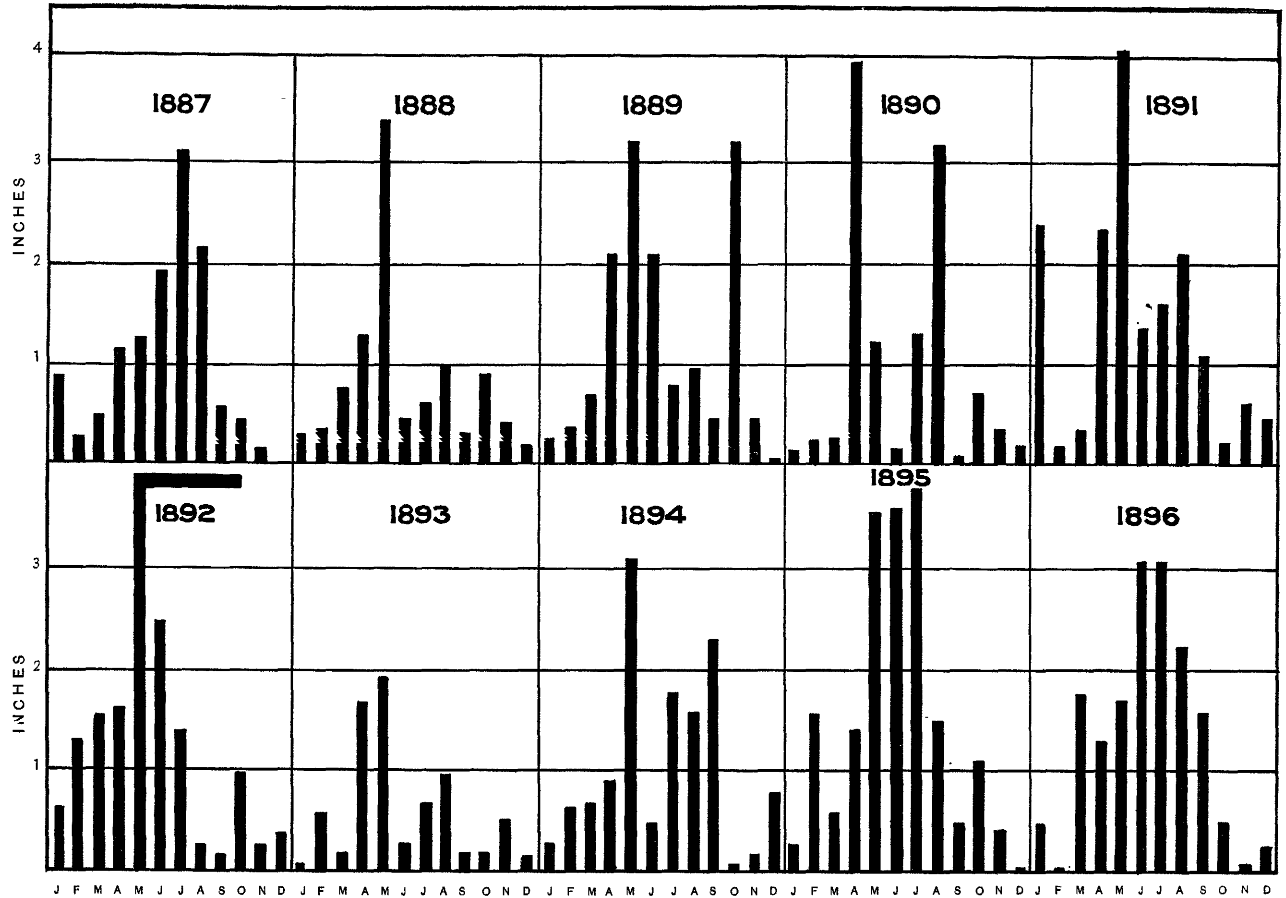


DIAGRAM OF MONTHLY RAINFALL AT FORT COLLINS, COLORADO.

been used for one or two missing months. The means given at the bottom of the table are not the averages of the figures above, but are the total of the monthly means, including thus portions of years otherwise defective:

Annual rainfall, in inches, within or near Cache la Poudre Basin.

Year.	Cheyenne.	Boxelder.	Fort Collins.	Loveland.	Greeley.
1887	(11.82)		12.12		
1888	14.51		9.79		
1889	14.65		14.48		14.58
1890	14.47	(11.71)	11.41		
1891	18.97	20.45	17.50		
1892	13.50	13.37	15.45	15.08	
1893	9.22		7.06	7.03	5.04
1894	12.98		12.36	10.77	5.93
1895	14.76	19.83	18.07	16.17	
1896	20.73	17.83	15.76		13.52
Mean	12.62	15.88	14.09	12.18	10.71

The distribution of the rainfall by seasons is somewhat irregular, the greatest amount occurring during the months from April to August inclusive, nearly two-thirds of the total amount for the year falling at that time. This fact is illustrated by the following table showing the mean monthly precipitation at six important stations, the figures being obtained by averaging the records for all of the months during which observations were kept. In the column on the right these have again been averaged and computed in parts per hundred to still further illustrate the distribution by months; for example, the average of these records for the month of May, assuming that they all have equal weights, shows that 19.98 per cent of the total precipitation for the year has occurred during that month, or, in other words, one-fifth of the total amount of rain fell at that time. Next to this comes July with 13.08 per cent of the total precipitation of the year. Next in quantity of rain stand April and June, these being approximately equal.

Mean monthly precipitation at specified stations in Colorado.

Month.	Cheyenne.	Boxelder.	Livermore.	Fort Collins.	Loveland.	Greeley.	Per cent.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	
January	0.49	0.84	0.92	0.70	0.29	0.20	4.32
February	0.42	0.54	0.56	0.56	1.04	0.41	4.43
March	0.78	1.33	0.72	0.80	0.88	0.50	6.28
April	1.47	1.26	1.86	1.73	1.43	1.57	11.69
May	2.22	3.30	2.86	2.92	2.75	1.88	19.98
June	1.55	1.77	1.80	1.67	1.12	1.38	11.66
July	1.90	2.22	1.03	1.85	1.83	1.59	13.08
August	1.54	2.14	1.34	1.32	0.29	1.04	9.62
September	0.97	1.06	0.64	0.92	1.09	0.54	6.55
October	0.69	0.64	1.92	0.90	0.82	0.68	7.09
November	0.32	0.41	0.41	0.42	0.28	0.76	3.26
December	0.27	0.37	0.17	0.30	0.36	0.16	2.04
Total	12.62	15.88	14.23	14.09	12.18	10.71	100.00

WATER SUPPLY.

The principal source of water supply for the agricultural lands near Greeley is Cache la Poudre Creek, a comparatively small amount being derived from wells and from the impounded storm waters of intermittent tributaries. The main stream has been measured at the point where it leaves the canyon above Laporte, the observations having been continued for a longer number of years here than on any other stream in the arid region. The record therefore has a peculiar value, giving the fluctuations of discharge through a series of years. The position of the gaging station is shown on the small map (fig. 2) by the dot marked G. S. (gaging station). This is above nearly all of the irrigating canals and ditches, the principal exception being the North Poudre Canal, which irrigates about 4,000 acres, mainly in the valley of Boxelder Creek. The drainage area above the gaging station, as measured by planimeter on the Land Office maps of Colorado and Wyoming, is 1,060 square miles,[1] a region mainly mountainous in character.

By one of the provisions of an act of the general assembly of the State of Colorado, approved March 5, 1881, the office of State hydraulic engineer was created, and this officer was empowered to make measurements of the waters of streams used in irrigation. Under this act Mr. J. S. Greene was employed to make measurements of Cache la Poudre Creek, a station being established in Marsh Canyon.[2] From

[1] The area given in the second biennial report of the State engineer of Colorado, p. 91, is 972 square miles, as measured on Hayden's drainage map of Colorado.

[2] First report of the State engineer, Eugene K. Stimson, of Colorado, for the years 1881 and 1882. Denver, 1882, p. 16.

his measurements computations were made of the daily discharge from June 20 to August 5. It was found, however, that the act was defective, and further measurements could not be made until a remedy was provided. During 1882, therefore, no further attempt was made to ascertain the flow of the stream.

Early in 1883 a site for a gaging station was selected on what was known as McBride's preemption, about one-half mile above the mouth of the canyon and 12 miles above Fort Collins. The bowlders were removed by blasting, and the channel was cleared out and straightened as well as was found possible with small expenditure. Gage readings were continued during the irrigation season, and occasional measurements were made of the velocity by means of an eight-vaned Fteley meter, manufactured by Buff & Berger, the instrument being provided with an electrical registering device. After the completion of work at the river station all of the ditches taking water from Cache la Poudre Creek in which measuring flumes had been built were examined and computations were made as to their capacities at various heights of water.

In the fall of 1883, after the river had subsided, a remeasurement was made of the cross section of the channel, and it was found that this had changed so greatly as to vitiate the original computations, although these had value as approximations. Propositions were made to the ditch owners taking water from this river that they furnish the necessary funds to build a permanent measuring flume where a self-recording nilometer could be installed. By volunteer contributions the sum of $1,650 was obtained and used in the construction of a measuring flume and small house for sheltering the instrument. These preparations were completed in November, 1883. In March of the following year the nilometer was placed in position and measurements of velocity were begun. It was found necessary to use for this purpose a stouter instrument, as the stream was of the character of a torrent, carrying at times a considerable amount of drift. The instrument devised, known as the Colorado current meter, has been in successful operation for many years in the turbulent waters of that State.[1]

The record was continued through the season of 1885 and 1886.[2] It was noted at that time that the river has, in common with all mountain streams, a daily variation quite marked from the first of May to the last of October. This is due to the rapid melting of the snow in mountains under the influence of the sun during the daytime and the cessation of such melting at night. The greatest variation amounted to about 8 inches, or a difference of 1,500 second-feet.

[1] Second Biennial Report of the State Engineer of Colorado (E. S. Nettleton), for the years 1883 and 1884, pp. 6-8. The daily discharge was computed from March 15 to October 16, 1884. The results are shown on pp. 84-91. Those for 1883 were not printed.

[2] Third Biennial Report of the State Engineer of Colorado (E. S. Nettleton), for the years 1885 and 1886, pp. 55-57. The daily discharge was computed from April 14 to October 10, 1885, and from April 27 to October 17, 1886, pp. 62-68.

During May the point of maximum discharge was reached about 4 a. m. and the minimum about 7 p. m., the time becoming later as the season advanced. By the last of July the maximum flow was at 1 p. m. and the minimum at 3 a. m. Occasional storms also increase the volume of the stream rapidly, that on the night of May 20, 1884, causing it to increase in volume from 3,153 second-feet to 6,848 second-feet in eight hours. On August 18, 1884, the river rose a height of nearly 5½ feet in thirty minutes, subsiding almost as quickly.

The results of the measurements and computations made during 1887 and 1888 were not given numerically, but are expressed graphically.[1] For the succeeding years, 1889 and 1890, the station was maintained in part by the Division of Hydrography of the United States Geological Survey. About that time the station was found to be in poor condition, the plank flooring, resting on piling, having become bulged and

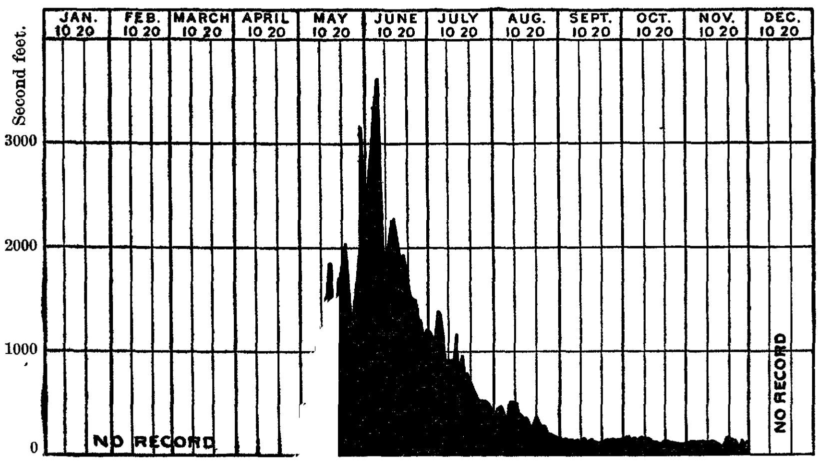


FIG. 4.—Diagram showing daily discharge of Cache la Poudre Creek for 1894.

rotted, so as to necessitate its removal. The walls of timber and plank gave way, resulting in gradual change of the cross section. Thus the results did not possess the accuracy possible while the section was in good order.[2]

On June 9, 1891, a heavy flood in the river, occasioned by the breaking of Chambers Lake dam, destroyed the registering apparatus belonging to the State of Colorado, and another instrument was substituted by Prof. L. G. Carpenter, of the Agricultural College at Fort Collins.[3]

[1] Fourth Biennial Report of the State Engineer of Colorado (J. S. Greene) for the years 1887 and 1888, in two parts; Pl. XV.

[2] Fifth Biennial Report of the State Engineer of Colorado (J. P. Maxwell) for the years 1889 and 1890. The results of computations of daily discharge for 1889 are given on page 22 and those for 1890 on page 23.

[3] Sixth Biennial Report of the State Engineer of Colorado (J. P. Maxwell) for the years 1891 and 1892, p. 18. Results of the computations of daily discharge for 1891 are given on page 22, and those for 1892 on page 23. Also, see Colorado Agricultural Experiment Station Bulletin No. 22, Preliminary report on the duty of water, L. G. Carpenter, p. 22.

During 1893 and 1894 the flow of water was reported at the weir in the canyon by the automatic register. The results are given in the progress report of the Division of Hydrography.[1]

During the succeeding years, 1895-96, occasional measurements were made under the direction of Professor Carpenter, but the results have not been made public.

DAILY MEAN DISCHARGE OF CACHE LA POUDRE CREEK.

The following tables of daily mean discharge of Cache la Poudre Creek have been arranged by months for convenience of comparison of the amount flowing in different years. The figures have been obtained from the following sources:

1881. First Biennial Report of the State Engineer, p. 16. Discharge computed from June 20 to August 5, 1881.

1882. No measurements were made during this year.

1883. Figures not published, but found in manuscript in the office of the State engineer. The discharges from March 23 to May 3, 1883, are only approximate, being obtained by interpolation, assuming that the cross section did not change. From May 4 to July 4, 1883, the discharges are deduced from gage reading and are claimed to be close approximations. From July 4 to August 20 the amount of decrease was assumed to be two-thirds of the amount of decrease per day from July 20 to August 20.

1884. Second Biennial Report of the State Engineer of Colorado, pp. 6-8, 84-91. Discharge computed from March 15 to October 16, 1884. Figures are also given in the Third Biennial Report, on pages 61 to 67.

1885. Third Biennial Report of the State Engineer, pp. 62-68. Discharge computed from April 14 to October 10, 1885.

1886. Third Biennial Report of the State Engineer, pp. 62-68. Discharge computed from April 27 to October 17, 1886.

1887. Fourth Biennial Report of the State Engineer. Figures not published. Diagram on Pl. XV. Discharges shown from March 18 to October 23, 1887.

1888. Fourth Biennial Report of the State Engineer. Figures not published. Diagram on Pl. XV. Discharges shown from March 14 to October 23, 1888.

1889. Fifth Biennial Report of the State Engineer, p. 22. Discharge computed from January 1 to December 31, 1889.

1890. Fifth Biennial Report of the State Engineer, p. 23. Discharge computed from January 1 to December 31, 1890.

1891. Sixth Biennial Report of the State Engineer. Discharge computed from January 1 to December 31, 1891.

1892. Sixth Biennial Report of the State Engineer, p. 23. Discharge computed from January 1 to April 17, and from May 18 to August 16, 1892.

1893. Progress Report, Bulletin United States Geological Survey, No. 131, p. 31. Computations from May 11 to August 31, 1893.

1894. Progress Report, Bulletin United States Geological Survey, No. 131, p. 31. Computations from May 2 to November 30, 1894.

1895. Progress Report, Bulletin United States Geological Survey, No. 140, p. 112. Mean monthly discharge only.

1896. Preliminary figures for May and June. By L. G. Carpenter.

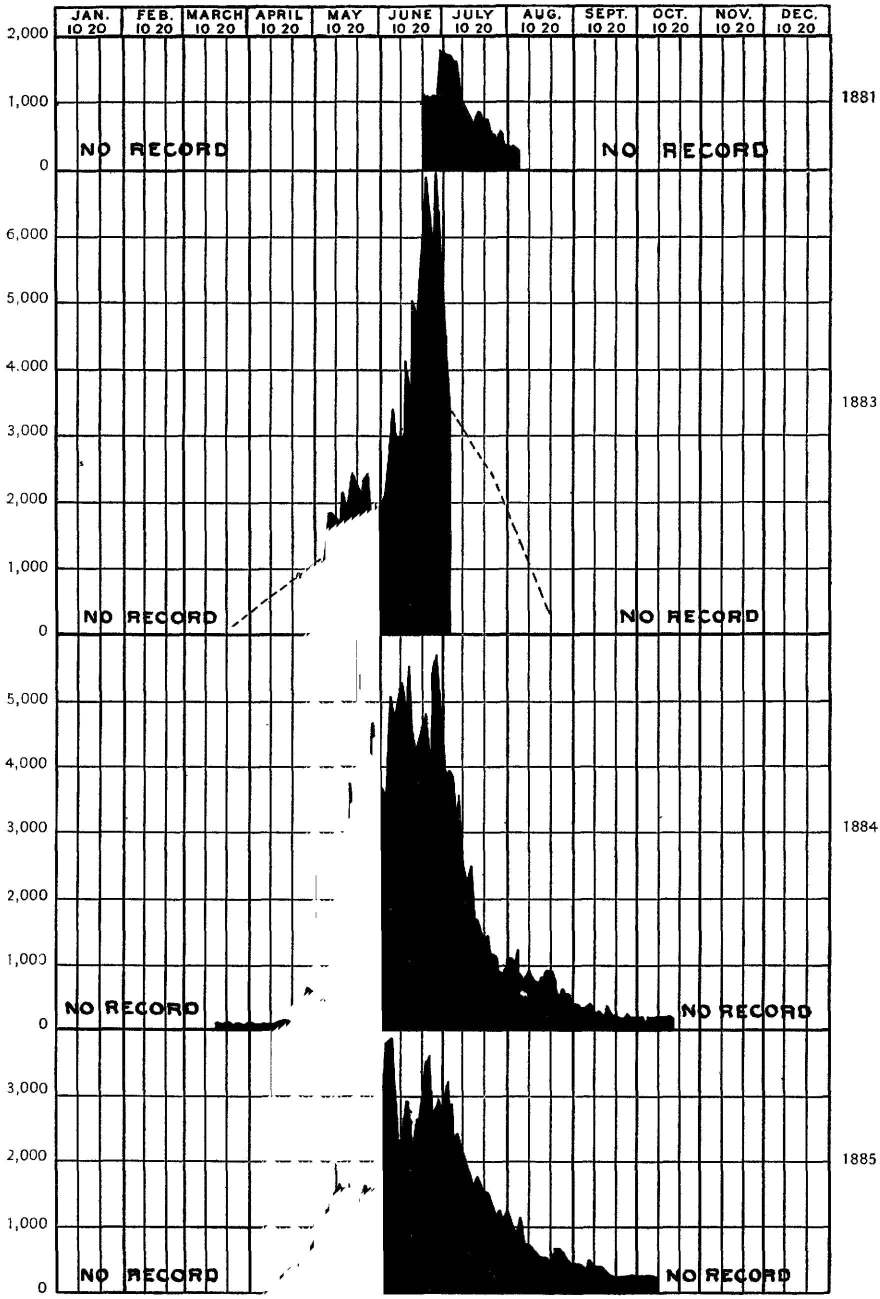
[1] United States Geological Survey Bulletin No. 131, Report of progress of the Division of Hydrography for the calendar years 1893 and 1894, p. 31.

Estimated daily discharge, in second-feet, of Cache la Poudre Creek for the months of January and February.

Day.	January.				February.			
	1889.	1890.	1891.	1892.	1889.	1890.	1891.	1892.
1	71	45	86	70	73	104	131	98
2	130	65	83	65	75	133	118	98
3	130	69	61	54	86	137	109	98
4	89	78	50	50	101	133	100	104
5	111	101	50	52	98	104	89	104
6	115	101	46	52	92	78	83	104
7	98	83	44	50	92	75	66	112
8	83	75	46	54	122	75	63	104
9	108	59	52	60	133	89	66	112
10	98	78	52	60	130	107	66	112
11	134	86	66	60	108	104	68	122
12	173	98	76	60	111	98	68	122
13	193	104	76	58	101	86	68	115
14	193	101	78	58	75	78	66	128
15	183	101	86	54	69	73	66	128
16	173	101	109	50	71	85	57	128
17	164	78	109	50	83	75	57	128
18	168	78	112	54	108	73	57	128
19	243	81	145	56	75	69	57	134
20	306	78	131	63	89	49	59	125
21	324	75	131	72	101	43	66	112
22	342	78	131	72	101	52	71	109
23	255	83	145	72	134	49	73	109
24	164	92	131	72	150	37	68	112
25	146	73	131	72	198	49	83	112
26	118	73	141	72	198	44	86	128
27	89	78	115	72	173	52	86	128
28	118	83	83	72	142	69	83	134
29	108	89	88	83	------	------	------	128
30	98	87	88	92	------	------	------	------
31	73	78	109	98	------	------	------	------
Average	155	82	92	64	110	79	76	116

Estimated daily discharge, in second-feet, of Cache la Poudre Creek for the month of March.

Day.	1883.	1884.	1888.	1889.	1890.	1891.	1892.
1	------	------	------	125	89	70	128
2	------	------	------	104	104	63	134
3	------	------	------	86	101	59	134
4	------	------	------	78	92	52	128
5	------	------	------	73	78	50	122
6	------	------	------	58	71	50	106
7	------	------	------	55	67	55	98
8	------	------	------	55	65	71	92
9	------	------	------	52	71	73	94
10	------	------	------	52	58	68	60
11	------	------	------	40	49	66	60
12	------	------	------	41	47	66	62
13	------	------	------	41	52	61	72
14	------	------	110	41	52	55	72
15	------	73	100	41	60	52	72



DIAGRAMS OF DAILY DISCHARGE OF CACHE LA POUDRE CREEK FOR 1881, 1883, 1884, AND 1885.

Estimated daily discharge, in second-feet, of Cache la Poudre Creek for the month of March—Continued.

Day.	1883.	1884.	1888.	1889.	1890.	1891.	1892.
16	......	71	100	42	85	52	72
17	......	67	110	44	104	54	40
18	......	62	120	47	101	54	60
19	......	64	150	44	101	57	72
20	......	78	110	43	101	63	72
21	......	92	110	43	101	73	72
22	......	48	120	47	107	76	72
23	107	64	130	48	125	73	72
24	133	70	150	46	114	70	72
25	159	72	140	46	104	66	67
26	185	76	120	43	101	57	50
27	211	67	90	43	98	52	50
28	237	55	110	43	98	46	50
29	263	50	150	44	85	42	50
30	289	63	130	47	78	40	50
31	315	75	130	55	78	32	56
Average	211	68	120	54	85	59	78

Estimated daily discharge, in second-feet, of Cache la Poudre Creek for the month of April.

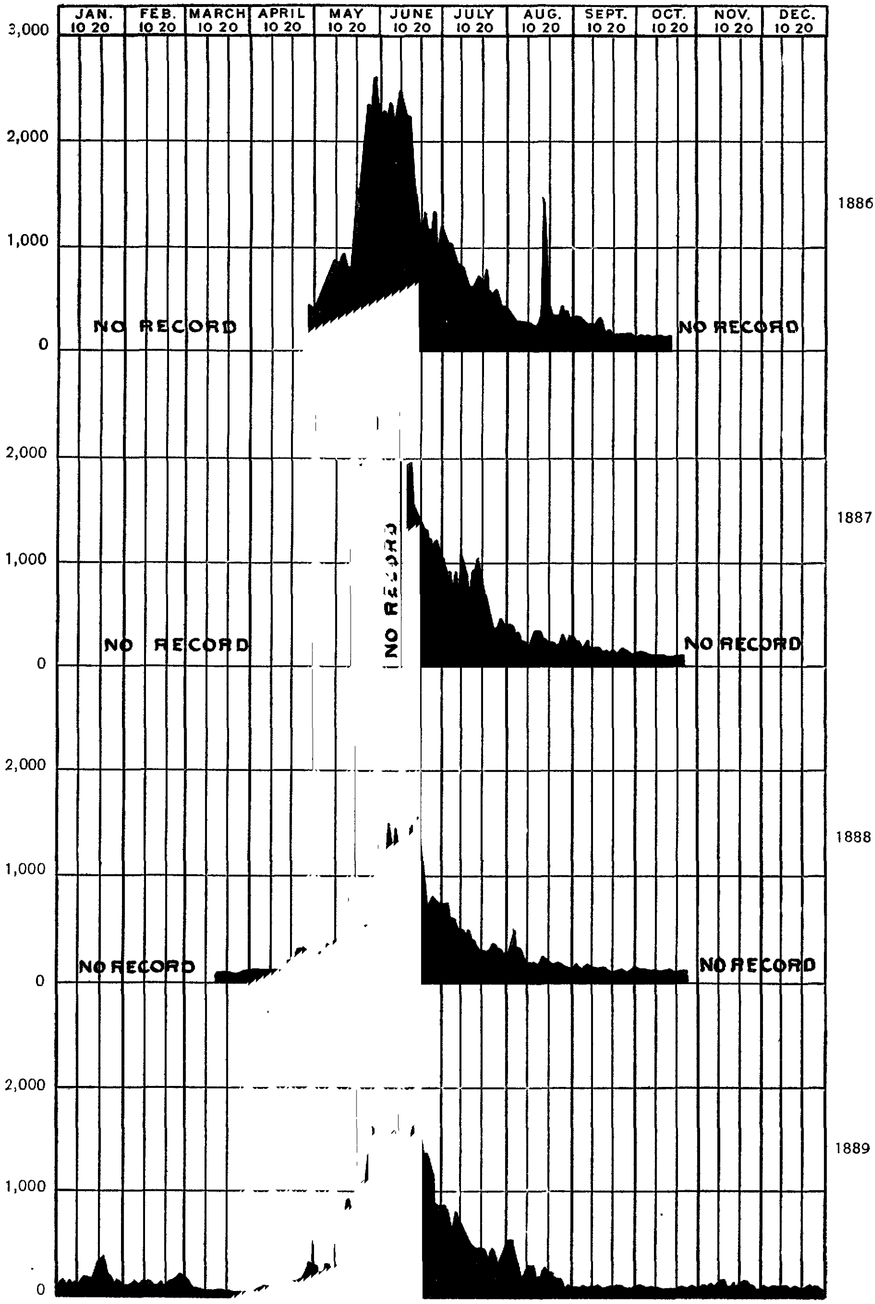
Day.	1883.	1884.	1885.	1886.	1888.	1889.	1890.	1891.	1892.
1	341	92	......	......	120	48	73	39	60
2	367	76	......	......	110	48	71	50	67
3	393	74	......	......	100	52	69	59	60
4	419	71	......	......	100	57	71	48	60
5	445	70	......	......	110	58	73	48	72
6	471	68	......	......	100	65	92	54	72
7	497	65	......	......	100	71	107	59	72
8	523	71	......	......	110	78	101	75	72
9	549	78	......	......	110	75	98	86	84
10	576	78	......	......	100	68	89	97	92
11	601	83	......	......	110	59	98	109	98
12	627	93	......	......	100	59	107	109	98
13	653	125	......	......	100	65	122	103	98
14	678	115	241	......	100	70	137	81	98
15	705	120	250	......	110	68	137	71	98
16	731	129	274	......	120	73	133	68	112
17	757	122	284	......	130	88	133	78	112
18	783	189	314	......	160	129	141	134	......
19	809	176	336	......	170	122	178	166	......
20	835	174	358	......	190	101	237	166	......
21	861	177	447	......	220	101	243	159	......
22	887	201	410	......	330	101	271	159	......
23	913	186	441	......	350	101	300	194	......
24	941	279	398	......	330	107	336	214	......
25	967	439	505	......	340	146	455	258	......
26	993	535	559	......	350	198	474	296	......
27	1,019	708	609	447	330	237	481	338	......
28	1,045	702	624	416	310	288	435	323	......
29	1,071	666	732	387	270	342	372	323	......
30	1,097	602	822	369	260	312	366	344	......
Average	718	219	447	405	181	113	200	144	84

Estimated daily discharge, in second-feet, of Cache la Poudre Creek for the month of May.

