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The Agricultural Experiment Station

OF THE

Colorado Agricultural College

RETURN OF SEEPAGE WATER

TO THE

LOWER SOUTH PLATTE RIVER

IN

COLORADO

By RALPH L. PARSHALL

COOPERATION BETWEEN THE DIVISION OF AGRICULTURAL ENGINEERING, BUREAU OF PUBLIC ROADS, U. S. DEPARTMENT OF AGRICULTURE, COLORADO AGRICULTURAL EXPERIMENT STATION, STATE ENGINEER OF COLORADO, AND THE COUNTIES OF WATER DISTRICTS NOS. 1 AND 64 OF COLORADO

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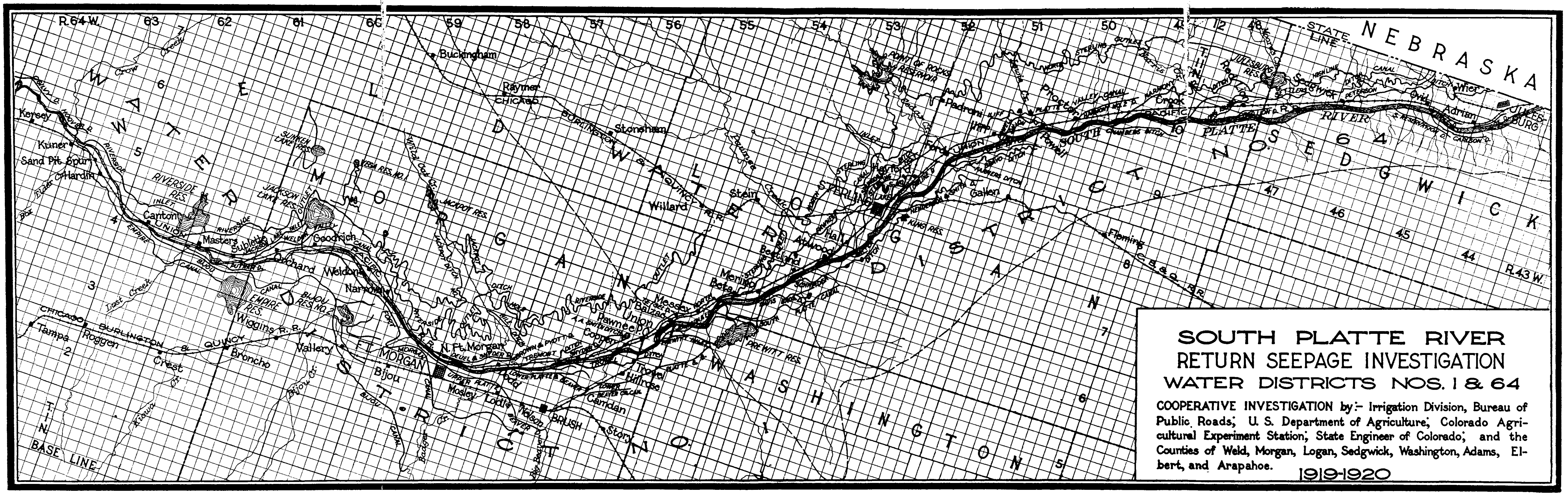

SOUTH PLATTE RIVER
RETURN SEEPAGE INVESTIGATION
WATER DISTRICTS NOS. 1 & 64

COOPERATIVE INVESTIGATION by:– Irrigation Division, Bureau of Public Roads; U. S. Department of Agriculture; Colorado Agricultural Experiment Station; State Engineer of Colorado; and the Counties of Weld, Morgan, Logan, Sedgwick, Washington, Adams, Elbert, and Arapahoe.

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RETURN OF SEEPAGE WATER
TO THE
LOWER SOUTH PLATTE RIVER
IN
COLORADO

By RALPH L. PARSHALL

The investigation of the water returning after diversion to the South Platte River between Kersey and Julesburg was undertaken to determine the extent and distribution of such return waters, the periods of maximum and minimum return flow and various other phases relative to the problem. This study does not constitute the first or original investigation of this nature on the river, but it is believed that the plan of organization and the extent of the work permit closer approximations to the return flow than have heretofore been possible. Bulletins Nos. 33 and 180, published by the Colorado Agricultural Experiment Station, on the Seepage or Return Water from Irrigation, by L. G. Carpenter, give an account of the extent of the return flow for short periods during the early nineties. The State Engineer of Colorado has, for a number of years, kept records of the return flow of this stream, which show that there is a gradual yearly increase.

Past investigations were made by a series of measurements taken during the fall or spring, when it was assumed that the river flow was more or less constant. The seepage measurements made by R. G. Hosea, now Deputy State Engineer of Colorado, during the years 1916, 1917, and 1918, were much more extensive than those previously made and comprise a number of series made at various times of the year. Comparisons of the results obtained from these earlier investigations with the results obtained from the recent study, will be found later in this discussion, furnishing the basis for conclusions as to the average yearly increase in the return flow.

It is impracticable to make any positive and clear distinction between "seepage" and "return waters" in this discussion. It was entirely beyond the scope of this investigation or study to attempt the differentiation between seepage, waste and run-off waters entering the river from the so-called inflow streams referred to in this bulletin, and, similarly, it was not possible to segregate and tabulate the amounts of water incapable of measurement that enter the channel. "Seepage", as here used, refers to water entering the river channel in the form of infiltrating or percolating waters, from springs, from water-bearing strata and water collected in sloughs or bayous in the river trough, all augmenting the stream flow. "Waste water" is here defined as surplus or excess water diverted from the stream and later returned intentionally or knowingly. "Run-off waters", as here used, refer to surface water supplies resulting directly from precipitation.

The interpretations made and conclusions drawn herein are based upon the assumption that the inflow streams tributary to the river, of practically measureable volumes, are either waste waters or natural runoff, while that portion of the supply entering the river channel from water-bearing strata and hidden or submerged springs is water originally diverted at higher points, returning to the river, but excluding waste water as defined above. The assumption is not strictly correct as to either class because a part of the water supply derived from such inflow streams is nearly always seepage, the remainder being waste from canals and run-off, while that coming from springs and small unobserved streamlets may result, in part, from natural causes and not directly from irrigation.

The return water to the South Platte River is due, without question, to the application of irrigation water to the immediate basins of the river valley and of the tributaries leading to this stream; to the seepage return from the canals and ditches and large storage reservoirs; and also to the waters absorbed in the banks and sandbars along the river at high stage, which return when the flow of the river is decreased. A part of the water applied to areas quite remote from the stream eventually reaches the river, thus adding its quota in maintaining the strength of the river's flow.

It was not until the early sixties that irrigation was practiced in the Platte Valley or its tributaries; it is known that before the development of irrigation in this valley, the flow of the river at times during the summer months was exceedingly small; and at places the stream would sink beneath the sands of the river bed. This condition was not conducive to the extensive development of irrigation systems. Naturally, at first, the ditches leading from the river were short in length, small in capacity, and served relatively small areas along the river bottom. These small irrigated areas proved successful in demonstrating the possibilities of irrigated agriculture, and at the same time the water applied began filling the soil, raising the water-table and causing a return flow to the river channel. At first this effect was insignificant, due to the relatively small amount of irrigation and the limited amount of water available for this purpose. Later, larger and longer ditches were constructed and also reservoirs were created in natural basins adjacent to the stream, which were filled by the more abundant water supply during the spring run-off.

This new development provided water for more extensive areas, which, in turn, created a more pronounced return flow. The tributaries to the South Platte River, being mountain streams, maintained a more uniform flow and perhaps were better suited to the early development of irrigation, and as this development on the side streams was expanded with other reservoir systems, at first of small capacity, it has without doubt had a very marked effect upon the flow of the South Platte River itself. The construction of the canals and reservoirs in the Poudre Valley and the application of water there has probably influenced the return flow to the South Platte River below the junction of these two streams. The practice of irrigation, including the use of extended distributing systems, has created conditions which not only tend to maintain a constant return flow but also have apparently increased the river's discharge beyond all expectation.

From 1883 to 1885, several large canals were constructed in the South Platte Valley, and in the Third Biennial Report of the State Engineer of Colorado, published December 1, 1886, this statement occurs:

"This amount (flow in river) is largely increased by seepage, which is continually going on and increasing each year and also increasing as the area of irrigation is extended, thereby affording a more equal and continued supply of water both early and late in the season, an advantage not enjoyed on the streams close to the mountains."

This statement, made so soon after the development of the several canal systems, would seem to warrant the assertion that the increased seepage to the river from the applied irrigation was soon apparent. The Sixth Biennial Report of the State Engineer contains the following statement by James Hurley, Commissioner of District No. 1:

"There were 43,730 acres irrigated in 1892, being 26,730 acres more than in 1890. There has been a good flow of water in this district which must be largely due to seepage, as the Platte, as well as other streams above Greeley, was drawn dry to furnish water for the district through which they run."

These statements seem to indicate that the seepage to the river was unmistakably of sufficient quantity to be of practical importance.