Day.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.
1	1,111	501	954	404	......	250	283	435	355	......	......	......
2	1,149	453	1,029	466	......	270	237	494	394	......	......	492
3	1,174	496	1,067	525	......	290	214	552	441	......	......	481
4	1,049	521	1,165	581	......	250	237	666	565	......	......	483
5	1,042	477	1,186	617	......	280	282	764	806	......	......	572
6	1,352	508	1,237	654	......	370	348	722	1,053	......	......	663
7	1,580	521	1,279	724	......	390	324	633	1,160	......	......	793
8	1,848	671	1,258	772	......	310	237	666	1,239	......	......	1,057
9	1,829	965	1,465	873	......	330	237	729	1,179	......	......	1,299
10	1,707	1,387	1,488	900	......	390	300	743	1,044	......	......	1,208
11	1,716	1,845	1,592	873	......	400	254	800	823	......	217	1,246
12	1,776	2,067	1,522	937	......	350	254	836	908	......	344	1,321
13	2,192	1,978	1,522	908	......	360	397	800	710	......	278	1,453
14	1,988	1,793	1,522	882	......	460	736	729	766	......	308	1,538
15	1,848	1,897	1,534	848	......	550	903	736	710	......		1,829
16	1,942	3,491	1,557	805	......	740	947	807	970	......	......	1,838
17	2,172	3,738	1,499	816	......	790	888	888	1,092	......	......	1,355
18	2,399	3,576	1,420	937	1,150	650	851	1,078	1,130	276	......	1,315
19	2,325	3,022	1,279	1,186	1,620	610	807	1,109	1,208	282	......	1,697
20	2,201	3,375	1,290	1,465	1,910	550	736	1,186	1,250	278	......	1,842
21	2,104	5,393	1,333	1,534	1,950	540	822	1,388	1,312	270	1,047	2,051
22	2,289	4,289	1,465	1,836	1,910	490	1,055	1,592	1,355	292	1,043	1,779
23	2,339	3,933	1,545	1,914	1,680	520	1,062	1,461	1,409	388	920	1,585
24	2,355	3,695	1,592	2,045	1,840	530	1,086	1,405	1,858	570	841	1,302
25	2,092	3,609	1,523	2,195	1,810	550	1,147	1,469	2,499	618	870	1,483
26	1,914	3,828	1,534	2,407	1,820	560	1,380	1,583	2,273	847	974	1,650
27	1,776	4,382	1,476	2,378	2,000	560	1,364	1,651	2,173	1,067	876	1,817
28	1,838	4,610	1,522	2,599	2,100	530	1,642	1,710	1,979	1,084	812	1,984
29	1,997	4,215	1,498	2,660	2,380	610	1,486	1,650	2,018	1,067	878	2,151
30	1,803	3,757	1,664	2,584	......	750	1,477	1,510	2,044	1,075	1,107	2,318
31	1,928	3,637	1,965	2,250	......	770	1,886	1,575	......	872	929	2,485
Av.	1,833	2,536	1,419	1,308	1,847	484	770	1,044	1,224	642	763	1,390

Estimated daily discharge, in second-feet, of Cache la Poudre Creek for the month of June.

Day.	1881.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.
1	......	2,035	3,474	2,378	2,349	......	880	1,960	1,736	2,005	750	......	2,652
2	......	2,091	3,598	3,355	2,307	......	1,090	1,608	1,804	1,979	786	......	2,820
3	......	2,273	3,996	3,815	2,349	......	1,350	1,502	1,625	1,790	1,112	......	3,046
4	......	2,400	4,493	3,815	2,422	......	1,490	1,323	1,510	1,542	1,415	1,230	3,206
5	......	2,468	4,835	3,858	2,392	......	1,370	1,282	1,339	1,634	1,002	1,108	3,461
6	......	2,802	5,064	3,390	2,264	......	1,250	1,559	1,225	1,840	960	1,041	3,672
7	......	3,050	4,914	2,706	2,293	......	1,250	1,583	1,139	1,902	1,084	1,197	3,514
8	......	3,386	4,785	2,335	2,407	......	1,410	1,486	1,178	2,436	1,260	1,767	2,782
9	......	3,050	4,854	2,236	2,509	......	1,170	1,502	1,193	5,060	1,468	2,198	2,094
10	......	2,880	5,196	2,236	2,584	......	1,220	1,388	1,217	3,600	1,636	2,667	1,908
11	......	3,067	5,177	2,614	2,509	......	1,200	1,298	1,201	3,065	1,522	2,912	2,067
12	......	4,142	4,894	2,989	2,378	......	1,210	1,258	1,186	2,635	1,260	2,949	2,236
13	......	3,771	5,135	2,925	2,278	......	1,190	1,298	1,242	2,190	1,114	2,252	2,346
14	......	3,688	5,459	2,799	2,278	1,970	1,260	1,307	1,225	1,860	1,200	......	2,291
15	......	4,183	5,248	2,524	1,993	1,970	1,420	1,559	1,282	1,728	1,457	......	2,104
16	......	5,006	4,720	2,293	1,784	1,770	1,450	1,608	1,315	1,624	1,360	......	2,027



DIAGRAMS OF DAILY DISCHARGE OF CACHE LA POUDRE CREEK FOR 1886, 1887, 1888, AND 1889.

Estimated daily discharge, in second-feet, of Cache la Poudre Creek for the month of June—Continued.

Day.	1881.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.
17	......	4,783	4,553	2,321	1,704	1,590	1,320	1,486	1,331	1,501	1,658	......	1,791
18	......	4,798	4,318	2,599	1,580	1,520	1,360	1,518	1,339	1,373	1,444	2,386	1,915
19	......	5,097	4,421	2,675	1,454	1,480	1,550	1,534	1,298	1,752	1,645	2,483	1,717
20	1,104	6,008	4,720	2,907	1,420	1,430	1,290	1,486	1,266	1,579	1,579	2,427	1,586
21	1,053	6,293	4,833	3,338	1,376	1,360	1,050	1,315	1,266	1,545	2,535	2,274	1,452
22	1,053	7,292	4,723	3,407	1,322	1,360	920	1,307	1,258	1,479	2,450	1,905	1,458
23	1,037	7,292	4,259	3,529	1,227	1,250	650	1,242	1,282	1,534	2,285	1,758	1,427
24	1,078	6,748	4,838	3,287	1,237	1,250	730	1,178	1,225	1,545	2,312	1,616	1,375
25	1,095	6,402	5,159	3,055	1,250	1,190	780	1,062	1,201	1,848	2,178	1,422	1,250
26	1,092	5,893	5,404	2,675	1,387	1,250	750	1,016	1,163	1,579	2,165	1,354	1,216
27	1,074	6,924	5,530	2,799	1,398	1,250	750	948	1,155	1,260	1,564	1,246	1,228
28	1,727	6,566	5,611	2,989	1,311	1,080	680	874	1,139	1,049	1,445	1,244	1,120
29	1,681	6,058	5,415	2,799	1,258	1,050	690	837	1,062	1,076	1,392	1,177	1,065
30	1,640	5,723	4,747	2,675	1,247	1,050	680	837	1,016	985	1,332	1,132	1,067
Average	1,239	4,539	4,812	2,911	1,876	1,401	1,114	1,339	1,280	1,900	1,512	1,815	2,063

Estimated daily discharge, in second-feet, of Cache la Poudre Creek for the month of July.

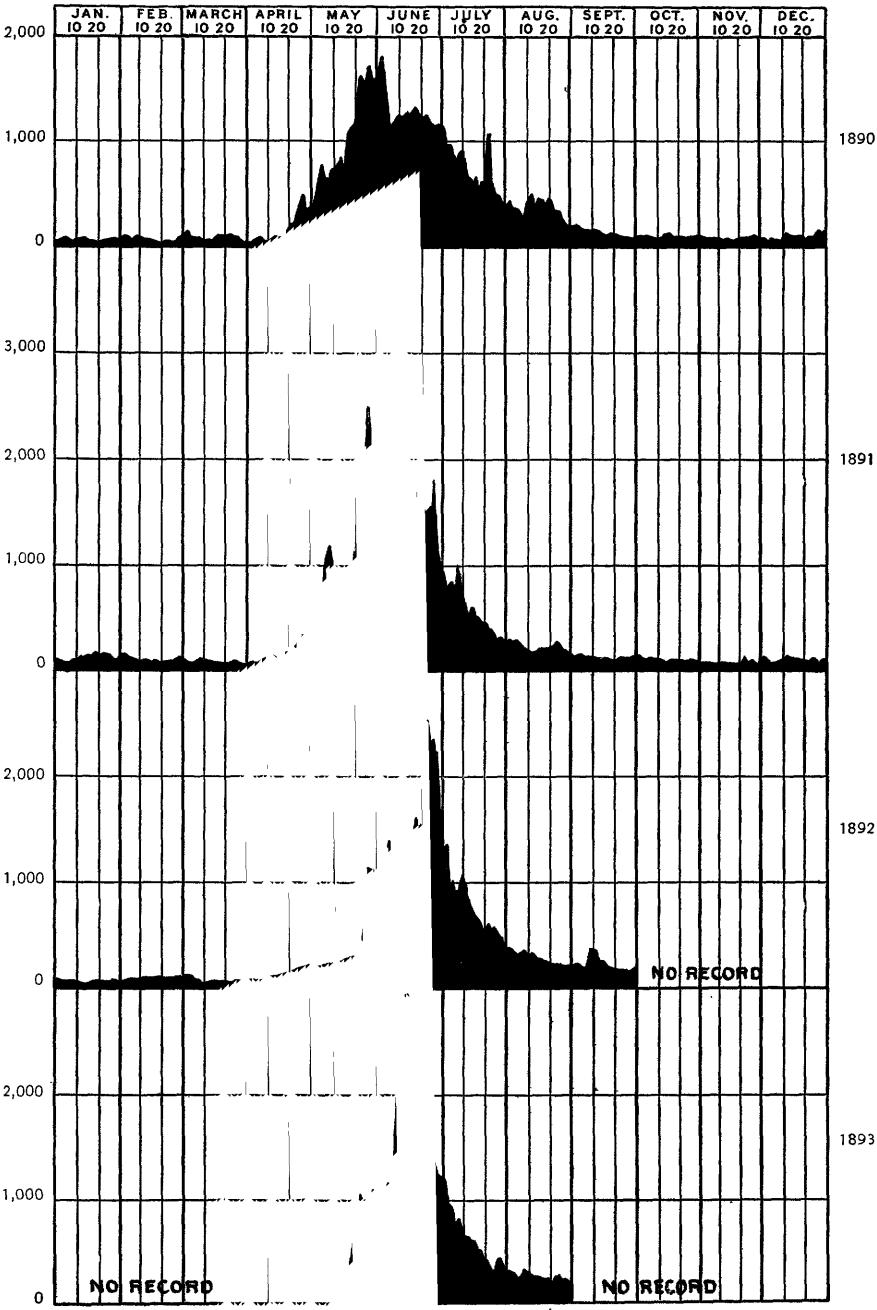
Day.	1881.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.
1	1,622	5,082	3,852	3,055	1,176	980	670	844	970	784	1,392	1,144	1,109
2	1,600	4,447	3,970	3,186	1,126	900	690	844	963	849	1,340	1,038	1,082
3	1,600	3,988	3,845	2,878	1,057	920	610	779	957	864	870	996	1,109
4	1,582	3,395	3,848	2,830	1,038	880	560	722	896	824	1,020	997	1,273
5	1,510	3,344	3,459	2,830	1,038	720	550	633	852	768	993	947	1,234
6	1,507	3,294	3,309	2,321	972	700	540	579	822	832	950	795	1,158
7	1,393	3,243	3,581	2,349	927	700	490	680	764	1,003	908	840	1,078
8	1,203	3,193	3,572	2.378	873	880	560	757	736	907	984	833	956
9	1,084	3,143	3,180	2,208	839	700	510	757	857	768	1,084	744	925
10	963	3,092	2,575	2,181	831	1,260	490	736	770	699	1,000	693	925
11	853	3,042	2,360	2,019	764	890	470	653	712	626	960	663	923
12	786	2,992	2,218	1,939	700	830	450	599	601	558	857	678	936
13	740	2,941	2,305	1.888	685	740	510	546	590	531	822	661	1,177
14	680	2,891	2,458	1,784	639	710	420	513	546	524	784	602	878
15	635	2,840	1,933	1,688	609	940	410	461	613	512	736	608	982
16	673	2,790	1,753	1,712	602	960	350	435	533	492	698	576	899
17	845	2,739	1,755	1,762	609	960	330	416	481	462	648	526	782
18	823	2,689	1,622	1,676	692	1,060	320	397	515	432	639	511	817
19	814	2,639	1,522	1,652	707	890	310	385	559	426	564	476	820
20	713	2,588	1,428	1,557	669	810	290	366	559	415	530	454	728
21	715	2,513	1,462	1,522	764	710	280	354	1,000	392	584	401	696
22	585	2,438	1,198	1,476	566	580	300	294	1,023	381	558	384	647
23	522	2,362	1,194	1,398	552	510	350	378	613	354	512	359	602
24	547	2,287	1,145	1,258	545	490	390	360	502	322	538	348	567
25	481	2,211	1,123	1,176	588	420	380	336	448	302	493	353	561
26	564	2,136	982	1,206	539	420	340	312	403	283	443	444	567
27	528	2,061	955	1,176	466	410	320	265	403	278	402	463	553
28	484	1,985	903	1,076	441	490	310	271	360	288	396	406	522
29	396	1,910	862	1,155	410	450	310	306	348	307	380	383	497
30	376	1,834	1,026	1,145	404	440	260	416	336	307	348	354	461
31	361	1,759	1,063	1,076	393	450	270	448	366	298	342	343	444
Average	877	2,834	2,144	1,860	717	735	421	511	648	542	735	614	836

Estimated daily discharge, in second-feet, of Cache la Poudre Creek for the month of August.

Day.	1881.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.
1	343	1,683	1,068	1,057	369	430	390	455	360	292	327	336	479
2	350	1,608	1,022	1,029	309	410	500	435	342	284	322	343	494
3	337	1,533	1,120	972	299	400	380	403	324	273	307	321	512
4	319	1,457	1,231	918	289	380	310	306	294	269	293	282	440
5	302	1,382	863	937	279	350	300	249	255	269	272	256	379
6		1,306	849	1,116	264	330	280	209	222	251	268	251	396
7		1,231	820	1,019	255	320	240	159	183	233	288	251	513
8		1,157	772	856	255	260	220	146	173	212	271	293	487
9		1,081	860	788	255	250	190	183	198	200	302	327	477
10		1,006	934	772	250	220	180	231	336	200	288	298	464
11		930	860	740	241	230	180	237	403	192	251		427
12		855	804	685	237	360	190	220	348	184	232		393
13		780	780	624	232	370	180	188	354	180	202		362
14		704	796	595	232	380	170	146	403	173	228		365
15		629	788	552	237	380	150	137	397	208	202		369
16		553	827	518	237	350	220	137	385	225	192		347
17		478	833	479	289	320	250	133	385	220			319
18		403	916	466	1,476	280	210	154	306	233			298
19		327	925	460	479	250	220	225	383	238		239	295
20		250	922	441	416	240	210	193	366	238		189	282
21			800	559	343	250	160	178	348	242		226	278
22			683	566	314	230	150	150	294	269		218	271
23			590	559	294	220	160	146	271	288		248	274
24			625	545	274	250	150	141	282	273		219	240
25			653	518	416	320	150	141	251	229		191	229
26			603	491	387	280	150	111	238	229		161	212
27			625	466	342	260	140	98	234	220		155	204
28			594	441	347	250	140	86	183	217		158	179
29			511	416	325	320	140	81	178	192		158	182
30			443	398	279	320	140	67	159	173		141	165
31			423	369	264	320	140	71	150	155		151	162
Average	330	968	792	657	338	307	213	188	290	228	265	235	175

Estimated daily discharge, in second-feet, of Cache la Poudre Creek for the month of September.

Day.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1894.
1	446	347	264	300	160	73	159	148	171
2	390	325	274	290	180	73	173	151	182
3	369	309	274	250	140	73	183	155	178
4	350	299	284	230	130	69	159	158	179
5	361	294	255	220	120	67	150	151	161
6	364	299	232	200	120	67	138	134	152
7	397	337	223	220	120	67	130	131	140
8	410	387	215	270	130	71	130	138	227
9	360	387	215	190	150	65	122	138	296
10	318	358	215	180	140	59	111	138	281
11	302	349	210	170	120	58	108	138	276
12	314	325	210	170	110	56	101	138	246
13	294	314	198	160	110	58	98	138	219
14	271	274	177	150	110	60	89	128	178



DIAGRAMS OF DAILY DISCHARGE OF CACHE LA POUDRE CREEK FOR 1890, 1891, 1892, AND 1893.

Estimated daily discharge, in second-feet, of Cache la Poudre Creek, etc.—Cont'd.

Day.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1894.
15	313	255	169	140	110	69	85	125	165
16	375	246	162	140	120	73	85	125	155
17	319	241	158	130	110	73	85	125	157
18	280	232	162	120	90	71	81	122	152
19	255	223	177	130	80	73	81	118	146
20	239	218	143	140	80	73	86	115	135
21	233	218	136	120	80	73	89	138	118
22	231	218	122	110	80	75	92	138	113
23	237	218	115	120	90	73	78	138	108
24	269	218	122	140	90	73	73	141	105
25	260	218	130	180	80	70	73	141	108
26	246	210	136	170	80	68	73	141	107
27	245	210	147	160	70	71	73	141	101
28	240	218	143	150	80	71	73	148	99
29	235	218	140	150	100	69	65	151	132
30	230	215	136	140	110	67	58	151	145
Average	305	272	185	175	103	69	103	138	164

Estimated daily discharge, in second-feet, of Cache la Poudre Creek for the month of October.

Day.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1894.
1	225	210	133	120	100	71	57	151	144
2	212	206	133	150	110	73	55	148	158
3	203	202	140	150	90	69	55	145	135
4	197	202	130	140	100	69	58	128	141
5	203	202	133	130	110	71	60	131	118
6	199	202	133	110	100	71	73	134	146
7	199	202	130	110	100	67	73	141	151
8	212	202	133	120	110	61	73	134	143
9	209	202	133	130	100	56	73	122	128
10	215	206	130	120	100	55	73	115	131
11	202	......	127	130	110	56	67	112	120
12	202	......	122	120	100	60	89	112	107
13	197	......	120	120	100	69	118	112	99
14	200	......	120	110	110	68	118	112	94
15	200	......	120	120	120	69	118	112	93
16	196	......	122	130	100	65	101	112	93
17	......	......	130	150	120	65	80	115	93
18	......	......	......	140	130	67	81	122	93
19	......	......	......	150	120	69	81	112	89
20	......	......	......	150	130	75	83	112	97
21	......	......	......	140	100	73	83	112	82
22	......	......	......	140	120	71	71	112	85
23	......	......	......	150	130	69	73	115	87
24	......	......	......	......	......	69	78	112	84
25	......	......	......	......	......	69	78	109	84
26	......	......	......	......	......	71	78	106	84
27	......	......	......	......	......	73	89	107	78
28	......	......	......	......	......	75	89	106	74
29	......	......	......	......	......	86	89	104	71
30	......	......	......	......	......	85	89	104	71
31	......	......	......	......	......	92	92	104	78
Average	204	204	129	130	109	70	80	118	105

Estimated daily discharge, in second-feet, of Cache la Poudre Creek for the months of November and December.

Day.	November—				December—		
	1889.	1890.	1891.	1894.	1889.	1890.	1891.
1	92	89	100	79	69	67	84
2	71	83	98	91	78	60	95
3	75	81	98	96	67	61	72
4	86	78	95	-----	55	55	54
5	69	69	84	-----	56	52	60
6	71	67	84	-----	60	67	72
7	73	71	77	91	60	46	72
8	92	73	72	95	65	52	77
9	111	71	72	96	65	48	77
10	122	68	77	93	60	50	82
11	122	58	82	89	48	107	109
12	98	55	82	94	73	80	100
13	85	49	87	85	73	71	100
14	86	52	84	80	78	65	100
15	101	44	79	85	89	58	98
16	98	39	67	77	86	60	100
17	107	41	72	42	33	63	92
18	107	42	72	116	89	67	74
19	111	43	70	150	73	53	72
20	101	52	82	146	67	55	72
21	101	55	100	115	61	44	72
22	92	61	95	107	55	67	72
23	98	63	84	60	58	67	74
24	89	69	84	57	73	58	92
25	67	61	82	103	61	55	87
26	58	65	87	90	71	60	56
27	45	73	84	92	81	71	56
28	56	55	84	91	67	83	72
29	65	53	82	89	43	101	72
30	73	63	84	93	41	86	72
31	-----	-----	-----	-----	39	101	72
Average	87	61	83	83	64	65	79

Estimated mean monthly discharge of Cache la Poudre Creek from 1881 to 1894.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1881	------	------	------	------	------	*a* 1,239	877	*b* 330	------	------	------	------
1883	------	------	*c* 211	718	1,833	4,539	2,834	*d* 968	------	------	------	------
1884	------	------	*e* 68	219	2,536	4,812	2,144	792	305	*f* 204	------	------
1885	------	------	------	*g* 447	1,419	2,911	1,860	657	272	*h* 204	------	------
1886	------	------	------	*i* 405	1,308	1,876	717	338	185	*j* 129	------	------
1887	------	------	------	------	*k* 1,847	*l* 1,401	735	307	175	*m* 130	------	------
1888	------	------	*n* 120	181	484	1,114	421	213	103	*o* 109	------	------
1889	155	110	54	113	770	1,339	511	188	69	70	87	64
1890	82	79	85	200	1,044	1,280	648	290	103	80	61	65
1891	92	76	59	144	1,224	1,900	542	228	138	118	83	79
1892	64	116	78	*p* 84	*q* 642	1,512	735	*r* 265	------	------	------	------
1893	------	------	------	------	*s* 763	*t* 1,815	614	*u* 235	------	------	------	------
1894	------	------	------	------	1,390	2,063	836	175	164	105	83	------

a June 20–30, 1881.
b August 1–5, 1881.
c March 23–31, 1883.
d August 1–20, 1883.
e March 15–31, 1884.
f October 1–16, 1884.
g April 14–30, 1885.
h October 1–10, 1885.
i April 27–30, 1886.
j October 1–17, 1886.
k May 18–29, 1887.
l June 14–30, 1887.
m October 1–23, 1887.
n March 14–31, 1888.
o October 1–23, 1888.
p April 1–17, 1892.
q May 18–31, 1892.
r August 1–16, 1892.
s May 11–14 and 21–31, 1893.
t June 4–13 and 18–30, 1893.
u August 1–10 and 19–31, 1893.

SETTLEMENT IN CACHE LA POUDRE VALLEY.

During his tour in Colorado, in 1859, Horace Greeley was impressed with the belief that the higher lands were adapted to cultivation if irrigated. On his return to New York he discussed the matter, and with the cooperation of N. C. Meeker gave the proposition great publicity. The colony plan presented through the columns of the Tribune culminated in 1870 in the formation of Union Colony, which, settling in Cache la Poudre Valley, gave to their town the name of Greeley.[1]

When the colony arrived, it found a few settlers in the valley, who had occupied the bottom land mostly for the pasture and wild hay it offered. They had taken out from the Cache la Poudre Creek a number of small canals, which had in cultivation under them, as near as can be ascertained, about 1,000 acres. They generally believed that the higher bench land lacked fertility, and that it was extremely unwise on the part of the colony people to construct canals for its irrigation.

UNION COLONY.

Union Colony, under the leadership of N. C. Meeker and the auspices of Horace Greeley, undertook, in the spring of 1870, the settlement of the lower end of Cache la Poudre Valley, the headquarters being upon the site of Greeley. The leaders of the colony constructed, as quickly as possible after their arrival, a ditch on the south side of the creek, on the site of the one that now irrigates the lots in town and

[1] Second Biennial Report of the State Engineer of Colorado for the years 1883–84, p. 20.

the lands in its vicinity. There were only some 200 acres put into crops, but the ditch was small and poorly constructed, and without a dam at its head in the river to divert the low water into it, so that not enough water could be obtained for this small area.

This first ditch demonstrated the great fertility of the soil when sufficiently moist to enable vegetation to avail itself of its plant food. The original cost was $6,333. It was enlarged three times, in 1871, 1872, and 1873, and then cost in all, with dam, about $25,000. It has

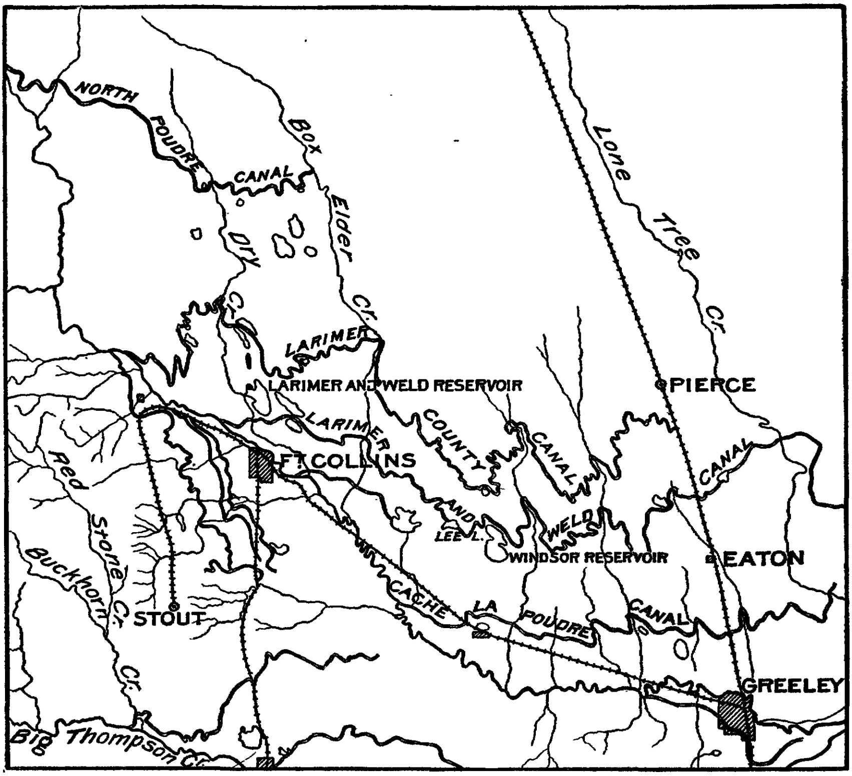


FIG. 5.—Map of canals near Greeley, Colorado.

a capacity, by the decree of the court, of 173 second-feet. In 1894, as shown by a table in the State engineer's report, it is credited with having only 1,275 acres under irrigation, of which 480 are reported as pasture and waste land. This, no doubt, leaves out of account the town lots irrigated from this canal, which have a probable area of 300 acres. The insignificance of the area thus reported as under cultivation shows that if this had been all the colony would have been a failure as an agricultural community, and there was no other industry for it in this locality to pursue.

CANAL AND RESERVOIR SYSTEMS.

A number of canal systems were projected by Union Colony, the first of these, or No. 1, never begun, being planned to head in the canyon above La Porte and terminate at Crow Creek, covering nearly all of the lands later watered by the two canals known as the Larimer County and the Larimer and Weld County canals. Canal No. 2, later known as Cache la Poudre Canal, was begun during the fall of 1870.[1] Canal No. 3 was the town ditch described above. No. 4 was to come out of Big Thompson Creek and water the lands on the bluff south of Greeley, now irrigated by the Loveland and Greeley Canal. Thus canals Nos. 2 and 3 were the only ones constructed under the original plans of the colonists.

A list of the most important canals and ditches is given on page 51 in connection with the crop statistics of this district. The location of the three largest is shown on the accompanying map (fig. 5) and a general description of them is given below. These, in geographic order, are Cache la Poudre Canal, immediately north of the city of Greeley; above this Larimer and Weld Canal; and still above, and in a general way parallel, Larimer County Canal. Still further to the northwest is also shown on this small map the lower end of North Poudre Canal, belonging to the North Poudre Land, Canal, and Reservoir Company, and described on page 58.

CACHE LA POUDRE CANAL.

The survey of what was originally known as Canal No. 2 was prosecuted during the summer of 1870, and the construction of its whole length—35 miles—was practically completed during the autumn of that year and the spring of 1871. It was supposed to be in shape to deliver an abundance of water to all the crops that could be got in under it for irrigation during the summer of 1872. Some 2,000 acres were put in crops, but most of them were burned up for want of water. It was a year of scarce supply, there was no dam in the river, and the head of the canal ran for a mile and a half along the edge of a slough upon which its lower bank rested, and this bank soon settled so that it could not hold the passing water. This loss of crops by the most enterprising and courageous colonists—men of moderate means—came near paralyzing the whole enterprise.

During the fall of 1871 and spring of 1872 an enlargement was made and a dam put in the river. The cost of the first construction was about $27,000 and of the enlargement $20,000 more. This year the river had an ample supply, and the spring was moist, and hence favorable for plowing and the germination of seeds. The result was an area planted of some 6,000 acres and fine crops. However, the canal was yet quite too small for the 25,000 acres of land under it

[1] History of Greeley and the Union Colony of Colorado, by David Boyd, 1890.

owned by colonists, and two other enlargements were made in 1874 and 1877, making the total cost up to that date about $87,000.

The Cache la Poudre Canal—originally Union Colony Canal No. 2—was the earliest of the large systems. It was for a long time deemed unnecessary to supplement its river supply by a reservoir. However, it was found that in more than one-half the years the river water gave out before the potato crop was made, and that the farmers under it were at a disadvantage as compared with those who had

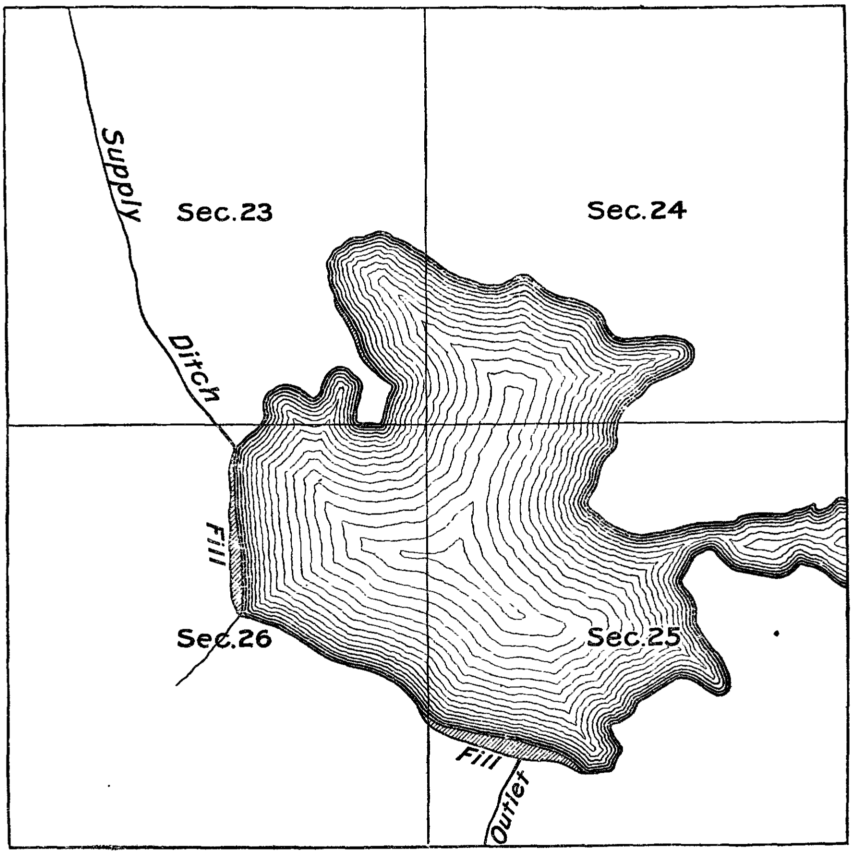


FIG. 6.—Map of Cache la Poudre Reservoir.

water from the Larimer and Weld Reservoir, the contents of which were used for the potato crop in 1891. In 1892 the farmers under the Cache la Poudre Canal commenced to take steps toward building a reservoir. They found a site (shown in fig. 6) about 4 miles above their canal, the contents of which could be emptied into it about 2 miles below its head, and could be filled by constructing a feeding canal some 8 miles long and heading in the river just below the tail-race of the Linden Flouring Mills, which enters the river at Fort Collins.

These mills have an early appropriation from the river, dating back to 1867, for 93 cubic feet per second. As this claim antedates the adoption of the constitution of the State by 9 years, the courts have decided that the provision in that instrument giving claims for water for irrigation purposes a superior right to those for mechanical purposes does not apply in this and similar cases. Hence the water of the river must be run to the head-gates of the mill canal, however low the river is, except for the use of the few canals that antedate it and whose heads are above the mill tailrace. Since none of the water is consumed in furnishing power to the mills, it does not affect canals below it. There is nominally a claim for 401 second-feet prior to its claim, but the heads of more than half of the ditches making the claim are below its tailrace and many of the others have been abandoned. The most important claim above its tailrace is that of 19 second-feet by the Larimer and Weld Canal, but this only antedates it for irrigation purposes; for storage purposes its reservoirs rest on their own date, which is 25 years later than that of the mills. The Pleasant Valley and Lake Canal also has a claim of 40 feet antedating that of the mills, and this heads above the mill power canal, and hence as long as irrigation lasts can take the water, and does in the autumn, when it is scarce, to the detriment of the mills. The same is true of Dry Creek Ditch to the extent of an appropriation of 12 second-feet.

While irrigation lasts these three claims greatly disturb the mill supply when the river is low, early in spring and late in autumn, and hence its proprietors put in steam power to use when water is scarce. Should they abandon the use of the water altogether, an interesting question will be raised concerning the legal rights of the Cache la Poudre Reservoir to the water which the position of its head-gates in the river just below the tailrace now allows it to store to the extent of what runs through the mill race, in spite of the fact that its claims to water for storage purposes postdate nearly all the other important reservoirs. These are all supplied by canals that head above the tailrace, and nearly all—and at times all—the winter supply of the river must be allowed to flow by for the mill, and hence for the sole benefit of the reservoir we are considering. The main reason for locating the head of their reservoir supply canal where it is was to obtain this very water, and now, if the mill should abandon its use, who would have the right to it? Should it be turned back into the river and be subject to the appropriation already made, or should this reservoir continue to enjoy the privilege?

Cache la Poudre Canal has been conveyed by Union Colony for a nominal sum to a new company, composed of the farmers owning the land and water rights under the canal. The new owners have expended about $25,000 in straightening the course of the canal (shown in Pl. VI), constructing permanent dam and head works, and putting in checks at the head of nearly every lateral. These were needed because the slope of 3.2 feet per mile was too steep for a canal of this size and resulted in erosion of the bed and lowering of the channel. The head works are of stone masonry laid in cement. The gates are of iron, and each is constructed of an upper and lower section, only one of which is moved when the head at the gates is high, less power being thus required for lifting.

The duty of water under Cache la Poudre Canal has been computed by Prof. L. G. Carpenter.[1] The length of time during which this canal has been in operation and the consequent long experience of farmers render the measurements of considerable value for comparative purposes. The amount of water taken into the canal was measured daily or estimated from a record kept by an automatic register. The results given in the following table show a comparatively large duty if a long season is taken, but, on the contrary, for the month of June alone, when water is in abundance, the average duty drops off rapidly, falling to from 65 to 95 acres per second-foot.

Duty of water under Cache la Poudre Canal in acres per second-foot.

Period.	Days.	1890.	1891.	1892.
May 1 to September 1	123	132	153	112
April 1 to September 1	153	164	192	146
May 1 to November 1	184	198	232	176
June alone	30	72	95	65

The total cost of the canal has been $112,000. There are some 300 80-acre water rights held in the canal and represented by a share of stock for every 10 acres. Each is entitled to a proportionate share of the water in the canal at all stages. It will be seen that the average cost of an 80-acre right in the canal was $373⅓. Such rights, when the land under them has become so wet as not to need irrigation, have been selling to parties owning lands lately taken up at the lower end of the canal for $2,000 apiece. This price does not include a right to water from the reservoir, which is owned by another company, although most of its stock is held by the parties who own the canal. Rights to 80 acres in this reservoir were sold in 1896 for $800 apiece. Placing the cost of the reservoir at $120,000 and the number of rights at 300, the cost per right would be $400, apparently giving a profit of 100 per cent on the investment. Of course in all such enterprises for a while the capital invested is unproductive. In this case the period was not long, since the work was prosecuted with vigor, the reservoir being fit for use one year after its commencement. Those not owning land have generally been able to rent their reservoir rights at a fair interest on the investment.

[1] Colorado Agricultural Experiment Station Bulletin No. 22, Preliminary Report on the Duty of Water, pp. 18-21.

VIEW OF GREELEY CANAL NO. 2; NEARLY EMPTY.

CACHE LA POUDRE RESERVOIR.

This is the most expensive of all the reservoirs in the valley. In the argument before the court the cost is placed at $125,000. The statement obtained from the company gives $28,643 for real estate for site of reservoir and right of way of supply canal, 8 miles long (capacity, 150 second-feet), and outlet canal, 4 miles long (capacity, 200 feet per second); also $81,623 for construction, making a total cost of $110,266. It has by far the longest and highest embankment of any of the reservoirs in the valley. At the outlet this embankment is 38 feet high, the height of water above the bottom being 30 feet. The breadth of the base at this place is 300 feet. The inside face has a slope of more than 3 to 1, and still the riprapping slides down each year on account of the action of the waves. When first laid it had a uniform slope from top to bottom, but now the slope is quite irregular, through the action of the waves moving the rocks and washing away the embankment under them. This is of good material, being largely composed of coarse gravel brought from a hill near one end by wheel scrapers. The rock for riprapping was brought from the foothills by rail to the nearest point, which is 2 miles off, and thence by wagon. It cost per ton, laid down, $110. It is medium-sized, flat sandstone, the refuse of the quarries where building and flagging stones are taken out.

The conduit is but a few feet deep below the level of the natural surface, the material of its foundation being a tenacious clay. The base is of wide flagstone laid on a grout bedding of gravel, sand, and Portland cement. The width is 5 feet inside, walls 2½ feet high, spanned by an arch 2½ feet high in center. There are two collar walls extending from the masonry of the conduit into the embankment, to prevent the water from working its way along the connection of the earth and masonry. It has shown no signs of weakness at this place, but when the reservoir is full the embankment gets quite soft throughout. However, it yearly gets less so. It settled 4 to 5 feet the first year after the water was turned in, although the teams had traversed it back and forth with wheel scrapers bringing the gravel and earth from the ends of the fill.

The gates and means of raising them are a novelty, the invention of Mr. Gordon Land. The front of the inlet of the conduit is a steep inclined plane, some 20° from the vertical. The aperture is divided into two sections by a timber running midway up and down in the plane of the incline, and on the outer edges of it are fastened iron plates of about the weight of wagon tire. A similar timber and tire are on each side of the aperture, thus forming a double track for two iron gates. These latter are each attached to two axletrees which have wheels at their extremities and are brought to bear upon the track when the gates are being raised.

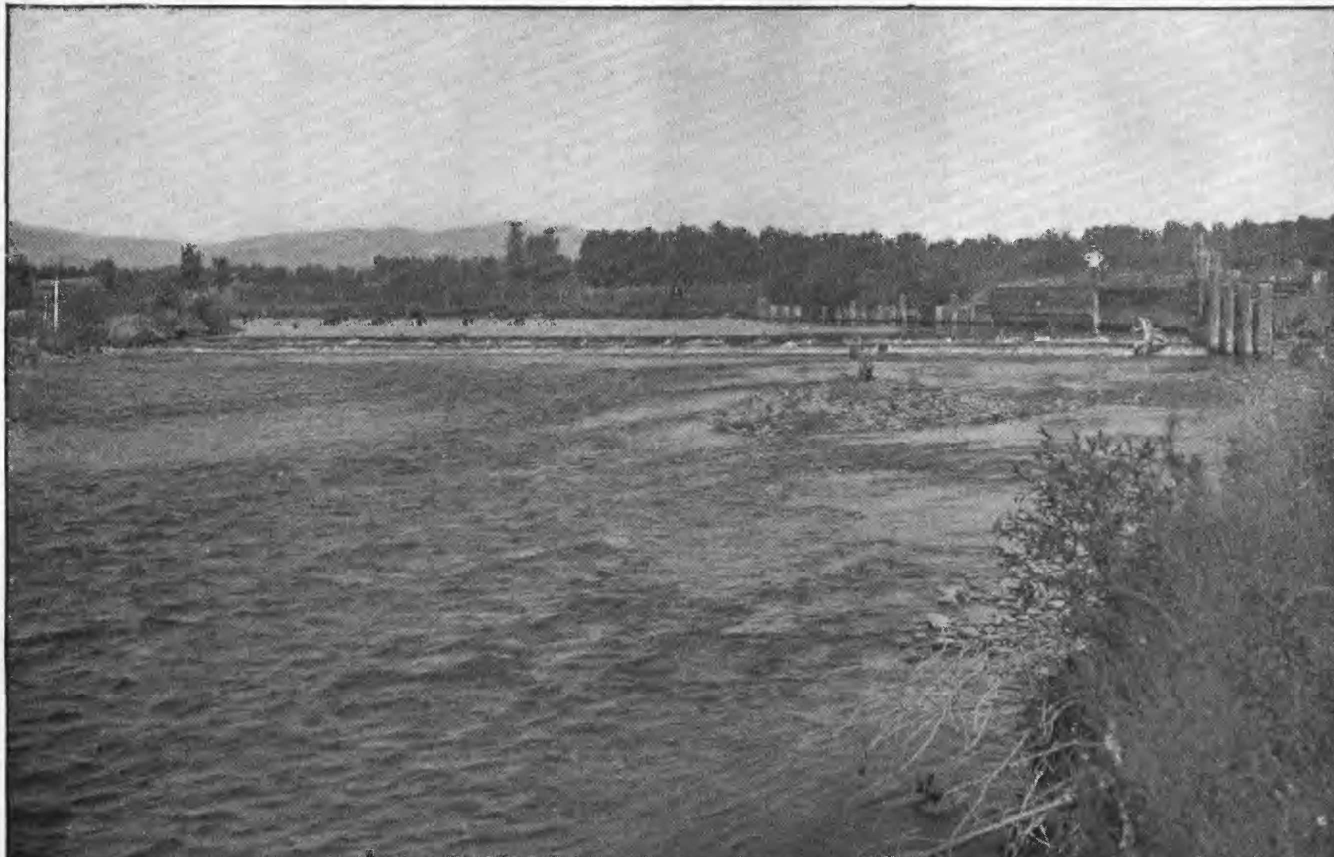
This is done by means of a wire rope, one end of which is attached to a cog-geared windlass placed on the top of the embankment and the other end to a lever attached to the axle of the gate, which axle is eccentric, so that the movement of the lever causes the wheels to bear on the tracks and to roll along it, instead of having the edges of the gate drag over the edges of the supports behind it, as in raising the ordinary gate. Each rope passes over a pulley placed at the top of the incline. It should be further said that the axle and wheels are attached to the upper and outer sides of the gates, and the front and rear axles are yoked together so that the rope acts on both and presses their attached wheels against the tracks in lifting the gates.

The cost of this reservoir equals that of the canal of which it is an adjunct. It furnishes only 5,654 acre-feet, while during the irrigation season of 1894 the canal drew from the river 70,610 acre-feet, or more than twelve times as much. Hence it is to be said that reservoir water is costly.

At present prices of farm produce it certainly does not pay to store water at this cost. Storage reservoirs, even of the most economical location, can not as a general rule be profitably employed in irrigation, except as adjuncts to canals that have for the most part their supply from a fairly permanent source during the irrigation season. None of the streams in this State except those of the western slope hold out in the latter part of the season so as to furnish water enough to complete the growth of certain crops, save for a few claimants of early rights. The one crop in this valley for which there is need of later water than the streams afford is potatoes. Up to 1895 this crop has been on an average profitable, even though we have been forced to seek a wider market than that of the plains and Rocky Mountain region. Hence the late development of reservoir construction in this valley.

It will be further noted that when a canal is already built, with all its laterals and means of distribution, and a reservoir can be constructed so as to deliver its water into it near enough to the head to supply the greater part of its customers, the case is very different from that of building a reservoir that has to provide all the means necessary for the distribution of its contents. This is the case of nearly all of the reservoirs in this valley. When that can not be done, the exchanges noted on another page effect the same economy so far as they can be brought into practice. When, however, the relation of the reservoir to the canal is like that of the one we are considering, it gives an independence and certainty not to be found where the use of the water by its owners depends upon so many contingencies.

As stated on a preceding page, the feeding canal for this reservoir



VIEW OF DAM AND HEAD GATES OF LARIMER AND WELD CANAL, POUDRE VALLEY.

heads in the river immediately below the tailrace of the Linden Mills, at Fort Collins. This location was made for the purpose of securing the water from this mill, as intimated above. The destruction of the mill has given rise to one of the most perplexing questions in regard to water rights. The mill in its use of water power has proved a great detriment to the irrigation of the valley, since in order to turn its wheels it has been necessary to allow the water to pass the head gates of all the canals feeding reservoirs except this one. The other parties in interest would undoubtedly have purchased the rights of the mill and turned the water back into the river to be used for storage in the order of its appropriation were it not for the claim of vested rights made by this lower reservoir.

Recurring to the value of this reservoir as an investment, it may be said that in spite of the comparatively early appropriation of water by the canal it would not be possible without it to obtain in two years out of three sufficient water for the potato crop. The number of sacks of potatoes produced under this canal in 1894 was 602,485. During that year the crop sacked was worth, on an average, 70 cents per hundredweight. Deducting 5 cents for the cost of the sack and 10 cents for harvesting, the net value is 55 cents. The seed and labor cost the same amount for a half as for a whole crop. We may set down to the credit of the reservoir one-half of this crop, which at 55 cents per hundredweight amounts to $165,683, or a third more than the cost of the reservoir. That, however, was an exceptional year, both as to product and price. It would be fair to estimate the average crop under this canal at 500,000 hundredweight, and the average price at 40 cents per hundredweight. Allowing one-half the crop as due to the reservoir water, this would amount to $62,500, or one-half the cost of the reservoir.

LARIMER AND WELD CANAL.

The Larimer and Weld Canal takes water from Cache la Poudre Creek above Fort Collins and about 12 miles above the head of Cache la Poudre Canal. The total length is stated to be 50 miles, and the average bottom width 25 feet. Water is diverted by a wing-crib dam 177 feet long and 4 feet above the bed of the stream.[1] The dam and head gates are shown in Pl. VII. This canal has under it one-third of all the land under ditch in the valley and has a capacity greater by one-fourth than that of any other. It can take in the average flow of the whole river except during the 60 days commencing with the middle of May. In Pl. VIII is given a view looking up the canal to the head-gates. Before its final enlargement, which was, in fact, its real construction, there was nominally appropriated 2,735.87 cubic feet per second, this being more than the average flow of the river for any one month. The older canals could not use so much water as this, but

[1] Report on Agriculture by Irrigation at the Eleventh Census. F. H. Newell, 1894, p. 135.

could take so much that during years of scarcity this canal could at no time receive a full head. Every year the supply fell to its second appropriation of 19 feet before the time to irrigate potatoes, which up to 1895 was the best-paying crop.

LARIMER AND WELD RESERVOIR.

An excellent site for a reservoir was found at a point a mile and a half north of Fort Collins, about a quarter of a mile above the canal and only 2 miles from its head. This could be supplied from two small canals above the Larimer and Weld, the bottom of the reservoir being only 2 feet above that of the canal. This site is a natural basin, in which, when filled to the lip of the lower rim, the surface of the water would be 25 feet above the bottom of the outlet, and which, it is estimated, would contain 350,000,000 cubic feet or 7,700 acre-feet. The canal company did not wish to undertake this work, but permitted the farmers who held contracts for water from it to take the site which it had surveyed. These farmers represented water rights covering 15,000 acres. They formed a company known as the Larimer and Weld Reservoir Company, proceeded to condemn the site and procure the means of feeding it.

The following are the principal items of expense and relate to construction to hold a depth of 25 feet:

Surveying and engineering	$2,870
Land and rights for water	13,768
Construction	21,796
Attorneys' fees	5,796
Court expenses	2,312
Miscellaneous	18,240
Total	64,782

It will be seen that only about one-third the expenses was for construction, not including surveying and engineering. In fact, no considerable embankment had to be made for that depth. An inlet canal was of necessity built from Dry Creek, which was its feeder, this in turn being supplied by two small canals in which a right of carriage had been purchased. The expenses of construction were increased from the fact that a wooden conduit was put in at first. The parties living under the reservoir deemed it unsafe. This necessitated its removal and the substitution of a cement and rock conduit, costing about $5,000. The quantity of land originally purchased was some 700 acres. This, with the right to run water through the inlet ditches, cost about one-fifth of the whole.

In 1895 the company resolved to increase the capacity to a depth of 30 feet. This required the construction of a bank over 2,000 feet long on the top, and this, with the additional land to be purchased, added to the cost $25,000 more, making the total cost about $90,000. This

VIEW OF HEAD GATES OF LARIMER AND WELD CANAL AND OF THE CANAL BELOW THEM.

addition of 5 feet to the upper surface increased the cubic contents by one-half. However, in being measured out over a weir, the reservoir does not come up to the estimated capacity by one-third. In fact, on drawing the water down from a depth of 29⅓ feet to 4 feet a content of only 325,000,000 cubic feet was given. This discrepancy between the capacity estimated from depth and contour, and measured as above, is true of all other reservoirs in this valley that have been tested in the same way. The weirs are not constructed so that the Francis formula will apply to them, but they are rated by a current meter at different depths, just as the weirs in the canals are measured to find their intake from the river.

The accompanying views, Pls. IX, X, XI, illustrate the embankment and outlet of this reservoir. The first (Pl. IX) is a view from the inside of the reservoir after the water has been drawn off. The rectangular mass of masonry in the center is the wall of the well which surrounds the space where the gates are placed. Its interior dimensions are 6 feet by 10 feet. The wall is 3 feet thick and is composed of heavy rubble masonry laid in Portland cement and connected with flanking walls.

The next view (Pl. X) shows the lower side of the outlet of the reservoir. In the middle is the heavy lower retaining wall, extending only a portion of the way up the embankment. The latter was constructed of earth, with a slope of 1½ to 1. At the right are posts standing at various angles. These were driven into the ground to keep the earth from slipping into the canal below the masonry, as it was tending to do after becoming moistened by percolation from the water in the reservoir. The next view (Pl. XI) is at the lower end of the outlet canal of the reservoir where it discharges over the weir into the Larimer and Weld Canal.

On account of the exchanges which are being made for river water it will be apparent that a high degree of accuracy of measurement is desirable, or at least that the same system of measurement should obtain in measuring the outflow of the reservoirs and the intake of canals, and this is attempted; but those who have studied and experimented most on measuring water under ordinary and diverse conditions best know how difficult it is to obtain accurate results.

The large expenditure in litigation was brought about by the fact that after the reservoir had been constructed by the farmers the canal company refused to allow them to run the reservoir water in the canal. The farmers had contracts with the company to furnish them so much water, but they were not stockholders in the company. The contracts also provided that the holders of these contracts should become stockholders after the company had sold water rights to the estimated capacity of the canal to furnish water. But this limit, which was 500 eighty-acre water rights, had not been reached, and moreover these same farmers had gone into the courts asking an injunction prohibiting the company from selling any more than the 370 rights that then had been sold, since there was a provision in the contracts that in times of scarcity the water was to be prorated with all the rights sold and in force. It was contended that the company had sold more than it could furnish, this word applying equally to the water to be obtained from the river and to the capacity of the canal to carry.