Perhaps no other Colorado stream has such an abundant return flow as the South Platte River. Various factors influence this return flow, such as the sandy nature of the soil, the liberal use of water in irrigation and the nearness of the irrigated areas to the river. It appears that in the vicinity of the large storage reservoirs, the return flow is greatest; however, seepage is returning to the river channel in greater or less quantity thruout its whole course. R. G. Hosea has estimated the average annual flow of the South Platte River into Nebraska to be

300,000 acre-feet, which is very largely seepage. It is safe to say that a large percentage of the return flow has been applied a number of times in actual irrigation as the water passes down the river valley. Table 1 has been prepared to show the discharge in acre-feet of the river at Julesburg but, because of incomplete records for each full year, it was necessary to limit this table to eight months. The average flow from April to November for a period of 17 years is 264,200 acre-feet; and it is safe to assume that the remaining portion of the year, on the average, would more than make up the amount necessary to cause the general average to exceed an annual discharge of 300,000 acre-feet.

TABLE 1.—Discharge in acre-feet of the South Platte River at Julesburg for the months of April to November for the years 1902 to 1920. Table compiled from the biennial reports of the State Engineer of Colorado.

Month	1902	1903	1904	1905	1906	1907	1909	1910
April	2700	26500	1000	113200	37800	10000e	63700	17100
May	2300	2300	5900	363600	18600	6600	25900	2800
June	1700	800	98900	285800	2500	3400	168000	500
July	1200	200	11200	12200	2400	3800	72500	400
Aug.	200	8000	3000	42700	1300	3200	85000e	1200
Sept.	9100	900	1400	2500	1800	2400	98600	1000
Oct.	7900	1000	4700	4200	41800	5800e	71900	1400
Nov.	2200	1300	6500	18500	49200	9200	79700	1400
Totals	27300	41000	132600	842700	155400	44400	665300	25800

1911	1912	1914	1915	1916	1917	1918	1919	1920
1500	17100	94100	73800	3600	25700	8500	30700	42100
1500	7000	363000	189000	4600	109000	6900	18900	88900
1000	1900	265000	141000	3000	281000	7700	2800	19100
700	3700	11700	7100	1600	32000	21700	1400	5500
3400	38000	14400	15200	1800	2100	17600	800	4200
700	35000	26500	8800	2100	4500	12500	7900	22300
1300	25300	20700	48000	6800	33300	29600	28500	21300
1600	20500	46600	58400	11800	23400	26400	25000e	17100
11700	148500	842000	541300	35300	511000	130900	116000	220500

Mean for 17-year period 264,200 acre-feet.
(e) estimated.

The plains area adjacent to the South Platte River has many depressions or arroyos leading to the stream, and before the extensive use of water for irrigation, many of these water courses were dry except when carrying flood flow caused by heavy, local showers or cloud-bursts. Today many of these formerly dry channels are carrying living or perpetual streams, returning to the river seepage and waste water from irrigation. A very large proportion, however, of the return water appears in the river channel as invisible streams of percolating water or from hidden or submerged springs. In many places along the river bottom are sloughs and channels that parallel somewhat the main river channel, and these carry seepage or return water. These water courses vary in size from small streamlets to streams of several second-feet, but for the most part are too small to be included in the measured streams and are accounted for as unobserved return waters. These sloughs and channels along the river bottom are assumed to be carrying water returning to the river channel from lateral seepage. It has been observed that the amount of water flowing in these channels varies directly with the stage of water in the river channel itself, and when there is a greater depth of water in the river, the return of the seepage or underflow is retarded temporarily because of the rise in the water-table, which later, in turn, increases the flow in these parallel channels. Other noticeable features are the accumulation of the seepage from the storage reservoirs into creeks or drains leading to the river, and also under favorable conditions, where two ditches parallel each other quite closely, it has been observed that the lower one accumulates a fair head without diversion from the river. Fig. 1 shows a typical seepage stream.

Fig. 1.—A typical stream of seepage or return water flowing to the river channel. This stream of 15 second-feet has been accumulated in a distance of about 1.5 miles.

The diversions from the river after the spring floods have subsided are practically all from seepage or return water supplies, and only during summer floods or freshets is the river flow increased. The flow of the stream is not constant because of variations of the inflow and outflow. It also has been observed that there is a marked diurnal change in the discharge, especially in that portion of the river in District No. 64. The ditches diverting seepage water, drains or collecting channels, all seem to indicate a gradual, daily rise and fall when left undisturbed. Where considerable water is flowing in the river, the daily variation is less noticeable because of the interruption due to changes of diversions and possibly increased flows caused by water admitted from the storage reservoirs. Further comment will be made concerning the diurnal variation of the return flow.