This case has been in court some five years. The company won in the district court and in the court of appeals, while these decisions were reversed in the State supreme court, which sent the case back for trial again in district court, which gave the farmers their case, as instructed by the upper court. However, there seemed to be another appeal to the supreme court, the company meantime being restrained from selling any more water rights until the case is finally adjudicated. The expenses of this case, as well as that concerning the reservoir's own suit, were paid by the reservoir company, and hence swells the account on this score.

As regards its own suit to compel the company to carry the water, an order to this effect was obtained from the county court of Weld County, which was, nearly as soon as given, countermanded by a judge of Arapahoe district court in the absence of the judge of this district; but upon hearing before this same judge, he reversed his own decision, and the farmers were allowed to carry their reservoir water in the canal of the company.

This was allowed partly on account of a statute of the State providing that a canal already in existence, and having the capacity and proper location to carry the water of a party not an owner of the canal, must carry it, and so prevent burdening the real estate with parallel canals, which were becoming a nuisance before the enactment of this law. In the present instance, if the farmers had been forced to build a canal to distribute their water, it must have been either immediately above or below a canal some 40 feet wide, and if above, they would have to flume across this canal wherever there was a lateral, the laterals being the property, in part at least, of the farmers who had lands under them. These laterals were as frequent as one a mile. On the other hand, if below, they would have to flume the reservoir's canal over each of these laterals, in fact, making a monstrosity of construction, a monument of human perversity and folly.

Of course, although the canal in an equitable sense belonged to each farmer in proportion to the quantity of water he had purchased to be delivered through it to his land, still legally the canal belonged to the canal company, and what the reservoir people got was a temporary easement for the use of the canal when there was but little or no water in the river to which the canal was entitled, and for this temporary use they were expected to pay. Another suit in court fixed the amount, which was made low by the jury, no doubt on account of the virtual part ownership of the farmers in the canal.

VIEW OF OUTLET AND EMBANKMENT OF LARIMER AND WELD RESERVOIR, FROM THE INSIDE, AFTER THE WATER IS DRAWN OFF.

They had paid, on an average, $1,000 apiece for each 80-acre water right, which was to be 1.44 cubic feet per second when there was water enough in the river. Taking out some 30 preferred rights granted the owners of the old ditch, there were in force some 340 of these rights, for which the company had received $340,000, while the construction of the canal had not cost more than $150,000. It was a part of the contracts with the farmers that they should become shareholders in the company as soon as the estimated capacity of the canal had been reached. But this question was in court, and, as we saw above, has been decided in favor of the farmers, namely, that it had been reached at the time they enjoined the company from further sales of water rights, because the deficiency of water in the river during the ordinary irrigation season prevented the company from being able to furnish. The ambiguous phrase "capacity to furnish" was at last, and by the highest court, construed against the company, which was the drawer of the instrument, in accordance with the general practice of the courts.

LAKE LEE.

At the time the order of the county court was issued to allow the reservoir people to take possession of the canal and run their water through to those entitled to receive it, there was running in the canal some 19 cubic feet of water per second belonging to its old appropriation. This was being stored in a reservoir named "Lake Lee," an expansion of the canal some 15 miles below its head. Its area is about 90 acres, and a depth of 9 feet can be drawn off when it is filled to the limit of height. When the water of the reservoir was turned into the canal, it mixed with that carried by the canal for the benefit of all consumers, while those owning and entitled to reservoir water were about one-half of the consumers. The order of the court therefore put the canal for certain-named days wholly in the hands of the reservoir people, under the penalty of damages to the other consumers. The writer was put in charge of the reservoir and canal at these times and until more amicable relations were restored. The plan adopted was to carefully measure the height of water in Lake Lee at the time the reservoir water reached it, and then to make an estimate as to the height to which the quantity in the canal would fill it during the days the reservoir water was being run. When the run was about finished, the outlet gates of Lake Lee were shut, so that there would be in it for all consumers what it was estimated would have been in it if the reservoir water had not been run. The instructions of the reservoir managers were to be sure and err on the side of leaving enough in Lake Lee, and the result was that no damages were claimed by the other consumers for loss of water by the operation of the canal by the reservoir company. Pl. XII shows the Larimer and Weld Canal at Lake Lee gates.

WINDSOR RESERVOIR.

It will be observed that this reservoir water was the property of about one-half of the consumers under the Larimer and Weld, and hence that only in the few cases where the others rented did they enjoy the use of the water. As a consequence, only those having reservoir water made a potato crop. Those outside of the reservoir, of whom the leader was B. H. Eaton, the owner of some 15,000 acres under the canal, undertook the construction of a reservoir for themselves. There is an excellent site for a reservoir some 25 miles from the head of the canal and close to it. The bottom of the canal at this point is about 50 feet above that of the reservoir. It has been filled to the depth of 28 feet and the water stored in it has been used for three years by means of the system of exchange before described. The cost of the reservoir up to date has been, as itemized by Mr. Eaton, as follows:

Land	$20,000
Condemnation and attorneys' fees	5,000
Outlet and inlet, the latter consisting mostly in enlarging the Larimer and Weld Canal from river to reservoir inlet	10,000
Surveying	1,000
Conduit and embankment	16,000
Total	52,000

The owners expect to expend $23,000 more to make it hold 12 feet more, or a depth of 40 feet of water at the conduit. This will be expended partly on the main canal, to enable it to take in flood water from the river for storage, and partly on the embankment. When the water is raised to the height of 40 feet, it is estimated the reservoir will hold 1,000,000,000 cubic feet.

The work on the embankment near the outlet conduit is in a very incomplete state, as will be seen from the accompanying view, Pl. XIII, taken from the inside of the reservoir when the water was drawn off. This shows the masonry in front and over the stone arch which forms the outlet. The gate, which is about 4 feet by 5 feet, is raised by a screw and lever. There is no flank masonry nor rock riprapping to protect the earth embankment. Such protective works were attempted by use of posts, poles, wire, and straw, but, as seen in the view, these were wrecked by the waves.

The conduit is of masonry laid in Portland cement; the bottom is of large, thick flagging stones procured in the foothills; the sides, 3 feet high and 4 apart, are crowned with an arch 2 feet high in the center; the walls of sides and arch, 2 feet thick, are of rubble masonry, resting upon the soft shale rock, which has between it and the flagging that forms the bottom some 6 inches of concrete made of gravel, sand, and Portland cement. There have been no signs of leakage along the surface of the conduit, but there is a tendency to

VIEW OF LOWER SIDE OF OUTLET OF THE LARIMER AND WELD RESERVOIR.

leak just above the shale into the outlet ditch below the end of the masonry of the conduit.

After the water has been raised in this and similar reservoirs the overlying clay becomes softened and sloughs off into the outlet canal. This was the occasion for great fear on the part of the people living under the Larimer and Weld Reservoir during 1895. A score or more of families abandoned their houses one rainy night when the reservoir was full and looked threatening. It is now proposed to wall up the outlet canals below the masonry conduits with a dry stone wall filled behind with gravel, which will allow the water to leak through while it prevents sloughing off.

When the Windsor Reservoir is complete it is planned to draw off the water at two levels, the one at the bottom, now in use, and another at a level 20 feet higher and distant 200 feet. The water from the upper outlet will be dropped into the same canal that is now used for the bottom level. The reason given for this is ease of management of the gates, which would be hard to raise under a pressure of 40 feet.

LARIMER COUNTY CANAL.

Larimer County Canal is to the north of and in general parallel with the Larimer and Weld Canal, covering a strip of land above the latter. It heads on Cache la Poudre Creek, about 8 miles higher up, but for its water supply this canal has for the most part been dependent upon a system of reservoirs, since it is the latest of those of large size in the valley, being preceded by 99 claims, aggregating 4,082.65 second-feet. In order of priority it follows third after the North Poudre Canal and Reservoir Company, there being two claims of 157.40 feet between. By its head in the main river, however, it obtains late water whenever, at rare intervals, there is any.

This canal was built by residents of the valley, who, though having the evidence of a deficiency of water before them, yet hoped that the unusually large supply of previous years would prevail in the future. They overestimated not only the supply obtainable for storage in reservoirs, but also the land that could be sufficiently irrigated from a given amount of water. Hence it may be said that until the last two years farming under this canal has been a series of failures. This company has on the plains six reservoirs fed by the canal. Of these two are important, Long Pond and Rocky Ridge. These have a united capacity of 340,000,000 cubic feet, or 7,500 acre-feet. The total storage capacity of all its reservoirs claimed is 480,000,000 cubic feet, or 10,560 acre-feet.

CHAMBERS LAKE RESERVOIR.

A company known as the Larimer County Reservoir Company placed a dam in the outlet of Chambers Lake, a natural storage basin near the head waters of the Middle Fork of Cache la Poudre Creek. The irrigators interested in the waters of this stream, fearing a scarcity of supply, commenced suit on the ground that the statute gave only the right to take water from a stream and store it, and not to place a storage dam in the stream itself. The dam, however, was constructed, but on June 9, 1891, it broke, letting the contents of the reservoir sweep down the channel of the river and inflicting much damage upon the farms situated in the narrow mountain valley. Passing through the canyon below the valley, it overspread the lower bottom lands, carrying away bridges, the force gradually diminishing as the mouth of the river was reached.

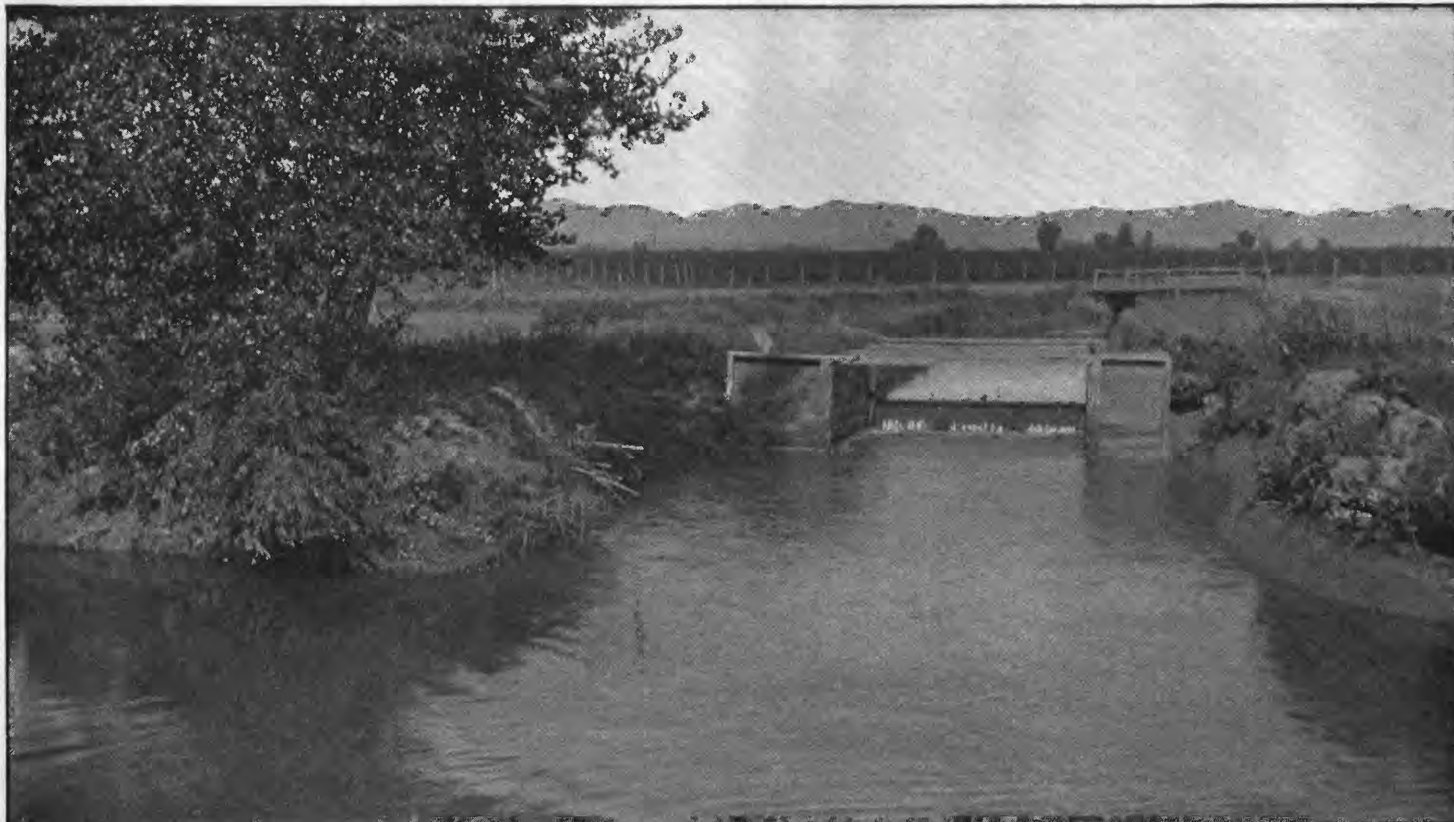
The parties injured sued and recovered damages, and as the reservoir company had no property but the destroyed dam, suits were brought against the Larimer Canal Company, on the ground that since it had been renting the water and was the controlling factor of the reservoir company it should be held responsible. It was held that any one placing a dam in a natural stream was responsible for injury resulting from its destruction.

The irrigators of the valley as a rule were not displeased to have this dam destroyed, as it was generally believed that water was unjustly taken from the river. The dam being 70 miles above the gaging station, out of the reach of the river commissioner, and wholly in charge of employees of the canal company, it was impossible to verify this belief. The experience gained here justifies the statement that no structure of this kind should be built except under State supervision or in accordance with regulations prescribed by the State engineer, such as will insure absolute safety in the building and management of dams, especially those upon the main drainage lines.

SKY LINE DITCH.

In 1892 the company owning the Larimer County canal was reorganized under the name "Water Supply and Storage Company," and during the next year undertook the work of building a ditch above Chambers Lake for the purpose of diverting into Cache la Poudre Valley water from the upper feeders of the Laramie River, a tributary of the North Platte. This ditch, shown in Pls. I and XIV, bears the graphic name of the "Sky Line," as it is about 10,000 feet in altitude. It is 5 miles long, has a capacity of about 100 second-feet, and cost $90,000. The work was practically all in rock, with but little fluming. In places it was necessary to build a bench of timber to support the lower bank, which is mostly of rock.

The Sky Line ditch takes water from streams so high up that it receives no supply until about the middle of June. The river commissioner estimates the amount delivered in 1895 at 650,000,000 cubic feet, or 14,300 acre-feet. During the season when water is being run the company keeps three men on this short canal to maintain it and to regulate the flow at the head so as to get as much water as possible.



VIEW OF OUTLET CANAL OF LARIMER AND WELD RESERVOIR, WHERE IT GOES OVER THE WEIR INTO THE LARIMER AND WELD CANAL.

As it is 70 miles above the gaging station, the river commissioner can not visit this canal to ascertain how much it is furnishing the river, and must depend upon the reports made by mail three times a week by the party in charge. When it has a full supply it furnishes about 100 feet, but later, by the 1st of September, it sinks to 25 feet. During 1894 and 1895 the water from the Sky Line ditch and that stored in the reservoirs has been practically all the supply the Larimer County Canal has had, and fair crops have been made. The capacity of the canal on the plains is said to be 469 feet, but it is apparent that it has only a sure supply of 100 feet besides the reservoirs, the contents of which are now used before the water from the Sky Line is available.

Since the reservoirs belonging to this canal are filled from it, the water, being at a lower elevation, can not run back and be distributed by means of it. Hence other distributing canals would need to be built and could supply water only to the lower lands. Instead of this, a system of exchange with the river has been adopted through the consent of all parties and in accordance with a ruling by the State engineer. This may be effected either by dropping the water of the reservoirs back into the river for the use of canals below, which are all older, or it may be accomplished by running the reservoir water directly into either the Larimer and Weld or the Cache la Poudre Canal when either is entitled to water. An equal amount is then claimed from the river. Not only do the reservoirs of this canal make this exchange, but also those filled from the Larimer and Weld Canal next below. This receives the river water of the Cache la Poudre Canal, which is just below and also older. This exchange has worked well and is a great saving of expense in construction of distributing canals. It also renders the water available for all the lands that the canal can reach.

The reservoirs of the Larimer County Canal Company have not been very expensive to construct, as but little or no embankments have been made. The conduits from the two principal ones are made of rock, the bottom and cover of large, thick flagstones, with joints filled with cement mortar, and the sides are of rubble masonry laid in cement. The largest two can be filled to 30 feet, and the gates are raised by a screw. Each cost for construction about $10,000 and $2,000 for right of site.

APPROPRIATIONS FROM CACHE LA POUDRE CREEK.

In addition to the three canal systems described above there are in all about 25 other canals and ditches taking water from Cache la Poudre Creek, most of these being relatively small. Without describing these it will be recognized that the apportionment of water among all these canals and ditches must be a matter of extreme difficulty. It is further complicated by the fact that many of these have more than one appropriation, so that although a list of the ditches as given on pages 51–52 shows only 28, there have been up to 1888 as many as 104 separate appropriations of water from Cache la Poudre Creek and its tributaries, these being due to the amount of water claimed at the original construction and by the several enlargements, especially of the older ditches. The matter is fully set forth in the following table taken from the State Engineer's Report for 1888:[1]

Appropriations from Cache la Poudre Creek.

Order of priority in district.	Name of ditch, canal, or reservoir.	Date of appropriation.	Cubic feet of water per second decreed to each priority.	Summation of decree to each ditch, canal, or reservoir.	Cubic feet of water previously appropriated in district.
1	Yeager	June 1, 1860	24.80		
2	Watrous, Whedbee & Secord	June 1, 1861	1.44		24.80
3	Dry Creek	June 10, 1861	11.67		26.24
4	Pleasant Valley and Lake	Sept. 1, 1861	10.97		37.91
5	Pioneer	Mar. 1, 1862	12.92		48.88
6	Boyd & Freeman	Mar. 15, 1862	66.05		61.80
7	Whitney	Sept. 1, 1862	48.23		127.85
8	Yeager (upper branch), first enlargement	June 1, 1863	8.70	33.50	176.08
9	B. H. Eaton	Apr. 1, 1864	29.10		184.78
10	Larimer and Weld	June 1, 1864	3.00		213.88
11	Pleasant Valley and Lake, first enlargement	June 10, 1864	29.63	40.60	216.88
12	Pioneer, first enlargement	Sept. 15, 1864	16.67	29.59	246.51
13	John G. Coy	Apr. 10, 1865	31.63		263.18
14	John R. Brown	May 1, 1865	8.00		294.81
15	Box Elder	Mar. 1, 1866	32.50		302.81
16	Chamberlin	Apr. 1, 1866	14.83		335.31
17	Taylor & Gill	Apr. 15, 1866	18.48		350.14
18	B. H. Eaton, first enl	June 1, 1866	3.33	32.43	368.62
19	Watrous, Whedbee & Secord, first enlargement	July 1, 1866	4.33	5.77	371.95
20	Boyd & Freeman, first enl	July 15, 1866	9.00	75.05	376.28
21	Larimer and Weld, first enl	Apr. 1, 1867	16.67	19.67	385.28
22	Mason & Hottell mill race	Apr. 15, 1867	93.07		401.95
23	Box Elder, first enl	May 25, 1867	8.33	40.83	495.02
24	Wm. R. Jones	Sept. 1, 1867	15.52		503.35
25	Josh Ames	Oct. 1, 1867	35.92		518.87
26	Martin Calloway *a*	Mar. 1, 1868	15.22		554.79

[1] Fourth Biennial Report of the State Engineer of Colorado for the years 1887 and 1888, pp. 148, 149, 150.

a Takes water from Boxelder Creek.

VIEW OF LARIMER AND WELD CANAL AT THE LAKE LEE GATES.

Appropriations from Cache la Poudre Creek—Continued.

Order of priority in district.	Name of ditch, canal, or reservoir.	Date of appropriation.	Cubic feet of water per second decreed to each priority.	Summation of decree to each ditch, canal, or reservoir.	Cubic feet of water previously appropriated in district.
27	Noah and Philo Bristol (lower) *a*	Mar. 10, 1868	15.22	....	570.01
28	Cañon Canal Co	Mar. 15, 1868	8.60	....	585.23
29	Watrous, Whedbee & Secord, second enl	June 1, 1868	4.33	10.10	593.83
30	Box Elder, second enl	July 1, 1868	11.93	52.76	598.16
31	Irrigating Ditch Co	May 1, 1869	60.08	....	610.09
32	Fort Collins	June 1, 1869	1.67	....	672.17
33	New Mercer Ditch Co	Sept. 1, 1869	4.17	....	673.84
34	Noah and Philo Bristol (upper) *a*	Mar. 1, 1870	14.83	....	678.01
35	Canal No. 3, Union Colony	Apr. 1, 1870	52.00	....	692.84
36	Dry Creek, first enl	Oct. 21, 1870	14.42	26.09	744.84
37	Cache la Poudre Co	Oct. 25, 1870	110.00	....	759.26
38	Fort Collins Irrigating, first enlargement	Apr. 1, 1871	31.66	33.33	869.26
39	Burnham & Emerson *b*	do	26	....	900.92
40	Wm. Calloway No. 1 *c*	May 1, 1871	21.05	....	926.92
41	Mill Power	July 1, 1871	160	....	947.97
42	Fletcher	Sept. 1, 1871	63.16	....	1,107.97
43	Whitney, first enl	Sept. 10. 1871	12.95	61.18	1,171.13
44	Cache la Poudre Co., first enlargement	Sept. 15, 1871	170	280	1,184.08
45	Larimer and Weld, second enlargement	Sept. 20, 1871	75	94.67	1,354.08
46	Canal No. 3, first enl	Oct. 1, 1871	41	93	1,429.08
47	New Mercer Ditch Co., first enlargement	Oct. 10, 1871	8.33	12.50	1,470.08
48	Chaffee Irrigating	Mar. 15, 1872	22.38	....	1,478.41
49	New Mercer Ditch Co., second enlargement	July 1, 1872	15	27.50	1,500.79
50	Canal No. 3, second enl	July 15, 1872	63.13	156.13	1,515.79
51	Pleasant Valley and Lake, second enlargement	July 19, 1872	16.50	57.10	1,578.92
52	Fort Collins Irrigating, second enlargement	July 20, 1872	33.33	66.66	1,595.42
53	B. H. Eaton, second enl	July 25, 1872	9.26	41.69	1,628.75

a Takes water from Boxelder Creek.
b Takes water from Lone Pine Creek.
c Takes water from north fork of Cache la Poudre Creek.

Appropriations from Cache la Poudre Creek—Continued.

Order of priority in district.	Name of ditch, canal, or reservoir.	Date of appropriation.	Cubic feet of water per second decreed to each priority.	Summation of decree to each ditch, canal, or reservoir.	Cubic feet of water previously appropriated in district.
54	Lake Canal	Nov. 1, 1872	158.35		1,638.01
55	Wm. S. Taylor	Mar. 15, 1873	28.60		1,796.36
56	Cañon Canal Co., first enl	Mar. 20, 1873	48.88	57.48	1,824.96
57	Larimer County Canal, No. 2	Apr. 1, 1873	175		1,873.84
58	Irrigating Ditch, first enl	May 1, 1873	20.42	82.50	2,048.84
59	Canal No. 3, third enl	May 15, 1873	16.65	172.80	2,069.26
60	Aquilla Morgan *a*	July 1, 1873	17.65		2,085.91
61	Brown No. 1 *b*	do	9.38		2,103.56
62	Boyd & Freeman, second enlargement	Aug. 1, 1873	24.23	99.28	2,112.94
63	Brown No. 2 *b*	Aug. 15, 1873	3.32		2,137.17
64	Strudevant No. 1 *c*	do	10.66		2,140.49
65	Strudevant No. 2 *c*	Aug. 20, 1873	10.66		2,151.15
66	Fort Collins Irrigating Ditch, third enl	Sept. 1, 1873	63.28	129.94	2,161.81
67	Dry Creek, second enl	Sept. 15, 1873	12.13	38.22	2,225.09
68	Vandewark	May 1, 1874	10.17		2,237.22
69	Brown No. 3 *b*	May 15, 1874	3.32		2,247,39
70	Mitchell & Weymouth No. 1 *d*	do	17.35		2,250.71
71	Andrew Boyd et al. *b*	Nov. 1, 1874	15.03		2,268.06
72	Cache la Poudre Co. Canal, second enlargement	Nov. 10, 1874	184	464	2,283.09
73	Larimer & Weld, third enlargement	Jan. 15, 1875	54.33	149	2,467.09
74	Wm. Calloway No. 2 *a*	Jan. 28, 1875	14.16		2,521.42
75	Witzler et al. *d*	Mar. 22, 1875	10.36		2,535.58
76	Warren Lake Reservoir (see. 56)	Apr. 15, 1875			
77	Brown, No. 4 *a*	May 1, 1875	6.72		2,545.94
78	Kitchel & Ladd	Oct. 1, 1875	2.95		2,552.66
79	Brown, No. 5 *a*	June 1, 1876	6.72		2,555.61
80	Brown, No. 6 *a*	do	6.72		2,562.33
81	Witzler et al., first enl. *d*	Mar. 1, 1877	3	13.36	2,569.05
82	Brown, No. 7 *a*	June 1, 1877	2.85		2,572.05

a Takes water from north fork of Cache la Poudre Creek.
b Takes water from Fish Creek.
c Takes water from Boxelder Creek.
d Takes water fro mLone Pine Creek.

VIEW OF OUTLET OF WINDSOR RESERVOIR FROM THE INSIDE.

Appropriations from Cache la Poudre Creek—Continued.

Order of priority in district.	Name of ditch, canal, or reservoir.	Date of appropriation.	Cubic feet of water per second decreed to each priority.	Summation of decree to each ditch, canal, or reservoir.	Cubic feet of water previously appropriated in district.
83	Cache la Poudre Co.'s, third enlargement	Sept. 15, 1877	121	585	2,574.90
84	Henry Smith	Apr. 1, 1878	7.23		2,695.90
85	Abram Washburn, No. 1	Apr. 15, 1878	9.57		2,703.13
86	Roberts, No. 1 *a*	do	5.76		2,712.70
87	Boxelder Reservoir Co. *b*	June 18, 1878	17.50		2,718.37
88	Larimer and Weld, fourth enlargement	Sept. —, 1878	571	720	2,735.87
89	Carter Cotton mill race	Apr. 1, 1879	127.30		3,306.87
90	Abram Washburn, No. 2	Apr. 15, 1879	15.43		3,434.17
91	Dry Creek, third enl	July 15, 1879	12.70	50.92	3,449.60
92	Pleasant Valley and Lake, third enlargement	Aug. 18, 1879	80.83	137.93	3,462.30
93	John McKay et al. *a*	Sept. 1, 1879	3.40		3,543.13
94	Fisk, No. 2 *a*	Dec. 1, 1879	10.28		3,546.53
95	Carter Cotton mill race, first enlargement	Dec. 31, 1879	37.17	164.47	3,556.81
96	Mitchell & Weymouth, No. 2 *c*	Jan. 19, 1880	16.27		3,593.98
97	North Poudre Land, Canal and Res. Co. *a*	Feb. 1, 1880	315		3,610.25
98	New Mercer Ditch Co., third enlargement	Feb. 15, 1880	136	163.50	3,925.25
99	Chase *a*	July 7, 1880	21.40		4,061.25
100	Larimer County	Apr. 25, 1881	469.80		4,082.65
101	Eagle Ranch *a*	Oct. 1, 1881	5.02		4,552.45
102	Pleasant Valley and Lake, fourth enlargement	Oct. 10, 1881			
103	Emerson Bros. *c*	Apr. 15, 1882	29.88		4,602.65
104	Roberts, No. 1, first enl *a*	Sept. 1, 1882	*d*4.09		4,632.53

a Takes water from north fork of Cache la Poudre Creek.
b Takes water from Boxelder Creek.
c Takes water from Lone Pine Creek.
d Up to 1897 only two changes have been made in this table. The first is in the reduction of No. 1, Yeager Ditch, from 24.80 cubic feet per second to 3 cubic feet per second. The second is a change in the order of priorities, by which No. 100, Larimer County Canal, becomes 97 and old 97, 98, and 99, become, respectively, 98, 99, and 100.

The above table is worthy of especial notice, since it is the guide for the district water commissioner in his distribution of water. When an earlier appropriator of water has less at his head gate than he needs, and when he believes that some later appropriator farther up the stream is getting water to which he deems himself entitled, he notifies the water commissioner, usually by telephone, of the situation, and if the commissioner deems his complaint well grounded, No. 104 is shut off, then 103, and so on up the list until the deficiency is remedied.

It will be seen that some of the canals have several enlargements, each of which stands upon its date of construction, as decreed by the district court. Cache la Poudre Company's Canal—original name, No. 2, of Union Colony—is an example. The original construction, No. 37, dates back to October 25, 1870. It is credited with a capacity of 110 second-feet, but there were 36 claims on the river preceding it, demanding in the aggregate 759.26 second-feet. The first enlargement, No. 44, dates from September 15, 1871, and is credited with 170 second-feet, which at that date made its total capacity 280 second-feet. At that time 43 claims preceded it, with an allowance of 1,184.08 second-feet. The second enlargement, No. 72, dates from November 10, 1874, and is credited with 184 second-feet, making in all 464 second-feet. This enlargement is preceded by claims for 2,283.09 second-feet. The third enlargement, No. 83, dates from September 15, 1877, and calls for 121 second-feet, making in all 585 second-feet, being preceded by claims for 2,574.90 second-feet.

The capacity of the river is such that if all these claims were valid there would be scarcely enough water to allow this canal its last appropriation, much less the Larimer and Weld for its fourth enlargement, No. 88, or 571 second-feet, its principal appropriation, but which is preceded by claims for 2,735.87 second-feet, which exceeds even the average June supply for every year on record excepting 1883, 1884, and 1885.

The third irrigating system in point of size is the Larimer County Canal. It is appropriation No. 100, and the canals preceding it call for 4,082.65 second-feet, a volume to which the river rarely ever rises, and which has been exceeded only in June 1883 and 1884.

To illustrate how excessive is the rating of these older ditches, take the Boyd and Freeman Ditch. It stands No. 6 on its original construction, and is granted 66.05 second-feet, dating March 15, 1862, or eight years before the settlement of Union Colony at Greeley. By reference to the table it may be seen that this ditch claims only 900 acres under it, mostly grass. This would give a duty of only 13.7 acres per cubic foot per second, even if it claimed only its first appropriation. In addition to this, however, it has two enlargements, bringing its claims up to 99.28 second-feet, or a duty of only 9 acres per second-foot. This matter is further discussed at length in the reports of the State engineer, notably in the Sixth Biennial Report, for 1891 and 1892, pages 13 to 17.

ANOTHER VIEW OF SKY LINE CANAL.

EXTRAVAGANT CLAIMS TO WATER.

This excessive adjudication was obtained largely by false testimony or was due to the ignorance of the witnesses, not even those who pretended to be engineers being able to compute the probable capacity of a canal from its slope and sectional area. Where formulas were used they were not applicable to small, crooked, poorly constructed ditches, such as were the early ones. Had there been water running in the river at the time the referee of the court took the testimony, the actual size of the ditches could have been approximated somewhat more closely; but it was late in the autumn of 1879 when this was being done, and the river was very low at the time. Moreover, there was no attempt made by the referee to have the ditches measured. This could have been done in the case of the smaller ones, which were also the ones whose capacity were the most excessively estimated. How much the capacity of the canals exceeds the supply can be seen by comparing the above decreed allowance with the table of estimated mean monthly flow given on page 27.

CACHE LA POUDRE CREEK.

When, in 1870, the Union Colony settled in the lower end of the valley and founded the town of Greeley, there were only about 1,000 acres in cultivation, all upon the bottom lands near the river, but the small canals then constructed claimed and had awarded them as appropriated 692.84 second-feet. There were in all some 23 small ditches taken out of Cache la Poudre Creek before 1870. If from this number are taken 4 small canals that were afterwards enlarged and at this time claimed only 42 second-feet, it is found that the 19 remaining ditches had under them in crops, according to the report of the State engineer for 1888, only 5,660 acres. To water this area they had at this latter date claims awarded them to the amount of 650 second-feet, or a cubic foot for every 10 acres. However, a provision in each decree restrains each ditch to so much of the quantity awarded as is needed for beneficial use and prohibits all waste. There are only 9 canals shown in the State engineer's report for 1894 that have records of the water taken in at their head gates for that year. These had crops to the extent of 106,000 acres, while the remaining 19 had only about 10,000 acres under crops. The fact is that by means of the irrigation of the uplands under the later larger canals, the lands under these lower canals, for the most part, need no water, but are, on the contrary, in many instances transformed into swamps.

There has been an opinion prevalent among the owners of the bottom-land canals that they, in some way, owned the water awarded by the court to their ditches which they could sell to other ditches when they did not need to use it where originally located. Moreover, if they did not need all of the water, or if, in fact, their ditches could not carry it, the owners thought that they had a right to sell or transfer the remainder to such persons or places as they might find convenient. While there might be some justice in allowing a person whose land was ruined by the irrigation of the uplands a right to use as much water as he had actually used upon these lands through some other canal, it would have been ruinous to later canals to allow a transfer of the excessive quantities erroneously decreed to the earlier. This situation is now well understood, and later decrees by the courts in other districts base grants to water to a canal only to the extent that it is proved that the water has been applied. These excessive claims allowed by the courts affect every district in the division of the Platte, and are even more extravagant in others than in Cache la Poudre district; so the people of Greeley engaged an attorney to cross-question witnesses and restrict claims as much as possible.

CONSERVATION OF WATER SUPPLY.

From a consideration of the appropriations of water from Cache la Poudre and a comparison of these with the amount actually flowing at the upper end of the valley, it is evident that there must be a deficiency in ordinary years. In years of scarcity the lands under all but the oldest canals do not have sufficient water to enable them to make a full crop. This is demonstrated by the fact that in 1894 the crops under all the later canals were more than double those of the averages of the preceding five years, these being periods of less than average flow. Even in 1894 the lands under the older canals, having all the water needed, produced better than those more stinted. This is shown by a comparison of the lands under the three largest canals of the valley. These are shown in the following table in the order of priority of appropriations:

Name.	Total area in crop.	Quantity of water.	Depth.
	Acres.	*Acre-feet.*	*Feet.*
Cache la Poudre Irrigation Company's canal	22,045	70,610	3.2
Larimer and Weld Canal	44,384	77,225	1.7
Larimer County Ditch	16,714	27,830	1.66

It is shown that the acreage under the first is about half that under the second, and, as can be seen from the table on page 52, there was half as much wheat, about as much oats, more than half as much barley and corn, and more potatoes. The latter is the most important crop, one-fourth of the land cultivated under each of these two canals being in potatoes. The showing under the Larimer County Ditch was still worse, as it had more than two-thirds as much land as the first under crops, while it had less than two-thirds as much wheat, less than one-third as much oats, a trifle more than its ratio of barley, but less than one-fifth as many potatoes.

These three canals, it will be seen, have under them about two-thirds of all the land in the valley. The rated capacities of these canals, for which the court has issued decrees, are 580, 720, and 480, the sum being 1,780 cubic feet per second. The total claimed by canals in this district at the end of 1888 and for which decrees had been granted them by the court, as shown on page 47, was 4,632.53 second-feet; that is, three canals have set apart to them by appropriation, as the decrees of the court stand, only about 38.4 per cent of the flow of the stream, while they have 66.6 per cent of the land irrigated. Many of the smaller ditches never could carry the quantities which were granted them by decree of the district court, and if they could carry them, they could not possibly use them.

CROP AREA.

The following table gives the crop statistics of Cache la Poudre Valley as obtained from a house-to-house canvass of the entire district.[1] Although absolute accuracy is not attainable in such matters, it is more nearly complete than anything of the kind that has been heretofore attempted in this State. There is also appended in the right-hand column a statement of the water received in 1894 by the nine principal canals, these being the only ones concerning whose intake a record was kept by the district commissioner:

Crop statistics in district No. 3—1894.

Name of canal or ditch.	Total.	Alfalfa.	Other grass.	Other crops.	Pasture and waste.	Wheat.	Oats.	Barley.	Corn.	Potatoes.	Fruit.	Water used.
	Acres.	*Acres*	*Acres*	*Acres*	*Acres*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Sacks.*	*Acres*	*Acreft.*
North Poudre	11,149	843	795	2,430	7,081	41,731	20,102	1,793	3,775	5,687	3	18,306
Larimer County	27,844	4,010	......	12,847	11,131	89,774	23,855	7,209	4,075	113,795	35¾	27,803
Larimer and Weld	59,507	7,428	878	32,182	15,123	283,998	89,004	17,599	6,702	554,303	53¾	77,225
Pleasant Valley and Lake	8,221	1,750	470	2,234	3,110	7,338	11,578	830	1,972	3,655	123	17,387
New Mercer	4,256	1,664	174	1,020	1,867	17,999	21,941	8,075	2,032	13,448	101½	11,110
Larimer County, No. 2	8,623	2,751	61	2,680	985	34,881	14,190	7,120	280	10,389	70¾	18,545
Fort Collins	1,179	492	45	387	374	720	799	425	65	860	33	......
Dry Creek	3,160	1,131	223	453	991	1,989	3,257	......	......	350	41¾	7,984
Little Cache la Poudre	1,300	567	61	642	204	1,544	2,033	......	......	1,420	24½	......
Taylor & Gill	464	159	9	174	164	......	300	175	100	1,350	28½	......
John R. Brown	290	60	75	70	85	......	490	......	......	......	5	......
From seepage	......	62	115	433	450	2,700	6,245	2,435	1,530	8,050	4	......
Cañon	497	160	5	90	197	250	120	57	300	500	5	......

[1] Seventh Biennial Report of the State Engineer of Colorado, for the years 1893 and 1894, p. 22.

Crop statistics in district No. 3—1894—Continued.

Name of canal or ditch.	Total.	Alfalfa.	Other grass.	Other crops.	Pasture and waste.	Wheat.	Oats.	Barley.	Corn.	Potatoes.	Fruit.	Water used.
	Acres.	*Acres*	*Acres*	*Acres*	*Acres*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Sacks.*	*Acres*	*Acreft.*
Watrous, Wheedbe & Secord	120	20	......	25	75	......	......	......	......	600	......	......
Box Elder and Res. Co.'s	1,280	50	......	100	1,000	900	300	......	25	200	......	......
Josh Ames	460	24	50	110	276	1,600	516	1,100	150	1,400	......	......
City	26	3	......	3	20	......	......	......	......	......	......	......
Lake	6,242	1,007	156	1,762	2,076	19,900	15,516	1,282	3,855	23,280	10½	11,262
John G. Coy	300	60	80	45	115	260	240	......	75	620	......	......
Pioneer	682	260	50	55	442	240	1,700	......	......	1,000	2	......
Box Elder	1,735	270	144	351	1,028	1,077	1,467	634	95	3,184	......	......
Cache la Poudre Irr. Co.'s	33,173	5,032	704	15,065	11,128	144,224	82,628	9,837	3,670	602,485	42½	70,610
Whitney	2,080	358	55	652	683	4,410	6,051	......	100	17,500	3¾	......
B. H. Eaton	......	......	......	......	......	......	......	......	......	......	......	......
Cache la Poudre Irr. Co.'s, No. 3	1,275	147	103	517	480	1,875	1,140	......	......	14,652	......	......
Wm. R. Jones	360	75	119	135	149	300	1,600	......	250	2,240	1	......
Boyd & Freeman	900	90	350	300	158	......	1,575	1,575	300	7,000	2	......
Ogilvy	3,800	720	......	1,357	1,728	13,290	7,465	......	......	29,660	......	......
Total	178,923	29,193	4,722	76,119	61,120	671,000	314,112	60,146	29,351	1,417,628	591¼	260,232

From the above table it will be noted that there are 61,120 acres recorded as waste and pasture land. Parts of this, perhaps not more than 2,000 acres, are above the levels of the canals, but the larger proportion is near the river and is kept so wet by the irrigation of the uplands that it needs no further application of water. Much of it has changed into cat-tail and rush-bearing swamps. This is true of certain basins and valleys among the uplands. Some of these basins have been utilized as reservoir sites. These are chiefly found in the upper end of the valley, on the north side. The surface of the country here is quite rolling. The soil is a somewhat stiff clay, resting upon a soft argillaceous shale which rises to near the brim of these basins, and thus renders them nearly water-tight.

Nearly all the land under cultivation, that is, under canals, is on the north side of the river, the only exception being a small area of about 12,000 acres near Fort Collins. The reason is that below the point where the canals on the south side are seen to terminate the level of the land rises abruptly from the first bottom of the river to a height of from 50 to 100 feet. Near Greeley the bluffs lower and enable a small area in and near the town to be brought under a canal taken from Cache la Poudre Creek about 6 miles above the place. The hilly region to the south and west of Greeley is irrigated by the Loveland and Greeley Canal, which takes its water from Big Thompson Creek, the next tributary of the Platte above Cache la Poudre Creek.

AMOUNT OF WATER USED.

The mountain watershed of Cache la Poudre Creek above the gaging station is about 1,060 square miles, or 678,400 acres. The area actually irrigated by the water which passes this point was computed by Prof. L. G. Carpenter to be 135,000 acres,[1] this being less than one-fourth of the extent of the mountain gathering ground. The total discharge as measured by the intake of the canals in 1894 during the irrigating season is computed by Professor Carpenter at 284,000 acre-feet. This would give a depth of run-off for that period of about four-tenths of a foot for the mountain watershed. This was a year of far more than average flow. It has been stated that the average for the four years ending 1892 was 227,302 acre-feet, which would give a depth of yearly run-off of about one-third of a foot.

The average discharge of all of the tributaries of South Platte River for the five winter months—November to March, inclusive—for four years, as given by the reports of the State engineer, was 472 second-feet, or 141,364 acre-feet. As irrigation is carried on during the other seven months, this amount is all that was available for storage except during times of flood.

The discharge of Cache la Poudre Creek for the five winter months was, from an average of these four years, 24,858 acre-feet, a quantity much exceeded by the capacity of reservoirs now constructed. The total average flow of the tributaries of Platte River for the other seven months is approximately 1,900 cubic feet per second, which for 213 days would be 34,966,000,000 cubic feet, or 769,252 acre-feet. The average for Cache la Poudre Creek for same months of the four years is about 500 cubic feet per second, or 9,202,000,000 cubic feet, or 202,444 acre-feet.

The area irrigated in 1892, as given in the engineer's report for the Platte division, was 678,620 acres, while in Cache la Poudre district it was 162,239 acres for the same year. This would give a depth of 1.13 feet over the area of the division of the Platte and of 1.24 feet for the Cache la Poudre district from the water received through the canyons of the respective streams. To this must be added the amount received from return seepage, or "underflow," which is used within the Platte division. The greater portion of the return from irrigation of Cache la Poudre district is also used within that district. As nearly as can be estimated, the return at that time was, for the whole division, about 1,000 second-feet, while that used in Cache la Poudre district is about 100 second-feet. This, added to the depths, respectively, would give for the division a depth of 1.70 feet of water applied, and for the Cache la Poudre district 1.49 feet.

The water flow during the four years under consideration, namely, 1889–1892, was below the average. The amount of water taken into

[1] Colorado Experiment Station Bulletin No. 22, January, 1893, p. 24.

all the canals during the irrigation season of 1894 in Cache la Poudre district, as measured by the commissioner of the district, was 260,232 acre-feet. If the same number of acres are considered as irrigated as in the other period, these results for 1894 give a depth of 1.70 feet. If, however, the area stated to be under crops in the report of the commissioner is taken, including in this meadows and alfalfa fields and rejecting that included under the heading "Waste and pasture lands," which are scarcely at all irrigated, it is found that the water received by the canals would have covered the land to the depth of 2.45 feet. This leaves out of account the waste by evaporation and percolation from some 332 miles of main canals and several times that length of laterals, which would be not less than 20 per cent. This amount, subtracted from the above, gives a depth of 1.96 feet.

QUANTITY AVAILABLE FOR STORAGE.

It has been found that the average flow through the canyon for the five months from November to March is about 84 second-feet. If to this is added the return underflow between the gaging station at the canyon and the head of the canal that feeds Cache la Poudre reservoir, there will be had the total winter water available for storage.

The shrinkage in return underflow during the winter, when the lands draining into the Poudre are not being irrigated, is greater in the upper end of the valley, between Fort Collins and the gaging station, than between Fort Collins and the mouth of Cache la Poudre Creek on account of the narrowness of the upper irrigated belt compared with the lower. In other words, the return underflow will be more constant in proportion to the width of the belt irrigated, since lands adjacent to the stream soon drain back into it all their surplus water when the source of this is cut off.

The average gain from the canyon down to Fort Collins, as shown by the two autumn seepage measurements of 1893 and 1894, was 28 second-feet, and by that of March, 1894, was 5 second-feet. The mean of these gives a little over 16 second-feet, which can be added to the winter flow through the canyon of 84 second-feet.[1] This gives an average total for storage purposes of 100 feet. All the underflow below this, out of the irrigation season, goes into the Platte and is not now stored, nor can it be stored for use on the lands of Cache la Poudre Valley. Suitable basins are found below on the north side of the Platte, in which can be stored the winter waste of the Platte and all its tributaries. These basins have been surveyed and articles of incorporation filed for their construction, but the enterprise is supposed to involve the expenditure of a million and a half dollars, and the capital to push it through is not yet forthcoming.

[1] Colorado Agricultural Experimental Station Bulletin No. 33. Seepage or return waters from irrigation, by L. G. Carpenter, pp. 20-22. Jan., 1896.

The total average winter supply of Cache la Poudre Creek for storage in reservoirs, all of which are now adjuncts of the four largest canals, may therefore be set down at 100 feet per second for 150 days, 1,296,000,000 cubic feet, or 29,750 acre-feet. Those under the North Fork canal do not come under this estimation, as the water they have been storing comes from that tributary above the gaging station.

The reservoirs of the Larimer County Canal claim 458,000,000 cubic feet, the two largest ones of the Larimer and Weld 900,000,000, and the Cache la Poudre Reservoir claims 368,000,000, making in all 1,726,000,000 cubic feet, and if this be reduced 30 per cent for overestimation, we have a corrected capacity of 1,208,000,000 cubic feet, or 88,000,000 cubic feet less than the average available winter supply. But this does not take into account evaporation and percolation that are taking place the year round from the reservoirs. The five main reservoirs have an average water surface for the year of about 1,200 acres, the minimum being about 300 acres and the maximum 2,100. The evaporation from a water surface in this climate is found to be about 6 feet deep. This would give a loss from the surface of the reservoirs of 7,200 acre-feet, or 313,000,000 cubic feet.

The extent of percolation can be estimated with much less certainty; but from the character of the sites of all the storage basins, save that of the Cache la Poudre Reservoir, it can not be great, since they are underlain by an impervious shale rock which also rises to form their rims. A tenacious clay overlies this rock, and hence it would appear that percolation would be small except through the artificial embankment, where it may be large; but that part of the escaping water which gets into the channel of the outlet canal is inconsiderable. If the percolation from these reservoir sites, estimated at 2,000 acres, was equal to that through the surface of the irrigated land of the valley, it would amount to 2 feet per second, or to 63,000,000 cubic feet for the year. It is quite likely that it is as much as this owing to the great pressure during that part of the year in which the reservoirs are well filled, and the average for each reservoir would be only two-fifths foot per second. This would make a total waste of 376,000,000 cubic feet, which is 288,000,000 cubic feet more than the river's estimated surplus. From the above estimates it is apparent that the average winter flow that can be utilized by the large reservoirs is inadequate to their needs. Besides this, it is not desirable, as a rule, to completely fill the reservoirs before the storms set in, as the spring winds drive heavy waves against the lower embankments, they being situated in the direction opposed to the prevailing northwest storms.

RESERVOIRS.

Besides the reservoirs mentioned there are a number of small ones, especially under the Larimer and Weld and the Cache la Poudre canals. Under the former the claimed storage capacity is about 175,000,000 cubic feet, and under the latter about 110,000,000 cubic feet. These reservoirs are used by one or more parties for storing the water from the canals when it is not needed, and to catch as much as possible when water is plenty. They have no independent means of drawing directly from the rivers. A number of reservoirs are in use, and more are projected that will obtain their supply from seepage water. One very large concern, the corporate name of which is the Windsor Reservoir and Canal Company, proposes to store 510,000,000 cubic feet in two reservoirs filled entirely from a ditch cut through a swamp made by irrigation.

Nearly all the reservoirs are connected with the four principal canals of the north side and are on the upper end of the canals. It happens that there is a series of depressions or basins naturally suited for this purpose in that part of the valley where they can be of most use. Farther east the land slopes gradually to the southeast or in the general direction of the dry creeks outlined on the map (fig. 2). In this lower end of the irrigated area the soil, though deep, is underlain by a heavy body of gravel, which gives good drainage and prevents waterlogging. Such a formation would be very undesirable under a reservoir, since, if not puddled, it would allow the water to waste by percolation.

In the reservoir region the soil, which is a stiff clay, lies directly on argillaceous shale. About 7 miles north of the river, near the lower end of the valley and on the ridges between the valleys of the dry creeks, the Laramie coal-bearing formation is found, and it extends thence northwest of Eaton, at which place alone it is mined. The depth to the coal is about 75 feet through clay, for the most part, the coal having a shale roof. The formation is dry here, but to the west is wet by the extensive irrigation practiced above.

The basins which have been utilized as reservoirs appear to have been formed by flexures or faults in the strata, and not by erosion, since in cutting the outlets the rock is found in the lower edge of the rim higher than it is toward the center of the basin. This rock is practically impervious to water. When the rock is wet, the water takes a lateral course over its upper layer, the clay next to it becoming quite soft and even disposed to slough off where a cut is made. This is the weak place in the structure of reservoirs on these sites, and has caused alarm on the part of people living under them.

There are now more reservoirs in the valley than can be filled with the available water. As a consequence the owners are asking that laws be passed fixing more definitely the time of year when water may be stored in preference to being used for irrigation. The regulations now require that water companies keep their canals running for the use of consumers from April 1 to November 1, except during the time taken for necessary cleaning and repairs. The reservoir law provides that any person shall have the right to take from natural streams of the State and store away unappropriated water not needed for immediate use, for domestic use, or for irrigating purposes. The general theory is that when growing crops need water for irrigation the person having such crops has a right to it superior to those wishing to store it for future use, even though the works constructed for storage purposes antedate the canal supplying such growing crops.

The superior rights for immediate irrigation is supposed to exist especially during the seven months that canals are required to be kept running, even though the water is being used only for moistening the soil for the mechanical purpose of enabling it to be more easily plowed or for storing up moisture for next year's use. The owners of a canal that has no reservoir constructed on purpose to store water for its use in times when it is not needed for irrigation may well claim that the soil on their farms answers such a purpose, and that they have as good a right to run water onto these farms whenever they can as the owners of canals with reservoirs have to run it into the latter. These parties insist that the only time when they can be prohibited from using water is the one in which nature withholds it from them, namely, when it freezes so hard that they can not run it onto the land. This time differs so much in different localities of the State and is also so dependent on the character and situation of the works of diversion that it precludes any rules being laid down by the legislature.

If the canals now having reservoirs were without them, they would have a prior claim for use of the water after the crops were grown (provided they had a prior right for the irrigation of growing crops), and the fact that they have built reservoirs to store the water at times when it is not needed for growing crops should not, in the judgment of the writer, impair their rights to store the water instead of using it on the soil which is to play in part the purpose of a reservoir.

If such were the rule, every canal's right to water for storage for future use would have the same date as the rights of the canals of which they are adjuncts. The rule, however, is that reservoirs have prior rights to water for storage among themselves according to date of filing claims with the State engineer, provided the work be prosecuted with due diligence, irrespective of the claims of the canals to which they are adjuncts.

All the reservoirs in the Poudre Valley are adjuncts of some canal previously built, and are constructed to furnish such canals at times of scarcity in the river during the season that growing crops need irrigation. This is usually in the latter part of the season and for the potato crop, which is grown extensively, especially in the lower end of the valley. The quantity of water available for this purpose is, as above stated, now exceeded by the capacities of the reservoirs, and parties are in court disputing one another's claims. It appears more likely that the courts will work out some generally recognized rule than that the legislature will be able to pass any law of general application, since the different irrigation localities hold diverse views and, indeed, have diverse conditions to be satisfied.

NORTH POUDRE LAND, CANAL, AND RESERVOIR COMPANY.

The North Poudre or uppermost of the canals, though among the latest in construction—its appropriation being No. 97 in the district—was the first to avail itself of reservoirs. The necessity for storing water which could not be used in the irrigation season early pressed itself upon the attention of the proprietors, not only because this canal was among the latest to appropriate water, but because the North Fork, from which it takes its supply, does not head back so far in the Snowy Range as do the other branches of the Poudre, and hence its water supply fails or becomes low early in the irrigation season. With perhaps the exception of the Larimer County Canal, these reservoirs are of more vital importance than those of any other canal in the district.

The number of reservoirs recorded in the reports of the State engineer up to 1894 is four. The date of the filing of these is December, 1891, but it is claimed that work was begun in 1883, and contention is made that priority dates from the commencement of work rather than from the date of filing claim, provided the work has been prosecuted with due diligence and the water applied to beneficial use within a reasonable time. This question is still in the courts, but reasoning from the position taken in regard to canals, it may be inferred that the contention will be sustained. Without these reservoirs the canal would be worthless.

The quantity claimed for these four reservoirs is 330,000,000 cubic feet, or 7,260 acre-feet. The proprietors of the canal report, in all, 12 reservoirs, with a united capacity of 800,000,000 cubic feet, or 17,600 acre-feet; but these later claims come after those of other important reservoirs, which may exhaust the supply available for storage.

A dam of considerable elevation was required at the point of diversion from the stream to raise the water into the head of the canal. This structure was made of timbers and loose rock, both obtained close by, and has proved so far safe and durable, in spite of the fact that the engineer, Patrick O'Meara, had but little faith in so loose a structure, built in part of perishable material. At its head the canal has also about a mile of fluming, a large portion of which rests on the rock prepared for it along the edge of the mountain. This flume has recently been replaced, and has needed much repairing. The dam and upper part of the flume are shown in the accompanying view (Pl. XV).

VIEW OF DIVERSION DAM OF NORTH POUDRE CANAL.

In proportion to its capacity, this canal is the most expensive in the district, having some tunneling besides the fluming. The cost is said to have been $150,000, which probably includes some work on the reservoirs. This latter was mostly done by the "Hartford Trust and Loan Company," behind which stands the "Travellers' Insurance Company." This company furnished most of the funds, and soon came in possession of the work and the land under it, which is said to be 16,000 acres. The company has found it a most expensive investment. It is stated that for the twelve years the net expenditure over income has been at least $10,000 per annum, this including the work done on the reservoirs. The flumes rebuilt under the direction of Engineer J. C. Ulrich are said to be models in this line of construction. One of these[1] is 2,200 feet long and 25 feet wide at the upper end, gradually tapering to 15 feet at the place where the water acquires its maximum velocity. The side planks are bolted, instead of being nailed to posts, and at the lower end the flume is

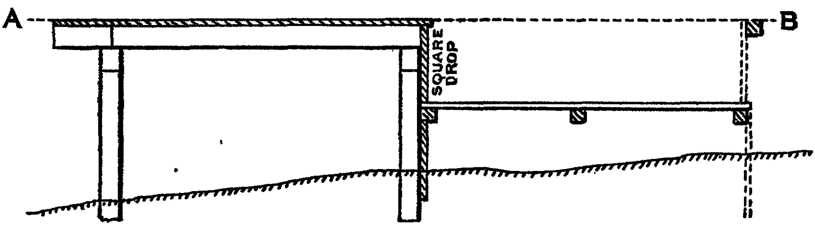


FIG. 7.—Vertical section of drop on North Poudre Canal. A B, line of canal.

given a perpendicular drop to guard against moving out, a tendency in flumes ending on the level with the canal below them. This ending of the flume is illustrated by fig. 7. In the new flumes all the lumber used is well seasoned and tarred, and this, in the opinion of the engineer, will much increase its durability.

The outlets of the reservoirs are deemed among the best in the State. They consist of iron pipes laid in Portland cement masonry and closed at the lower end by means of waterworks valves. In the larger reservoirs two pipes instead of one are used, to secure the easier operation of the valves. The fact that the means of opening and discharging the reservoir are at the lower end of the conduit pipes, and hence not covered by the water of the reservoir, as they are when either at the upper end or in the middle, is a great convenience and guards against numerous difficulties that attend operating under water. In the case of the North Fork Canal reservoir system a small discharge from each of its reservoirs into the canal will compensate for want of ample discharge in each separately.

[1] Annual Report of Am. Society of Irrigation Engineers, 1893, p. 188.

EXCHANGES OF WATER.

Besides the cases above mentioned, other friendly exchanges are made by the canals and reservoirs of different companies. During the season of 1895, Cache la Poudre Canal began to receive from the river widely fluctuating amounts, the quantity carried being on one day as high as 200 second-feet and on the next 25 second-feet. It is exceedingly difficult to distribute such a supply fairly to the consumers. In this emergency, the proprietor of the Windsor reservoir, just above the canal, allowed the water to flow through the Larimer and Weld Canal into his reservoir, and then to be drawn off in definite quantities for a definite time.

These civilities are the more worthy of notice, since all three of the parties have been and still are engaged in litigation as to their respective rights to storage water. Three suits have already gone through the district court and are now before the supreme court of this State. The claims of reservoirs to water for storage have never been subjected to a general judicial inquiry, like that given to claims of canals.

The law provides that when any party proposes to construct a reservoir he must send a notice, supported by affidavits, setting forth the name of the reservoir, the source of its supply, the name of its feeder, the time of commencing work on it, and its capacity in cubic feet. The data thus furnished is for the guidance of the river commissioner in allowing reservoirs to have water for storage, but may be attacked in court and claims there made good. In these investigations the time of commencing work gives precedence, provided work is prosecuted with due diligence, but the whole quantity that the reservoir can hold may not be granted as of date with the commencement of the work, provided some other party who began later has prosecuted work with superior diligence and has commenced to use before the first party was in a condition to store and use the whole of what he had claimed. Hence certain reservoirs in this district have a right to fill to a certain height and then fill to their full capacity after others are filled or partly filled. A record of the rights of reservoirs is gradually being had similar to that of canals, but these rights are in an inchoate state until the supreme court passes on them.

LEGISLATIVE AND JUDICIAL CONTROL OF WATER.

From the preceding statements regarding the canals and reservoir systems of Cache la Poudre Valley, the attempts made at water storage, and the complications arising, it is apparent that a considerable body of laws and court decisions must have been developed. It has been from this district, in fact, that many of the most perplexing water questions have arisen, and its public men have been foremost in the presentation and discussion of bills designed to protect irrigators in the enjoyment of the waters to which they are by use entitled.

VIEW OF NORTH POUDRE FLUME 300 FEET BELOW THE DAM.

Showing canal crossing the stream from which its waters are taken.

ORIGIN OF THE COLORADO SYSTEM.

The canals irrigating the lands of Union Colony were among the lowest taken from Cache la Poudre Creek. In the years succeeding the founding of the colony new canals were built higher up the valley and old ones enlarged. As a consequence, in the latter part of the year 1874, a time of unusual scarcity, the river was dry at the head of the canal that supplied the town, and there was great danger that trees, small fruits, and lawns would be ruined. A meeting was called, about 40 delegates representing the various irrigation interests being present. A proposition was offered to appoint a disinterested person to divide the water according to the necessities of the users, disregarding, for the present, priority of appropriation—a doctrine which was generally recognized, but which under the conditions then existing was found impracticable.

The men upstream would not listen to compromise, relying upon their advantage of position, nor would most of the Greeley people accept it, as they were afraid that the concession would be used as a precedent, and that they would thereby lose an undoubted right. Debate ran high. Threats of appeals to arms were freely exchanged. But at last the men above agreed to let down some water to save the most valued trees and shrubs in the town. The promise was not kept, and violence would have been resorted to but for a timely heavy rain, which both raised the river and moistened the parched gardens and lawns of the town and the fields in the country. From that day forth the people of Union Colony set their hearts upon having a law enacted to enable them to have the water of the river distributed according to the vested rights of all concerned. Still for some time no one outside could be led to take an interest in legislation of this kind, and the years 1875, 1876, and 1877 passed without anything being accomplished.

The constitution of the State, adopted in 1876, recognized in express terms the right of citizens to appropriate the waters of the State for beneficial uses, domestic, agricultural, and mechanical; but there was then no law to give this provision efficacy. Soon, however, other communities, especially the settlers on St. Vrain and Boulder creeks, encountered like difficulties, and the farmers around Fort Collins, who had at first opposed legislation providing for a distribution of water according to the rights of prior appropriators, began to favor it when they saw large enterprises inaugurated for the purpose of taking the water out of the river much higher up than the head of their canals, and thus threatening to deprive them of the advantage of position they had been enjoying.

IRRIGATION CONVENTION OF 1878.

As a result of the general appreciation of the need of State regulation and control, a convention of delegates representing the various irrigation interests met in Denver late in December, 1878, for the purpose of formulating a scheme of irrigation legislation. Only the Platte Basin, now designated Division No. 1, was represented. At that time there was scarcely any irrigation carried on in those drainage basins that now constitute the other five irrigation divisions of the State. Indeed, it was not until 1885 that there was any effort made in other parts of Colorado to have the State control and divide the water, as provided in the act of 1879.

At the convention held in Denver the sentiment in favor of and against regulation by a State law was nearly evenly divided. Those from the districts where the supply in time of scarcity was exhausted were in favor of such regulation, while those who still had plenty of water were opposed, as they feared it would impose on them a needless expense. Others, especially lawyers, held that rights could be better secured through the courts.

It was finally agreed that a committee of five draft a bill for a law providing: (1) for the division of the State into water districts corresponding with areas irrigable from certain natural streams or portions of streams; (2) for the appointment by the governor of a water commissioner for each district, whose duty it should be to divide the water in his district according to a record of priority of appropriation, to be ascertained by some sort of judicial proceeding; (3) for regulations in regard to construction and right of way for reservoirs; (4) for the appointment of a State engineer and for gaging the streams of the State.

The committee, consisting of David Boyd, of Greeley, chairman; John C. Abbot, of Fort Collins; Dr. I. L. Bond, of Boulder; Daniel Witter and J. S. Stanger, of Denver, drafted a bill, which in its essential features became law by the action of the next legislature. The provisions, however, relating to a State engineer and providing for the gaging of the streams were rejected on the ground that it would be too expensive to the State, the agricultural interests of Colorado being then deemed insignificant. It became apparent by the time the next legislature met that little could be accomplished without a State engineer empowered to make measurements of water, and provision was accordingly made therefor.

DIVISION INTO DISTRICTS.

For the benefit of those who are studying the Colorado system or endeavoring to amend or improve State or local regulations it is proper to present some of the difficulties that beset this committee, of which the writer was chairman, in its attempt to draft a bill providing for the matters above named. One of the most perplexing things to determine was how much land should be embraced in an irrigation district or area within which priority of appropriation as conferring priority of right to use should be applied, and a record made as a basis of division by the agents appointed for that purpose. Theoretically, such a record should embrace what is contained in one of the six grand divisions into which at a later date the State was divided.

The question was narrowed down to whether the whole South Platte and its tributaries within the State should be embraced in one record and be under one administration, or should be subdivided into a number of districts, for each of which a record of appropriations should be made without reference to the claims of the other districts of the division. It was finally decided that a record of the whole South Platte basin, covering so large a territory and embracing so many claims to water, would require for preparation an excessively long period, and that it would be almost impossible to execute the decrees, even when tabulated.

Eight of the districts now shown in Division I of the drainage map were then created. The first extended from the State line to the mouth of Cache la Poudre Creek; the second, from there to the mouth of Clear Creek, near Denver, taking in only the main channel of the Platte. Cache la Poudre basin was made the third and Big Thompson basin the fourth. St. Vrain Creek, except its main tributary, Boulder Creek, became No. 5; North and South Boulder creeks, No. 6; Clear Creek, No. 7, and the Platte above Clear Creek, No. 8. This latter was divided later into three, Bear Creek becoming No. 9, and all of the Platte above the canyon in South Park was numbered 23.

Recently district No. 1, which was about 150 miles in length, was divided into two districts, the lower one being numbered 64. South of this, Nos. 65 and 49 were created, both taking water from the upper forks of the Republican, which are dry creeks for the greater part of the year. Three other districts, which take their waters from the upper tributaries of the North Platte before they cross into Wyoming, were numbered 46, 47, and 48, and added to the first division. These five districts outside of the South Platte basin are relatively insignificant from an agricultural point of view.

In carrying out this scheme of districts, each with a separate record and administrative officers, the results were favorable as regards Nos. 3, 4, 5, 6, 7, and 8, each of which had an independent permanent supply from the mountains; but they were not so in numbers 1 and 2, which were wholly dependent upon streams passing through the six districts first named. The trouble was first felt in district No. 2, in which are situated the earliest ditches of the State, and which is supplied almost wholly by the streams embraced in what originally were Nos. 7 and 8. The vicinity of these latter to the city of Denver led to great development in the way of irrigation works about the year 1880 and thereafter, and when put in operation they soon exhausted the supply which district No. 2, on the Platte below Denver, had formerly received.

SUPERINTENDENTS.

The increasing difficulties in district No. 2 led to the enactment in 1887 of a law providing for division superintendents. The more important of the duties of each of these are as follows: Within thirty days after his appointment each superintendent of irrigation shall send notice to the clerk of the district court of counties in which judicial decrees have been rendered, fixing the priorities of appropriation, and shall request of the clerk a certified copy of every decree establishing such priorities. The superintendent shall then cause to be prepared a book to be entitled "The register of priorities of appropriation of water rights for division No. —, State of Colorado," within which he shall enter certified copies of decrees, and shall make out a list of all ditches, canals, and reservoirs entitled to appropriations of water within his division, arranging and numbering these in consecutive order, according to the dates of their respective appropriations within his division, and without regard to the number which they may bear within their respective water districts.

Water commissioners of the different districts are to report from time to time to their division superintendent the state of the water supply in their respective districts. From these reports he is "to ascertain what ditches, canals, and reservoirs are and what are not receiving their proper supply of water, and if it shall appear that in any district in that division any ditch, canal, or reservoir is receiving water whose priority postdates that of the ditch, canal, or reservoir in another district, as ascertained from his register, he shall at once order such postdated ditch, canal, or reservoir shut down and the water to be given to the elder ditch, canal, or reservoir, his orders being directed at all times to the enforcement of priority of appropriation, according to his tabulated statement of priorities, to the whole division and without regard to the district within which the ditches, canals, and reservoirs may be located." The district commissioners are subject to the orders of the superintendent, who may enter their districts and enforce his own orders if they are refused or neglected.

These rules read well, but they have been found impossible of execution. The water supply became deficient about the 1st of June, 1890. Many of the older canals in district No. 2 were empty, and an attempt was made to supply them by shutting down canals in other districts that postdated them. An order was given to cut off the supply of the Farmers' High Line and of four other large canals taking water from Clear Creek. The owners of these canals got a temporary injunction, which was afterwards made permanent, restraining the superintendent from shutting them off. The reasons given by the court for granting the injunction were—

First, that the superintendent did not have the necessary information from the water commissioner, in the form prescribed by law, on which to base his order.

Second, that the ditches in district 23, embracing the South Park, were not ordered closed to a date corresponding to those in the valley.

Third, that the law of 1887, which creates the office of superintendent and defines his duties, is unconstitutional, in so far as its effect is to determine rights of priority in the waters of the natural streams against persons who have had no day in court, by making the decrees rendered in one district binding and conclusive against claimants in another separate and distinct district who have also received decrees.

In regard to the first reason, it may be said that the kind of information required by the law to be obtained from the water commissioner to guide the superintendent in regulating the supply among the different districts of the division is difficult to procure from so wide a territory, and comes too late to aid him execute his trust with the promptness which the exigency of the situation demands. If a canal needs and is entitled to water to-day, it is usually ruinous to wait for ten days while the superintendent is getting the legal information, and hence the superintendent has to act, if at all, on the most uncertain and usually biased evidence.

The situation in district No. 23 may be examined somewhat at length, as it brings to light some interesting irrigation situations.

The water commissioner of district No. 23, after consulting with attorneys, declined to shut down any ditches whatever. The superintendent then made a personal inspection of the district, and endeavored to obtain the necessary information as to location of ditches, to enable him to close them down himself; but in addition to being unable to secure the needed information, he found that in the excited condition of the people it would require the State militia to enforce his order.

This was the last effort made to shut off the ditches of the South Park district, so far as the writer has been able to learn. The district is very large, containing about 2,500 square miles. The number of ditches reported is 209. Over 77,000 acres are claimed as under irrigation, all being native meadow land except about 300 acres. The quantity of water decreed to this land by the court is 4,665 second-feet—sufficient, if the ditches could carry it, to flood the area irrigated a foot deep every 8.7 days. Measurements made by the State engineer discovered the fact that many of the ditches fell far short of their decreed allowance, some receiving only about one-tenth of that amount.

It was, moreover, claimed by the users of water in this district that the early and heavy use of the water on the lands adjacent to the small streams that traverse the Park was a great advantage to the supply of the South Platte below its canyon, and measurements made by the State engineer seem to confirm this view. Nor is this unreasonable. This 77,000 acres of land is filled down to the bed rock with all the water the soil will hold by streams applied up to July. The irrigation is then stopped in order to cut and cure the hay. The water rapidly seeps out of the pervious soil, increasing the discharge of the streams during the succeeding months. Assuming that the soil and gravel to the depth of 6 feet is filled with water, this will be equal to a depth of 2 feet of water, and the 77,000 acres would have a storage capacity of 154,000 acre-feet.

That this early excessive irrigation up to about July 1 has the effect claimed is borne out by the fact that the measurements of the waters of the South Platte as they pass through its canyon show it, on the average, to be much smaller than Cache la Poudre Creek at the season of high water, and considerably larger during the fall and winter months. A belief of this kind, together with the injunctions obtained in other cases where the superintendent attempted to shut water from canals of one district for the benefit of earlier ones in another, has hindered the superintendent from interfering with this or other districts.

CONSTRUCTION AND OPERATION OF CANALS.

The object of an irrigation canal is to divert water from a natural stream and take it where it can be spread over the land. Other things being equal, the shorter a canal is in proportion to the service it renders, the more economical that service. Some canals run as far as 20 miles before they can deliver any water, while others begin to deliver within a few miles of their heads. The length of a canal depends mainly upon two things, first, whether there are canals close below that cover the upper part of the lands below the new canal; and, second, the degree of abruptness with which the land rises as it recedes from the stream. If the slope or fall of the stream is great, then a canal that has a small slope will gain in the height of its bed over that of the river as many feet per mile at the end of a certain number of miles as the difference between its slope and that of the river. This height of its bed above the bed of the river will bear it far away or near to the river in proportion to the steepness of the land lying between the canal and river.

The slope of the upper part of Cache la Poudre Creek after it leaves the canyon is for a number of miles 15 feet per mile, which gradually changes to 10 feet per mile at its mouth, giving an average of about 13 feet per mile. Assuming that a canal like the Larimer and Weld is started within a few miles of the canyon on a slope of 2 feet to the mile and follows the contour of the country to the north of the river for 65 miles, and that the meanderings of the canal and of the river are about the same, it is evident that at the lower end of the canal it should be 715 feet above the river at a point on the latter opposite to this terminus. However, where this opposite point in the river is to be taken is really determinable only by measuring down the river a distance of 65 miles, following all its meanderings.

The height of the Larimer and Weld Canal where it crosses the Denver Pacific Railroad, about 9 miles above the river, is 250 feet above the river crossing. The length of the canal to this point is about 50 miles, and accordingly, estimating a gain of 11 feet to the mile, it should be 550 feet above the river. The railroad distance in the river valley from Greeley to the head of the Larimer and Weld is 26 miles, which, multiplied by the grade of the road, assumed as 13 feet, gives 338, and this reduced by the fall of the canal for 50 miles, namely, 100 feet, gives a height theoretically of 238 feet. Hence it is to be assumed that the fall given to the river is that of a comparatively straight line running up its valley, and not the real slope of its bed, which must be about only half as much, since the bed of the river is more crooked than that of the canal. In Lone Tree Valley, which terminates at the mouth of Cache la Poudre Creek, and which has a nearly uniform slope of 25 feet to the mile, the distance of the Larimer and Weld Canal from the mouth of the creek is 12 miles. This would give a height of 300 feet, which corresponds closely with the other estimates, this point in the canal being about 60 miles from its upper end.

These relative slopes must be taken into account when any irrigation enterprise is contemplated in connection with considerations as to the fall which can be allowed a canal of a given carrying capacity without wearing its bed. Other related questions come, as to the alignment of the canal, the straightening by cutting and filling, and increasing the velocity; also how far shall the earth removed in excavation be placed back from the edge of the cut in forming the embankments, whether there shall be two embankments or only one (on the lower side) where there is a fill, and where, if there is only one, the water will run far back on the opposite side.

The experience gained from the results of the construction of two canals in our valley by the same engineer is deemed of practical value on these points. Union Colony Canal No. 2 was given a grade of 3.2 feet to the mile, a depth of only 2 feet, and a width on the bottom of 12 feet at the head. The course was very crooked, keeping for the most part in the ground, neither cutting nor filling much; the earth was piled close to the edge of the lower bank, and no embankment was made on the upper side, however far back the water might flow. This was economical in construction, but wasteful in the long run. The slope was none too much for the canal at the size it was first built, but it was finally enlarged to some five times its original capacity. The sharp bends were of necessity taken out, thus shortening the course and increasing the slope. The upper side had to be embanked where the water flowed far back, in order to prevent the action of waves on the lower bank and waste by evaporation; also to allow of the canal being filled and emptied rapidly.

The result of these changes was a great increase in velocity and resulting wear of the bed, which has now to be checked wherever water is taken from it. Portions of the bed not influenced by these checks are being worn away, and hence are in a condition to permit great loss by percolation. The lower bank has been allowed to remain where it was, but should have been set well back, because wherever there is much wear on the lower bank there is great danger of break. The expense of moving the earth back some 6 feet is insignificant compared to the advantage of having it there.

The experience gained in the construction of Cache la Poudre Canal was of value in laying out the Larimer and Weld Canal some eight years afterwards. In general the slope planned was only 2 feet to the mile except for a mile and a half near the head, where the bed of the canal was over large bowlders similar to those in the bed of the river at the same place and where the fall was 15 feet to the mile. This part was given 13 feet fall to the mile, and has stood the wear without being materially moved. The lower bank was set back some 6 feet and usually made broad enough to allow the driving of a wagon along its top. Cuts and fills were made to some extent to preserve the alignment from abrupt angles, care being taken, however, not to cut too deep when this would prevent the water from being taken onto the land near the canal. Small expansions of the canal on the upper side were prevented by an upper embankment, except at Lake Lee, described on page 39. This serves a useful purpose for storing small quantities received from the river in time of scarcity to be delivered to alternate sections of the canal in amounts that can be economically applied. Another expansion of this kind near the lower end was found to be wasteful in times of low water, and a canal has been cut around its lower margin to keep the water out of it except when there is a surplus. On the whole, this canal has too much slope for its present size, and usually must be checked where water is taken into laterals.

CONTROL BY TELEPHONE.

This district is probably unique in the possession of a special telephone line for water control. This line was erected in 1889, being in part paid for by the two counties of Larimer and Weld, and in part by the large canals. It cost $1,500 and is an annual expense of about $60. The river commissioner regards it as worth each year its entire cost to the several users of water.

Its upper terminus is at the head of the Larimer County Canal; thence it connects with La Porte, where the river commissioner lives, some 4 miles above Fort Collins. It has two connections with offices of canal companies in the latter place, one each at the head of the Larimer and Weld and Cache La Poudre canals, two in Greeley, and one in Lucerne.

At three different places, at three set times, the river commissioner can be communicated with by those having the irrigation affairs of the district in charge. At the head of each of the three principal canals a man stays day and night, and the bell of the telephone is close to his ear when he is in bed. If there should be a sudden rise of water in the river and the commissioner is notified of it, he can immediately communicate with these three men at the head of these canals and have them raise their gates to save it. If a break occurs in a canal, the party who discovers it can communicate with the man at the head by going to the nearest telephone station and have the water shut out in the shortest possible time, decreasing the damage.

The river commissioner must visit the gaging station daily to see how much water is in the river, this being his guide for supplying the different claimants according to their priorities. The station has a self-registering apparatus which gives the different heights to which the water rises during the twenty-four hours, and from the height in the channel the number of feet per second is found from a table experimentally prepared by the State engineer. The section where the measurement is made has masonry sides and a natural rock bottom, which give a definitely fixed cross section. Means of gaging every canal diverting water from the river are required to be put in by the owners, and these gagings are rated by the State engineer for the benefit of the river commissioner. Some of the smaller canals neglect to do this, and their water supply is estimated by the commissioner.

LATERALS.

The water is taken out of the canals by means of lateral ditches placed at short intervals. Usually they follow the crest of the ridges, and deliver water on both sides by means of sublaterals. Some of these laterals are very large, as, for example, those from the Larimer and Weld Canal. These carry as much as 100 second-feet, and in some instances have two ditch riders to distribute the water to the consumers. The laterals run as far as possible on the crests of the ridges that divide the valleys from one another, and the conditions in regard to their location are such that they can not be given any slope desired but must conform to the fall of the ridge followed. The average slope of the land between the canals and the river is about 25 feet to the mile. Hence, in general, the lateral has a fall as great as that. This will not cut very badly under a flow of a few feet of water, but with 100 second-feet, as with two laterals of the Larimer and Weld Canal, there is nothing to do but to put in drops here and there after the cutting has gone on for some time. These are built of 2-inch plank nailed to suitable timbers. It is deemed best to have a lower horizontal section of planked bottom and to give the water a forward instead of a sloping downward direction when it resumes its course in the channel of the canal.

MEASURING AND DIVIDING WATER.

From the main lateral, if it be a large one, the users divert water one or many at a time. It is measured to them, or a proportionate part of it set off for them, wherever it is deemed best. The quantity taken in by the lateral is estimated by the main canal ditch rider. Usually the measurement is made over a weir some distance below the head, and is computed from a table furnished by the State engineer, applying accurately, however, only to weirs put in according to the Francis plan. Large discrepancies are found in some of these weirs by accurate measurement. Usually more water is given than intended, as conditions for controlling velocity of approach are rarely present.

The Larimer and Weld Canal uses weir measurements. By its contracts it is bound to furnish 1.44 cubic feet per second for each 80-acre water right if this amount can be had from the river. In the other canals measurement is not necessary, since the consumers are at the same time owners of the canals and each has a proportionate right to all the canal can or does carry. Hence equitable division is all that is required. The usual course to effect this is to give for each water right so many sectional inches. This is fair, provided the sections

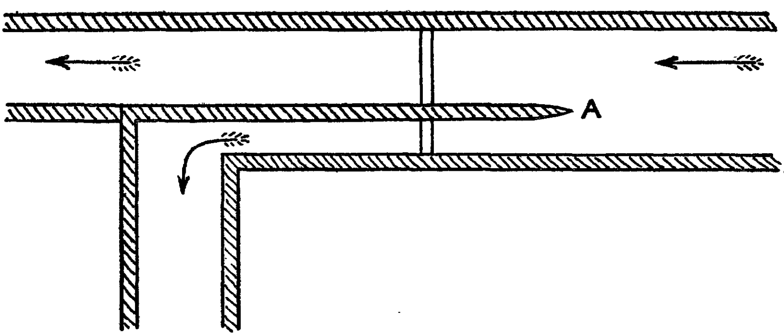


FIG. 8.—Plan of device for dividing water.

are of the same depth and the velocity of approach to the place where the section is measured is the same. The first condition can usually be secured, but often is not, and there is no uniformity in conditions to secure equal velocity of approach.

In the Cache la Poudre Canal devices called Max Clark boxes were put in both to measure and make a fair division. It was a modification of the Italian Soldati modulus, and at least did something toward making the velocity of approach to the measuring apertures uniform. It is not practicable to place a dividing device cutting off a proportionate portion of the whole in a large canal at each place where water is diverted, nor is this found practicable at the upper end of large laterals, but in the lower ends of these, and in laterals in general carrying not more than 25 second-feet, it can be done quite satisfactorily. A very simple and common form of divisor[1] is shown in fig. 8.

The partition at A is movable and may be placed at different distances from the side. When there is no desire to change the relative

[1] Measurement and division of water, L. G. Carpenter, Bulletin No. 27, Colorado Experiment Station, August, 1894, p. 9.

quantities taken through the two openings, the partition is fixed. This is usually the case, as it prevents changes being readily made by dishonest parties. When this partition is fixed, alterations can be made to suit parties by putting in a perpendicular strip of board in one side or the other. The view in Pl. XVII shows a device in laterals of Greeley Canal No. 2 by which the stream is divided into four parts.

COST OF IRRIGATION.

It has been impossible to obtain reliable figures concerning the cost of all of the canals and ditches taking water from Cache la Poudre Creek, but, as stated on previous pages, the expenditures in the construction of the two larger canals are shown approximately. The first of these, the Cache la Poudre, as stated on page 32, cost $112,000, and its reservoir $110,000; in all, $222,000. The cost of the Larimer and Weld has been placed at $150,000 for the canal, and for the two main reservoirs, $165,000, this including the estimated cost of completing the Windsor Reservoir. The total cost of this canal and its reservoirs is thus $315,000, and for the two canal systems, $537,000.

The total area of land in crops under these two canals, not including that designated as waste and pasture land, is 66,349 acres. This number of acres divided into the cost as just given gives an average of less than $9 per acre for the water. The price originally paid the railroad company for the land was $3 per acre, making a total first cost of land and water of $12 per acre. Until about 1895 this land, with water rights, has been considered as worth on an average $40 per acre without buildings. As a rule, the lands have actually been held at a higher figure than this.

Omitting the other two large canals on the north side of the river, viz, the Larimer County and North Poudre canals, a comparison of the cost and value of the remaining irrigating ditches would compare favorably with these figures, except in the case where the lands under some of the ditches have been injured by excessive seepage and by the rise of alkali. If, however, these two large canals are considered, a different estimate must be made. Both of these were built after the supply in the river was practically exhausted and when extraordinary expenditures had to be made to secure a supply.

The Larimer County canals on the plains cost about $90,000, the part in the mountains approximately the same, $90,000, and the two main reservoirs $24,000. Estimating the cost of the other reservoir at $10,000, the total is $214,000. With this expenditure, only 16,713 acres were reported in crops, making a cost per acre for water of about $13, or 40 per cent more than in the cases above cited. Besides this larger cost, the land under the canal, on account of uncertainty of supply, has a relatively small value, dependent largely upon the success of the Sky Line Canal. If this and the reservoir system result according to the anticipation of their projectors, the lands will be as valuable as those under other canals. The unfortunate condition of the North Poudre Canal has been mentioned on a preceding page, its financial success being dependent largely upon the possibility of diverting some of the headwaters of Grand River into Cache la Poudre Valley, in a manner similar to that of the Sky Line Ditch.

As to the cost of maintenance, it may be stated that the three principal canals of the valley employed each three riders, and there is also one man at the head and a general superintendent. The cost for supervision for the years 1893 and 1894, as reported by the river commissioner for this district, was $17,502, and the cost of repairs for all canals having superintendents was $52,472. It is assumed that these figures relate only to the expenses of the canals and not to the laterals. Taking the length of the former at 333 miles and the area in crop as 125,000 acres, the cost for superintendence and repairs per annum would be 28 cents per acre.

AGRICULTURAL PRACTICE.

Whenever sufficient water is obtained and applied at the right times, the products of the lands within this valley are remarkable. Fertility is, however, maintained largely by a judicious rotation of crops. The best practice is that in which about one-third the area is kept in alfalfa, to be plowed under after two years' use as a meadow. Both the upper and lower ends of the valley are excellent for small grains and alfalfa, but the lower part is best for potatoes, and the upper for apple orchards, of which a great acreage has been planted within a few years. The more clayey soil of the upper end of the valley renders it more retentive of moisture during the winter and early spring, and hence the trees do not suffer so much from dry winds and occasional hot suns as they do on more porous soils. Blight has been severe on all the fruit trees of the valley save plums, which do well everywhere in the State.

The farms of the Greeley colony under Canal No. 2, now known as Cache la Poudre Canal, are rarely smaller than 80 acres or larger than 160. The latter is regarded as the better size for profitable farming if the owner does not get too heavily into debt. The interest at 8 per cent and the yearly payment of installments on a large farm are a heavy load even for this fertile valley, and are a fixed sum, while the profits are uncertain. The operating of the larger farms is more profitable from the fact that as much farm machinery is needed for the 80 acres as for the larger tract. If the farmer is raising grain, alfalfa, and potatoes, he needs three distinct lines of machinery. A good equipment of these and all kinds of implements needed to turn and stir the soil and move the crops will cost not less than $800. There is a much smaller proportionate investment for the larger than for the smaller farms.

VIEW OF DIVISION FLUME IN LATERAL UNDER THE GREELEY NO 2 CANAL.

The size of the farm which may be made the more profitable depends upon the man. If the owner is a good worker himself, but unskilled in handling men and in management, then the smaller farm will be best. Many men on an 80-acre farm have done well, made a good living, put up good farm buildings, and have money out on interest. Others have done equally well with 160-acre farms, one-half of which they went in debt for, while others undertaking this have lost all.

APPLYING WATER.

The farmer having his share of the water in his own little ditch carries it to the highest point on his farm and leads it either along the side, end, or obliquely across in straight or curved lines, so as to keep it where it can fill the smaller ditches. By these the water is carried, if possible, to every square yard of the farm. Often much diking must be done on the farm, and before the lateral reaches it, so as to get the main distributing ditch where it will cover the most land. These dikes are expensive to make and equally so to keep up, and are a source of perpetual annoyance and often of waste. A farm is to be preferred whose feeding lateral runs along one side and does not meander here and there. A farm with a sag anywhere in it, especially in the middle, is to be avoided.

The ideal surface for irrigation is one raised a little at one end or on one side. It should have a fall of from 15 to 25 feet to the mile, as uniform as possible, and in one direction. For an 80-acre tract the following conditions, if they could be realized, would be best: The upper shorter side should have a fall of about 5 feet to the mile for the feeding-head lateral, and the long direction a fall of 15 feet to the mile, with the lower short end having the same fall as the upper. It will be seen that the upper ditch, which is a quarter of a mile long, will have but a fall of $1\frac{1}{4}$ feet, and a dam put into it at intervals of 10 rods will make a difference of level of such a section of only 2 inches. If fifty rows of potatoes head into such a ditch and there is a sufficient volume of water in it to furnish a little stream for every row, it can easily be diverted into all at a time, since the diminished head will make up for the fall of level of the lower end of the bottom of the ditch, while, if the fall in this feeder was great, only a few of the rows close to the dam could be fed, and those unequally, without constant care and changing. This is the ideal surface slope for a potato field. Such tracts may be found north of Greeley and extending up to Eaton.

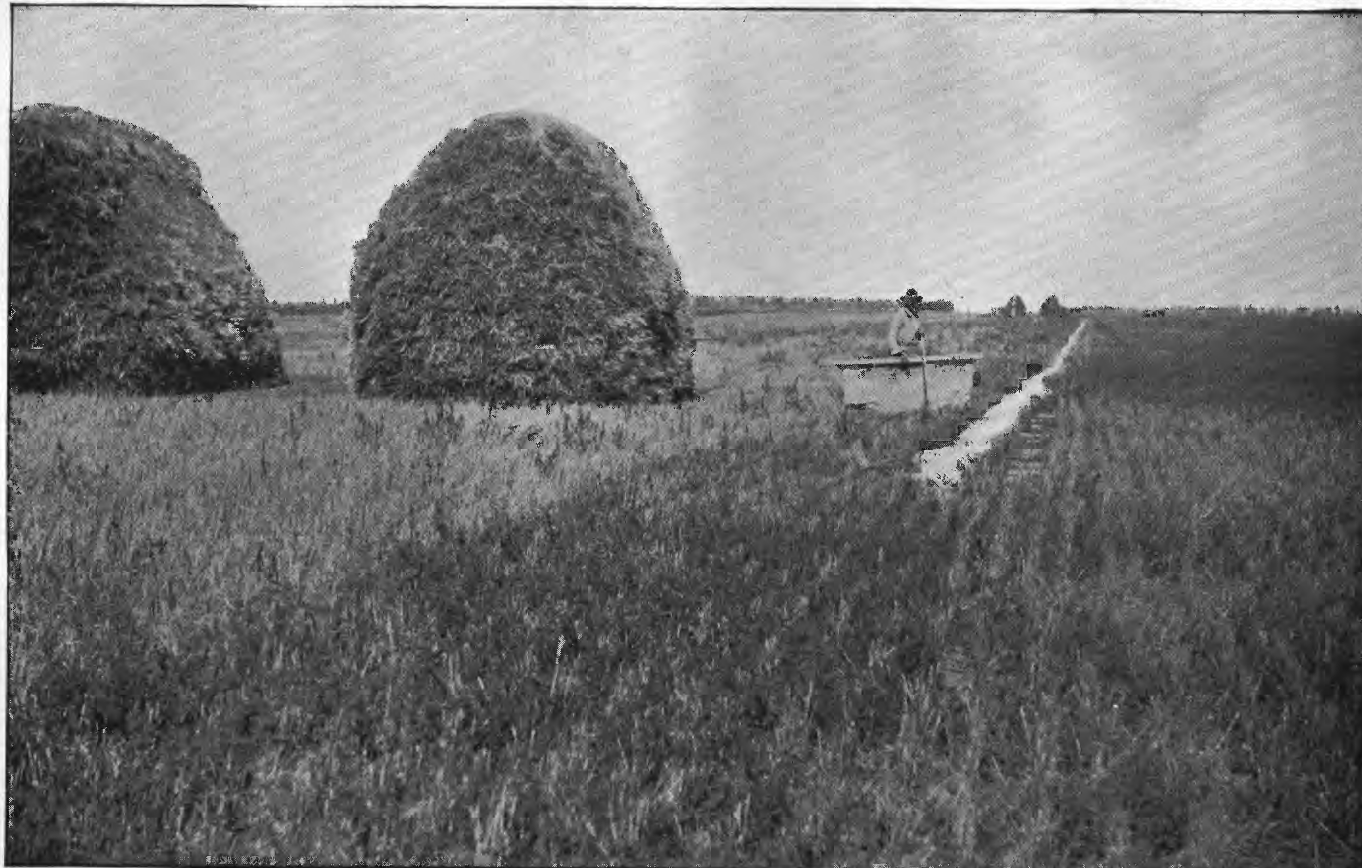
Such a surface is also desirable for grain or alfalfa, and to irrigate these crops by flooding, as is customary, the farmer has only to run through the grainfield or meadow a large double-moldboard plow, drawn by from four to six heavy horses, and penetrating to a depth of 12 inches, throwing a bank to each side and leaving a clean ditch behind it. These ditches are usually put a hundred feet apart, and plowed in before harvesting, but in an alfalfa field they are left permanently. At suitable intervals a canvas dam is put into the ditch, the pole to which the edge of the canvas is nailed supported on both banks. The cloth lies in the bottom and on the edges of the ditch and is kept down by a little dirt put on the edge. The bank is cut on one or both sides as desired, just above the dam.

The use of the canvas dam is illustrated in Pls. XVIII and XIX. The former view shows a man with a canvas dam in his hand ready to put it in the lateral flowing through a field of young alfalfa. This view was taken on September 20, 1896, of a field under the Larimer and Weld Canal, near the town of Lucerne. On the left and in the distance are shown stacks of wheat recently cropped from the field. Pl. XIX shows the canvas dam in place turning out water for the irrigation of a wheat field near Greeley. The stream, checked in its flow, is forced to find its way into the young grain.

Little has been done in Cache la Poudre Valley in the way of leveling the land preparatory to irrigation. This is necessary only with rolling land, and especially where there is but little fall to it. Even when the surface is quite uneven, if there is considerable fall, a farmer can generally lead the water over the higher spots, while when it is nearly level it can be got onto these spots only by diking the ditches that run through the field. These dikes within a field are a nuisance, and in most cases it is better to level down the humps. For this sort of work various kinds of scrapers are used.

If a field is level to start with, it is important to keep it so and not create artificial irregularities by cultivation. This is done if the plowing is in narrow "lands," the "back" and "dead" furrows proving a great annoyance when flooding. To avoid these the farm should be divided into a suitable number of rectangular fields and each of these plowed out one year and in the next. The small rise or hollow where the corners occur will prove a slight annoyance, but the work of alternate years keeps the change of level within narrow limits. To not only keep the surface of his farm in good shape but to improve it is the care of every intelligent farmer managing an irrigated farm. The action of both plow and cultivator, if carefully directed, is to improve the level of the surface, and the irrigation of rowed crops contributes to the same effect. The loose material in the steeper parts of the rows is carried into slight depressions and left there, and in a few years these disappear. The perfect potato field is without such depressions, but a surface entirely free from them is rarely found. They are less objectionable in a cornfield, as a little flooding does it less harm than potatoes, and hence it is advisable to raise a few crops of corn at first in such fields, even if the crop is not profitable.

To raise a good crop of potatoes on a steep field requires great pains and ingenuity. If the surface is not wavy as well as steep, the rows



IRRIGATING A YOUNG ALFALFA FIELD.

can be run diagonally across the slope, so as not to give them too much fall, which will make the bottoms wash away and lower the water surface, so that the rows are not moistened underneath. Some farmers run the rows directly down a steep slope, and in irrigating let a tiny stream trickle down between the rows for a day or two, and thus succeed in having the moisture penetrate the rows. To get the water to enter so many rows at once requires a very level head-feeding ditch, or the greatest pains and ingenuity in the way of checks to effect that end.

In general it may be said that steep, rolling, irregular land is much less desirable in a country that is irrigated than in one where it rains, and such a farm should be avoided, however rich the soil may naturally be. Still, if the soil is a pretty stiff clay, it may be irrigated without tearing it to pieces, even if rather steep; but in this case it is next to impossible to spread the water so evenly and thinly that the soil can absorb all that is applied, and hence usually a large portion of that used runs off into hollows and draws and is lost to the owner.

ALFALFA.

Alfalfa can be raised at a profit for $3 per ton in the stack in the field. The average weight of the crop is variously computed by those who make careful estimates at from 3 to 4 tons per acre for the three crops, and it costs from $1 to $1.25 per ton to put up the hay at the present reduced price of hands and haying implements. At these figures an income of $5 per acre can be safely estimated from land put down to alfalfa. Seed costing $1.50 will sow an acre. It is now usually seeded with the spring-sown grain, and if one does not want to plow it under for fertilizing purposes, a stand will last twelve years or more.

These figures differ widely from those given in Arizona and the Pecos Valley, New Mexico, where crops of 8 tons per annum and prices of $10 per ton are claimed. From personal observation the alfalfa fields near Phœnix, Arizona, do not show such luxuriance as those of Cache la Poudre Valley. In considering the price of alfalfa hay the true test is what it is worth to feed on the farm, and not its temporary local price when a country is being opened up. Such is the productiveness of this plant that if any considerable area is brought into cultivation the local market is soon glutted. Thus the only safe basis of price is its feeding value and the probable permanent selling price of the meat produced from feeding it.

By adhering principally to alfalfa raising and stock feeding, it will be seen, a fair rental can be expected from land, and $40 per acre would be a conservative price for such land. Large tracts of land can be handled economically by one management if alfalfa alone is made the crop, and hence men who possess farms of considerable size are drifting into this crop and find it more profitable in the long run than renting in small tracts for mixed husbandry. This latter practice is sure to run down a farm in a few years, while alfalfa farming at once keeps the land clean and increases its fertility amazingly. The best and most profitable farming here is done by men who own a moderately large farm and practice a mixed husbandry.

POTATOES.

Potatoes are usually planted after plowing under alfalfa. Two crops can then be successfully produced. Some farmers raise the two crops in succession, while others raise a wheat crop between. The former is the better way, as the land is usually too rich for the wheat if only one potato crop is raised. Besides, it often happens that the raising of one potato crop does not entirely kill the alfalfa, in which case it comes up in the wheat next year and smothers it, making it difficult to harvest. Usually the second crop of potatoes is the better, as there is likely to be a larger stand than when so much growth of roots and stubble are turned under and partly mixed with the soil, since the latter dries out rapidly from the free circulation of the air admitted by this light material.

The breaking of a well-set alfalfa field is no trifling matter. It may be done with three heavy horses, but it is hard work for them, and they will not be able to break more than 1 acre a day. The writer prefers using five heavy horses—three in the lead and two on the end of the beam. They can go right along and plow 2 acres a day. Alfalfa roots are very large and strong when the plants have attained a full growth. They give a jerky motion to the plow and it makes hard work for horses' shoulders. A cast-steel plow is used, and the share is so tempered that a file can just cut it. It is hammered out thin at the blacksmith's shop when it gets too thick to file easily. The reason for filing, rather than using the hard, thin edge, as in other plowing, is that the edge needs to be rough as well as thin, or the roots will slip along the sloping edge of the share and not cut well. In breaking, the plowing is done from 6 to 8 inches deep. In plowing stubble the practice is to get down about 10 inches.

If water can be had, it is better to irrigate the alfalfa field before plowing. It will be dry enough to plant in three days if it has not rained meantime. It is usual to harrow down or run over with a packer and leveler daily, so as to retain the moisture as much as possible.

The planting is now done with an Aspinwall planter, which may be regulated to plant from 11 to 23 inches apart. Good seed is indispensable, and is often hard to get. Under our forced cultivation the tubers deteriorate rapidly in form and vitality. Often the sprouts, when they start in the spring, are no thicker than knitting needles. A thin, weakly stand is sure to follow from the use of such seed. Seed is shipped in from sections where they are grown by natural rainfall. In 1896 a carload was obtained from the divide lying

IRRIGATING A WHEAT FIELD.

between Denver and Colorado Springs, a high region where the rainfall exceeds that of the plains, and where it suffices in spots here and there to produce a moderate-sized crop without irrigation. A new supply of seed seems to be needed about every three years to keep the stock in good shape, but much can be done by careful selection of home-grown seed. Storage in a comparatively damp cellar or dugout is now believed to keep up the vitality of the tubers better than storage in a very dry cellar. The latter tends to induce dry rot by the time the planting is being done, which is from May 15 to about June 10.

Early planted potatoes usually do not thrive well in this climate. The soil is too hot in July for the tubers, and if an attempt is made to keep down the temperature by frequent irrigation, the vines usually blight, turning yellow, both stem and leaves getting stiff. It is better to delay all irrigation until about the first of August, when the vines are beginning to blossom and the small tubers are beginning to form. August is much cooler here than July, the nights are longer, and there is more light rainfall and cloudy weather, all of which are aids to irrigation.

Soon after planting and before the potatoes come through, they are cultivated as deep as the ground is plowed with a two-horse cultivator, the soil being thrown onto the rows. The cultivator is followed by a fine-toothed harrow, nearly leveling its work but destroying all weeds and leaving the ground mellow. Two more cultivations are given, the last one throwing up the earth around the plants. This cultivation is followed by running through either a large single shovel with wings or a lister which makes a clean continuous ditch, but not quite down to the depth of the plowing. The top of the ridge is from 10 to 12 inches above the bottoms of the furrows.

By about August the vines have made a fair growth from the moisture stored in the soil and the light rainfalls. The roots have spread beneath the surface in the soil moved by the plow, and many of them have penetrated the unmoved soil in search of water. This is a healthy and thrifty movement on their part, and they are in a good position to utilize the moisture furnished them by irrigation. Water is allowed to flow gently between the rows, a larger stream being allowed to enter the rows when the land is level, so as to force it through, but if steep, it must be allowed to flow long and slowly on account of washing, and the irrigations must be repeated oftener. On level land two irrigations are usually sufficient, while four are none too many where the ground is steep or where it is very porous.

No rules can be given about the frequency of applying water except the general one that the soil in the rows should not be allowed to dry through and through so as to arrest the growth of the tubers. If this happens, then they take a new start when water is again applied and throw out knobs and become abnormal in form.

The main crop is harvested from October 1 to October 25. Some medium early ones are taken up all through September, but these are usually too unripe to keep long. The Dawden Digger is mostly used (see Pl. XX). It requires a man and four heavy horses to run it, and if kept going ten hours can dig 5 acres. The picking is paid for by the sack, which holds about 115 pounds. The price now is about 5 cents, which includes sorting and sewing. A sorter is mostly used, a horse dragging one along for four pickers, with one man to shake it, set off full sacks, and put on empty ones. These will keep a man sewing. If the potatoes are good, these six men will pick, sew, and sort 250 sacks per day. These on an average can be had from 2½ acres if the crop is after alfalfa, but no such average is obtained from all the acres planted, even in the best potato district. The most experienced and careful men sometimes fail to get even a thrifty stand, and as much poor land, or steep and uneven land, is planted, the general average from all planted in the valley will not exceed 60 sacks to the acre.

It takes about two men and a team to haul in and store the 250 sacks, which are put away in the dugouts on the farms, the sacks being laid on their sides and piled up about eight deep. Many sacks, however, are disposed of at the various railroad stations, being either sold and shipped away or stored at the potato warehouses.

Pl. XXI is a view of the potato dugout of Mr. H. B. Eaton, in the town of Eaton. It is excavated about 3 feet deep, and earth put on top and at sides. Teams drive in and out on a gentle incline. Capacity, about 20,000 sacks of 2 bushels each.

To operate such a digging outfit requires 7 horses and 9 men. Calling the services of 7 horses equal to 3 men, we have an average of 25 sacks per man, or nearly 50 bushels dug, sorted, sacked, sewed, and put away in the dugouts.

Sometimes the potatoes are taken up unsorted and stored away in bulk in the dugouts. In this case, about a bushel is put in a sack, which is neither tied nor sewed but piled onto the wagons and then dumped into shoots from the outside. The sorting is then done in the winter and spring. The sacks cost about 4½ cents by the thousand.

For the last five or six years the price of potatoes has not exceeded 75 cents per hundred pounds, while in 1896 it was only 25 cents. They are now worth from 50 to 60 cents. The crop in 1896 was short, not much more than half that of 1894, because of very dry, hot weather in the early part of the season preventing a good, thrifty stand and vigorous growth before irrigation was commenced.

In general it may be said that the crop can be raised at a profit in an average year for 50 cents per hundred, sacked and delivered at the depot. The outfit of tools, including alfalfa breaking-plow, harrow, cultivator, planter, digger, and sorter, costs about $300. The digger is a short-lived machine, and needs, on about an average, $10 per annum for repairs.

VIEW IN A POTATO FIELD NEAR GREELEY.

In several years after the colony settled here there was a home market, and hence a high price, as the competition was between those raised here and those shipped in. But gradually the supply began to more than meet the home demand, and shipments had to be made into the towns on the Missouri River and into Texas. Here we came into competition with potatoes raised in Iowa, Minnesota, Wisconsin, Arizona, and sometimes Utah and California. Still, compared with those localities that do not irrigate, with which we come in competition, we have the advantage in a dry and hence scarce year, when the price is high. The size is larger and the quality usually better, and therefore we get a higher price in the same market, say by from 10 to 20 per cent. Hence we are likely to keep on raising large quantities of potatoes in this region and at fairly remunerative prices on the average. But the days for making large profits have gone.

UNDERGROUND WATERS.

The percolating waters of the valley are of considerable importance, although relatively small in quantity compared to the amount flowing on the surface. The matter of seepage water has been fully discussed by Prof. L. G. Carpenter.[1] There are, however, a number of matters in connection with the character of water and the means of bringing it to the surface that are of importance not only in this valley, but elsewhere.

ALKALINITY OF SEEPAGE WATERS.

Seepage waters are nearly always heavily impregnated with alkaline salts, and storage increases the percentage of these deleterious constituents. If a reservoir is only 15 feet deep, there would be during the summer over one-third evaporated. As the salts held in solution do not escape, the water in the reservoir will be far more saline than it was when received. If the water stored comes from the river near its head and has been but little mixed with the return seepage always impregnated with salts or alkali, its storage will not materially injure it for irrigation.

The effect on soil using alkali water exclusively is soon made visible by efflorescence on the surface. Hence it is prudent to use stored water alternately with that brought direct from the river by the canals. Then when the drainage is good it may be expected that sufficient quantities of these soluble mineral constituents will pass off, leaving the soil comparatively free. The lower, older canals are making on this ground objection to exchanging the river water for the reservoir water in the manner described on page 60. This is a serious question; for alkali is easily developed and with difficulty removed. There is practically no way of removing it but by procuring good drainage and applying plenty of fresh water to the surface,

[1] Colorado Agricultural Experiment Station Bulletin, No. 33, Seepage and Return Waters from Irrigation, by L. G. Carpenter, January, 1896.

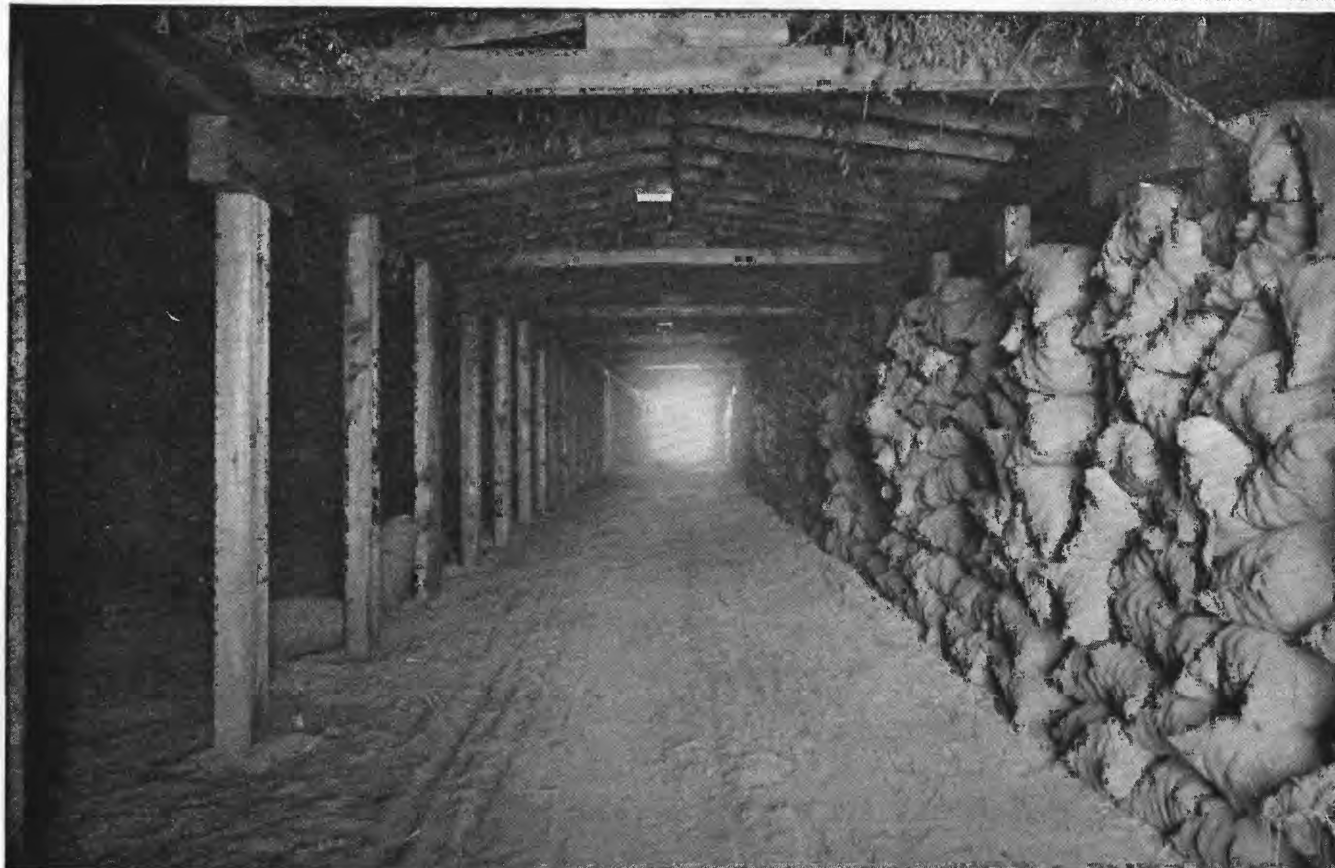
in this way dissolving and carrying off a share of it through the underdrainage. Surface flooding with fresh water will also help, but there must be good drainage, natural or artificial, or the land will be rendered too wet to raise a crop.

Little success has been made in reclaiming the wet alkali land in Cache la Poudre Valley, the most notable attempt being at the Agricultural College near Fort Collins. Here a swamp, made so by seepage water, has been deeply underdrained with tile, and the land now bears good crops. The writer undertook some work of this kind, which proved a failure because the tile were not laid deep enough to reach the sand or gravel, the chief outlet for the water that percolated through the soil. This is about 7 feet from the surface, and to tile land at that depth would cost more than the land is worth.

The drainage of the town sites of both Greeley and Fort Collins is of interest in this connection. When these towns were settled, there was no trouble in getting a dry cellar. After irrigation had been going on some three or four years, water commenced to rise in the cellars. In some of the lower places it showed itself even on the surface. Both towns are underlain with a deep gravel stratum, which it was believed would give a perfect drainage. The quantity of water applied in irrigating lawns especially, and by the great number of small ditches running nine months of the year, was more than the gravel could carry away, and so it began to force itself to the surface where lowest.

The town of Greeley first laid a deep drain on one side of Main street, extending to the river on the east and to the city limits on the west. It was put down 3 or 4 feet into the gravel. Sewer tile 18 inches in diameter was used without cementing the joints. This soon reduced the water level in the soil. There was a row of large trees along the side of the street whose rootlets penetrated the joints of the pipe and nearly filled it. This was all taken up and a larger pipe (at the lower end 2 feet) put in and the joints cemented, except at intervals of 200 feet, where manholes were left to let the water in and at which place the roots could be removed as occasion required. One cross drain was also put in, and now the drainage is satisfactory.

In the district immediately west of Greeley, and between its western boundary and Canal No. 3, water began to rise in the cellars, and about September 1, 1895, appeared on the surface a short distance west of the end of the town tile drain above described. The cause of this was traced to the removal from the bottom of the canal the winter before of the accumulated sand for the purpose of making mortar. When the water was let into the canal the spring following this removal, it was ascertained that several hours were required for the moderate volume to pass this disturbed area. The bottom of the canal is here a quite coarse gravel, allowing water to go through it like a sieve. The water could not be carried off by the drainage of the land



VIEW IN A POTATO DUGOUT.

below as fast as it went in. Prof. L. G. Carpenter[1] of the Agricultural College, states that a measurement of the amount of water in the ditch was made October 16, 1895. The quantity in the canal decreased from 25.86 second-feet above the place where the sand was removed to 20.80 second-feet a little distance below, or a loss of 5.06 second-feet. The total distance between the two measurements was about 760 feet. The total area of surface was about one-half acre. This would be equivalent to the discharge into the area wetted by the canal of the quantity covering it to a depth of 21 feet in twenty-four hours.

After the water was turned out of the canal, the cellars became dry, remaining so during 1896. Two years after the canal was originally constructed the same rise of the water in the soil was observed, but it disappeared after the sediment had coated over the surface of the gravel. The same effects of excessive percolation have been observed below canals of this district where the slope is so steep that the bottom is kept swept by erosion. When a check is put in, causing sediment to gather behind it, the percolation lessens or altogether disappears.

The drainage water of the city of Greeley is mingled with a limited quantity of sewage, which enters at the lower end of the discharge drain. This is carried across Cache la Poudre Creek in a wooden flume and is used for the irrigation of a market garden of about 200 acres. The quantity is approximately 5 second-feet up to about the end of the irrigation season, when it is more abundant. This drain affords an indication of the periodical fluctuation of underflow due to a change from ample irrigation to cessation. The strip irrigated is narrow, the canal not being more than from 1 to 1½ miles from the river, and the gravel bed deep and of coarse material.

PUMPING UNDERGROUND WATERS.

Nearly all of the water found in the soil and gravels comes from the percolation following irrigation. This is proved by the fact that the early wells dug in the valley often penetrated gravels without finding any water until the rock was entered. For instance, on the farm of the writer, in 1880, when the Larimer and Weld Canal was being built, a well was put down through 25 feet of soil, 25 feet of gravel, and 25 feet of shale rock. Here a thin layer of sandstone was found, yielding a small supply of hard, alkaline water. This well was about 6 miles north of Greeley, and its bottom was above that of the river, due south of it. Along the river bottom, which averages about 1¼ miles wide, water is found about on a level with that in the river, the sand and gravel underlying the soil admitting of its easy passage to and from the bed of the stream. The dip of the rock strata is toward the stream and slightly to the east.

The water in this well did not rise, indicating that there was no

[1] Seepage or Return Waters from Irrigation, L. G. Carpenter, Bull. 33, Colorado Agricultural Experiment Station, January, 1896, pp. 49 and 50.

pressure, or that the rock overlying this water-bearing sandstone was not impervious or water-tight, which was perhaps also indicated by the alkaline constitution of the water. After irrigation had been going on for two years, the water began to rise in the well, filling it up to the top of the rock and then gradually rising through the 25 feet of gravel. In five years from the digging of the well, the water stood within 25 feet of the surface, where it remains with but scarcely perceptible fluctuation. This is an example of what took place everywhere on the bench land, varied by the different conditions and depths of soil, gravel, and rock.

In Lone Tree Valley water was found at the bottom of the underlying heavy gravel bed, and an abundant supply is to be had above the Larimer and Weld Canal at a depth of 17 feet. The same condition occurs on Owl Creek, a branch that comes from the northeast. At Carrs Station, still farther north, on Lone Tree Creek, the water flows out at several places, presumably forced to the surface by the bed rock. At this latter point some small ditches furnish water to irrigate a few acres. Two wells, one pumped by steam and the other by a windmill, supply water for the irrigation of small tracts of land lying above the line of the canals.

Lone Tree Creek issues from the foothills at Granite Canyon, Wyoming. From there to the point where it ends in the Platte, at the mouth of the Poudre, is 75 miles. The watershed or catchment area has an extent of 536 square miles. The water found in the wells is quite soft, indicating that its origin is near the head of the creek. As the soil overlying the gravel is heavy clay, it is probable that but little of the rainfall penetrates it to any considerable depth, and is either evaporated or runs off from the surface into the bed of the creek. The surface run-off is an intermittent flow, but keeps its channel well defined.

In striking contrast are the conditions in this valley below the point where the Larimer and Weld Canal crosses. A short distance down the water flows permanently in the bed of the creek to such an extent that three or four small canals are taken from it. This water, unlike that usually seeping, is also quite soft, probably for the reason that the layer of soil above the gravel is thin, usually about 3 feet, and hence can furnish but little alkali to the water that percolates through it. The canal above is doubtless the principal source of the added underground water, since the bottom of its excavation must be near if not at the top of the gravel.

Two extensive pumping plants belonging to Andrew Wilson are located in Lone Tree Valley. The first is about 5 miles below the crossing of the Larimer and Weld Canal and 150 feet away from the creek channel. The depth to water here was 8 feet, and the well, 12 by 12 feet wide, was put into the water 10 feet. The well is cased with 2-inch plank, and was dug by machinery operated by a steam engine. The cost of well and two pulsometer steam pumps was $1,200.

The pumps raised a flow that, passing over a weir 2 feet wide, measured 5 inches deep. From this well in one year there were irrigated 240 acres, one-half in wheat, the other in potatoes. It took about 1 ton of coal per twelve hours, which cost at the Eaton mines, 2 miles distant, $1.50 per ton. The pump was operated night and day for about thirty days each season. This plant was erected in 1888, and the pulsometer pump was replaced in 1893 by one centrifugal pump operated by an engine, each costing $400. This is an improvement on the two pulsometers.

In 1892 Mr. Wilson put in another pumping plant, much more extensive, 2 miles farther up the creek. The well was put in a bend of the creek 93 feet from its bed. It is 12 feet by 12 feet wide and 27 feet in depth. Water here was found within 3 feet of the surface. The well cost $800, and the pump, engine, and boiler $1,700 more. The boiler is 60-horsepower, engine 35-horsepower. This pump, when operated constantly, can lower the water in the well 18 feet, leaving 6 feet still in the bottom. The pump is centrifugal and can in forty-five days raise enough water to irrigate 320 acres. It requires about 2 tons of coal a day. The coal is obtained at the same price and distance as in the first case. The owner considers this much cheaper than the purchase of rights in the Larimer and Weld Canal, in which, if obtainable, the cost is $2,000 per 80-acre water right from the canal and $800 per right for reservoir water, making an investment for water for the 320 acres of $11,200, as against $2,500 for the pumping plant. The expense of operation is considerably more, but not enough to equal the interest on the difference of capital invested.

The privilege of pumping water from his own land has not been continuously enjoyed by the owner. In the summer of 1895 he was restrained from pumping at the instance of parties who are diverting water from Lone Tree Creek below his plant. His pumps were stopped by the order of the district court about the middle of the irrigation season. He had already been through the courts in connection with his lower plant, and the case had been decided in his favor in the court of appeals at the spring term of 1893. This legal controversy is of general interest to those engaged in irrigation in the arid regions.

The district court in the first case instructed the jury as a matter of law "that water which percolates through the soil, without an evident and well-known channel, is regarded as a part of the land and belongs to the owner thereof, and he may make such use of the water as he sees fit while it remains on or under his land; second, that digging wells close to a stream, so that the waters of the stream necessarily percolates into such wells, thus diminishing the water previously appropriated, is but doing indirectly what the law forbids being done directly, and will not be allowed."

The verdict was for the defendant, because the evidence did not appear to the jury to prove that the pumping lessened the flow in

Lone Tree Creek. The court of appeals sustained the verdict "because the evidence was so vague, conflicting, and indefinite." But the court criticises the first instruction to the jury cited above in this fashion:

It is probably safe to say that it is matter of no moment whether water reaches a certain point by percolation through the soil by a subterranean channel or by a surface channel. If by any of these natural methods it reaches the point and is there appropriated in accordance with law, the appropriator has a property in it of which he can not be divested by the wrongful diversion of another, nor can there be allowed any substantial diminution. To hold otherwise would be to concede to superior owners of land the right to all the sources of supply that go to create a stream, regardless of the rights of those who previously acquired the right to the use of water from the stream below. Strictly and technically, the instruction should not have been given. There were no facts in evidence upon which it could properly be based. But in view of the fact that nearly all the evidence was directed to the question of whether the water supply was diminished by the acts of the defendants, the finding of the jury that it was not renders the instruction harmless. The other instruction (No. 2) given by the court appears to embrace and clearly state all the law of the case.

The ditch owners apparently made two claims, one for the water visibly flowing in the channel of the stream and one for a part of the water in the gravel below, which they affirmed they had forced up by means of a dam sunk in the bed of the channel at the head of their ditch. The testimony went to show that the pumping did not reduce the visible supply, and it was not proved how much the invisible supply was affected. From the nature of the situation it can be seen that no temporary shallow dam could raise and force the subterranean water into the head of the ditch, which was about 6 feet above the water table.

The valley at this place is 2 miles wide, and the depth of the underlying gravel is about 30 feet. Even if a comparatively wide dam were put into the creek down to bed rock it could not force the water table to rise except to a very limited extent and not to approach the height necessary to enter the head of the ditch. The water after being elevated a few inches behind the dam would undoubtedly move around its flanks in the surrounding gravel. In regard to this aspect of the question the court said:

In the case of a running surface stream the question of appropriation is of easy solution; but not so in a sunken stream, particularly where the water is at an indefinite distance below the surface. Under such circumstances it becomes at once apparent that to appropriate and utilize the water an impervious dam must be constructed and carried down to an impervious base to stop and retain the subterranean water and raise it to the ditch. Whenever such adequate provision is made, any act diminishing the quantity that would naturally reach the dam and add to the supply up to the limit of appropriation, whether by diversion upon the surface, the sinking of wells, and using pumps or otherwise, would be actionable. * * * It is in evidence that the plaintiff had constructed a dam across the stream to supply his ditch, but there is nothing in regard to the character of the dam. * * * The efficiency of the dam to stop, retain, and apply the sunken water should have been shown, for if the water found and taken by defendants by sinking wells and pumping would, in its natural course, have passed under the dam [and he might have said around it] the available supply could not have been materially diminished.

The second case involved both wells, but has more pertinence to the upper one, which is much deeper and placed in a bend of the creek where the water was near the surface. In this case it was shown that the pumping decreased the visible supply in the creek above the heads of the ditches.

On hearing the question of making permanent the temporary injunction which he had granted, Judge Jay H. Bouton, of the district court, said:[1]

This is a case of great importance to all parties interested, and has been commenced at a very critical season of the year, and that is the reason why I thought it should be determined on its merits now. To my mind there is but one question of importance in this case, and that is as to whether the defendant, by the construction of these wells in Lone Tree Creek or its valley and the pumping of water therefrom, has diminished the flow in Lone Tree Creek so as to deprive plaintiffs of water to which they were justly entitled under their decrees as entered in this district; and perhaps preliminary to that is the question as to whether it is a well-defined stream, the water therein flowing in a clearly marked channel, either regularly or intermittently, from which the plaintiffs were entitled to their decrees of priorities. I am clearly satisfied from the evidence that both of these propositions must be answered in the affirmative. The testimony introduced on behalf of the defendant, standing alone, sufficiently establishes the fact that there was a considerable diminution in the volume of water running in Lone Tree Creek after the defendant's pumps were operated, produced evidently by sinking and pumping of water to irrigate his land. If that is true, then he has no more right to sink these wells below the level of the ground, or below the surface of the stream, and thus pump from the stream than he would have to take it directly from the bank [bed] of the stream for the same purpose by means of the construction of ditches. Of this proposition I have no doubt whatever. The motion to dissolve the injunction heretofore granted is denied.

It has been held by the court that if, as the result of pumping on one's own land, it can be proved that a surface stream is diminished to the detriment of one who has a prior right to the use of the water, it will not be allowed, no matter how the stream is fed—that is, whether it derives its water in part from percolation from the estate of the one employing the pumping plant or not. This reverses the doctrine that water mingled in the soil below the surface is part of the estate—the fluid substance being as much a part of the soil as the solid portion. In this case the true derivation of the water is not hard to trace. It is due both to the water flowing at the bottom of the gravel which underlies the valley and to the percolation from the Larimer and Weld Canal and the lands irrigated therefrom, and not to rainfall on the lands of the immediate vicinity. In consequence of this ruling there must be a great loss to this valley of water for irrigation. The quantity secured by ditches is insignificant compared with what could be pumped. The bed of the creek is nearly on a level with the top of the gravel bed, and hence can receive into its channel but a

[1] Third Colorado Court of Appeals, 430, and 33 Pacific Reports, 280.

very small portion of the underground water that is slowly moving along to ultimately make its appearance in the bed of Platte River.

Beginning in 1888 there was considerable activity in erecting pumping plants. A building was put up to manufacture what were known as the Huffer pump and the Nye pump. These, after trial, have been cast aside for the reason that the pumps did little work for the fuel consumed. They were simple in construction, and hence cheap, but they were of primitive design, dating back to the infancy of the application of steam to mechanical purposes. The Swan hot-air pump, devised by one of the men prominent in promoting pumping and the manufacture of the pumps above referred to, is perhaps as economical as any in the market. One of these has been erected on the banks of Cache la Poudre Creek, near Greeley, pumping out of the river for the irrigation of adjacent lands of H. E. Churchill. This was asserted to have a capacity of 1,000 gallons a minute, or about 2½ second-feet. The boiler was so constructed that it could burn coal slack, which cost about $2 a ton laid down, about a ton a day being required. Under usual conditions it probably lifted steadily 1½ cubic feet per second to a height of 15 feet. It was used three years, but was discontinued in 1896, the reason being given that the land cultivated was of poor quality and did not pay expenses, the price of produce being so low. Another of these pumps, raising water 30 feet, was used by J. D. Miller on his farm in connection with canal water when the latter was scarce.

ARTESIAN WATER.

As the lowest part of the valley—that at Greeley—is in the Fox Hills formation, there is little hope of striking the Dakota at moderate depths if the Cretaceous formation here is as thick as reported. R. C. Hills gives the average thickness of the beds lying between the Laramie and the Dakota at 3,500 feet. The latter sandstone outcrops behind the hogbacks near Fort Collins.

In spite of discouragements a project was started in 1883 to put down an artesian well in Greeley. Swan Bros. took a contract for drilling 800 feet. Blue shale was struck at 40 feet. No water was found at 800 feet that would overflow, and the work was prosecuted to 1,150 feet, when a fine bluish-gray sandstone was struck. The flow was quite weak, and it was decided to go farther to see if a better flow could be obtained. A depth of 2,300 feet was reached and no other flowing water was found.

Six others have been put down to this 1,150-foot water, all of which gave a weak flow until pumping was commenced in one, when the water ceased to flow in all the others. The water rises to within 40 feet of the surface. The cost of these wells to the depth of 1,150 feet is about $2,500. The water is distributed by pipes to the different parties that have put down the wells, and is highly valued for washing purposes. It is not hard, but contains matter distasteful to most people. It was once regarded as medicinal in its properties, but now seems to have lost this reputation. The stratum of sandstone from which the water comes is about 25 feet in thickness, and on account of its fineness and hardness yields but a small flow.

Both in Greeley and in the country around it wells have lately been sunk into rocks believed to be of the Fox Hills formation. Soft water has been obtained, which, however, in no case rises to the surface. In Greeley the rock furnishing this water is struck at from 75 to 90 feet, and the water rises to within some 40 feet of the surface.

About 8 miles north of Greeley and 1 mile north of the town of Eaton an experimental well was put down by B. H. Eaton. The following account was obtained from the contractor, Dr. Swan: Above bed rock were 85 feet of soil and gravel. At 250 feet open, porous sand rock was found 30 feet thick, and in it a great abundance of soft water which rose to within 28 feet of the surface. At 450 feet a similar formation was found and the water rose to the same level. After this were shales and sandstones to 625 feet, but no overflow. At 625 feet blue limestone, 6 feet thick, was struck. The work was continued to 970 feet, but with no more sandstone nor water.

On the farm of the writer, about 3 miles south of the above, a well was put down in 1894 to a depth of 265 feet. Of this 55 feet were in soil and gravel to bed rock, the gravel being full of water to the top. Next below was a thin shale with coal indications; then a deep layer of sandstone, 80 feet thick, with plenty of hard water; then 40 feet of shale, underlain by 30 feet of sandstone, containing water, also hard; then 20 feet more of shale, when the sandstone was struck, which now yields the supply pumped from the well. The sand rock is very hard and close grained, and yields a small supply. The water comes to within 70 feet of the surface, but settles rapidly when pumped. There is 170 feet of 6-inch iron piping in the well. The total cost, pump and all, was about $500. Half a mile southeast of this well another was put down in which an abundance of soft water was found at the depth of 190 feet.

About twenty wells have been put down around the above two named within a radius of 3 miles. They vary so much in depth and in quality of water in the different sands as to lead to the inference that this country is much broken by faults and that at places the seepage water from the surface gets into the sandstone. In all the cases so far fairly soft and good drinking water is found in some of the sandstone strata and at a moderate depth, but the pressure in no instance is sufficient to make the water overflow, although it rises to varying depths from the surface.

These wells cost from $200 to $500 each, but furnish the best of drinking water, and have much improved the health of the localities where they are situated, especially in immunity from typhoid fever, the most fatal disease of this region. None of these deep wells have been put down more than 2 miles west of a line joining Eaton and Greeley.

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1895.

Sixteenth Annual Report of the United States Geological Survey, 1894–95, Part II, Papers of an economic character, 1895, octavo, 598 pp.

Contains a paper on the public lands and their water supply, by F. H. Newell, illustrated by a large map showing the relative extent and location of the vacant public lands; also a report on the water resources of a portion of the Great Plains, by Robert Hay.

A geological reconnoissance of northwestern Wyoming, by George H. Eldridge, 1894, octavo, 72 pp. Bulletin No. 119 of the United States Geological Survey; price, 10 cents.

Contains a description of the geologic structure of portions of the Big Horn Range and Big Horn Basin, especially with reference to the coal fields, and remarks upon the water supply and agricultural possibilities.

Report of progress of the division of hydrography for the calendar year 1893–94, by F. H. Newell, 1895, octavo, 176 pp. Bulletin No. 131 of the United States Geological Survey; price, 15 cents.

Contains results of stream measurements at various points, mainly within the arid region, and records of wells in a number of counties in western Nebraska, western Kansas, and eastern Colorado.

1896.

Seventeenth Annual Report of the United States Geological Survey, 1895–96, Part II, Economic geology and hydrography, 1896, octavo, 864 pp.

Contains papers by G. K. Gilbert on the underground water of the Arkansas Valley in eastern Colorado; by Frank Leverett on the water resources of Illinois; and by N. H. Darton on a reconnoissance of the artesian areas of a portion of the Dakotas.

Artesian-well prospects in the Atlantic Coastal Plain region, by N. H. Darton, 1896, octavo, 230 pp., 19 plates. Bulletin No. 138 of the United States Geological Survey; price, 20 cents.

Gives a description of the geologic conditions of the coastal region from Long Island, N. Y., to Georgia, and contains data relating to many of the deep wells.

Report of progress of the division of hydrography for the calendar year 1895, by F. H. Newell, hydrographer in charge, 1896, octavo, 356 pp. Bulletin No. 140 of the United States Geological Survey; price, 25 cents.

Contains a description of the instruments and methods employed in measuring streams and the results of hydrographic investigations in various parts of the United States.

1897.

Eighteenth Annual Report of the United States Geological Survey, 1896–97, Part IV, Hydrography, 1897, octavo, — pp. (In preparation.)

Contains a progress report of stream measurements for the year 1896, by Arthur P. Davis, and four other papers relating to hydrography. The first of these is by Frank Leverett, and relates to the water resources of Ohio and Indiana, especially as obtained by wells; the next is by N. H. Darton, on the artesian waters of South Dakota, being supplementary to his paper in the Seventeenth Annual; following this is a fully illustrated paper, by James D. Schuyler, on water storage, mainly for irrigation and the construction of dams; the last paper, by Robert T. Hill, describes the artesian conditions of a portion of Texas in the vicinity of San Antonio.

Water Supply and Irrigation Papers.

This series of papers is designed to present in pamphlet form the results of stream measurements and of special investigations. A list of these, with other information, is given on the outside (or fourth) page of this cover.

Survey bulletins can be obtained only by prepayment of cost as noted above. Postage stamps, checks, and drafts can not be accepted. Money should be transmitted by postal money order or express order, made payable to the Director of the United States Geological Survey. Correspondence relating to the publications of the Survey should be addressed to **The Director, United States Geological Survey, Washington, D. C.**

WATER-SUPPLY AND IRRIGATION PAPERS.

1. Pumping water for irrigation, by Herbert M. Wilson, 1896.
2. Irrigation near Phœnix, Arizona, by Arthur P. Davis, 1897.
3. Sewage irrigation, by George W. Rafter, 1897.
4. A reconnoissance in southeastern Washington, by Israel C. Russell, 1897.
5. Irrigation practice on the Great Plains, by E. B. Cowgill, 1897.
6. Underground waters of southwestern Kansas, by Erasmus Haworth, 1897.
7. Seepage waters of northern Utah, by Samuel Fortier.
8. Windmills for irrigation, by E. C. Murphy.
9. Irrigation near Greeley, Colorado, by David Boyd.
10. Irrigation in Mesilla Valley, New Mexico, by F. C. Barker.
11. River heights for 1896, by Arthur P. Davis.

In preparation:

12. Water resources of southeastern Nebraska, by Nelson Horatio Darton.

In addition to the above, there are in various stages of preparation other papers relating to the measurement of streams, the storage of water, the amount available from underground sources, the efficiency of windmills, the cost of pumping, and other details relating to the methods of utilizing the water resources of the country. Provision has been made for printing these by the following clause in the sundry civil act making appropriations for the year 1896–97:

Provided, That hereafter the reports of the Geological Survey in relation to the gauging of streams and to the methods of utilizing the water resources may be printed in octavo form, not to exceed 100 pages in length and 5,000 copies in number; 1,000 copies of which shall be for the official use of the Geological Survey, 1,500 copies shall be delivered to the Senate, and 2,500 copies shall be delivered to the House of Representatives, for distribution. (Approved, June 11, 1896; Stat. L., vol. 29, p. 453.)

The maximum number of copies available for the use of the Geological Survey is 1,000. This quantity falls far short of the demand, so that it is impossible to supply all requests. Attempts are made to send these pamphlets to persons who have rendered assistance in their preparation through replies to schedules or donation of data. Requests specifying a certain paper and stating a reason for asking for it are attended to whenever practicable, but it is impossible to comply with general demands, such as to have all of the series sent indiscriminately.

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