Two series of observation wells were put down for the purpose of studying the fluctuation of the ground-water, one line between the Riverside reservoir and the river, and the other on the south side of the river at Snyder. Elsewhere may be found a discussion pertaining to the variation of the water-table and velocities of the underflow.

THE SOUTH PLATTE DRAINAGE AREA

The plains area of the eastern part of Colorado, containing the valley of the South Platte River, is underlaid by an extensive series of sedimentary formations which lie nearly level, but steeply upturned against the front range of the mountains. Of these various strata, the Dakota sandstones are of early formation and are found at great depths, especially near the foothills, and superimposed are other strata of shales and sandstones of great thickness. Of these later formations, perhaps the Pierre shales are of greatest thickness. Over this is found the Laramie formation, consisting of shales and sandstones which constitute the top covering of the geologic deposits. Records of deep borings at Greeley indicate shale at 2,260 feet with the Dakota sandstones at still lower depths, while at a point in Kansas, 250 miles east of Denver but at about 2,500 feet lower elevation, the Dakota formation is 1,400 feet below the surface.

The South Platte River has for ages flowed to the east over this plains area and has, by erosion, established its valley between areas of higher elevation. The sands and gravel of the river bed contain great quantities of water which, in part, are the subterranean flow of the stream, while entering from the higher areas on either side of the valley are other waters following various underground strata.

The trough of the South Platte River and valleys of the tributary streams are well defined, and it would seem quite improbable that waters flowing within the watershed and valley of this river would find their way beyond this great drainage basin. It is true that water travels very great distances below the earth's surface, as is evidenced by the extensive artesian flows of South Dakota; and to determine to what extent, if any, waters from the South Platte River reach beyond its basin, an investigation was made in 1891, by E. S. Nettleton, Prof. Robert Hay and W. W. Follet, concerning artesian and underflow conditions in eastern Colorado, western Nebraska and Kansas. Their study shows quite conclusively that the flow of Frenchman Creek in Colorado and the sheet water contained in the water-bearing gravels in that vicinity do not have their source of supply from the South Platte Valley, and it is very unlikely that other streams flowing to the east between the South Platte and Arkansas rivers can claim waters originating from either of these great water sheds.

The South Platte River heads in South Park, Colorado, approximately 100 miles southwest of Denver. This stream, for the first one hundred miles, is confined to mountain canyons and through this course numerous other streams feed into its channel. Irrigation is practiced through its mountain course where meadows and small fields are irrigated, but, due to the nature of the soil and the topography, a large proportion of the water applied soon finds its way again to the river channel. The first large irrigation canal from the river heads near the mouth of

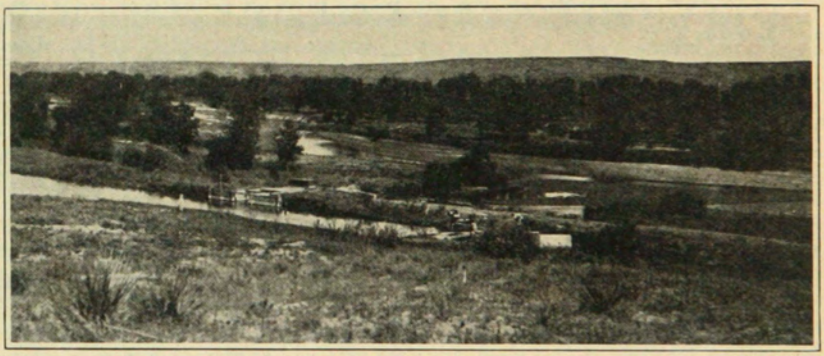

Fig. 2.—View of South Platte River Valley above Fort Morgan. Upper Platte and Beaver Canal in the foreground showing waste-way and rating flume.

the canyon twenty miles south of Denver. The general course of the river is north from the mouth of its mountain canyon to near its junction with the Cache la Poudre River, where the course is to the east, and then northeast from the vicinity of Fort Morgan to the Nebraska state-line. The main tributaries above Kersey are from the west and northwest, while those of the lower valley are from the north. Comparatively few streams enter from the south and these are of small capacity except in time of flood.

The main tributaries to the South Platte River are Bear Creek, Clear Creek, Boulder Creek, and the St. Vrain, Thompson and Cache la Poudre rivers. Of these, the Poudre is the largest, having a discharge during the spring run-off of approximately 5,000 second-feet, and a minimum flow, during the fall and winter months, of from 50 to 100 second-feet. Crow and Lodge Pole Creeks enter from the north, heading in Wyoming, but their flows are relatively small, Lodge Pole having an average discharge of approximately 20 second-feet. Bijou Creek, which enters the river from the south at a point 6 miles west of Fort Morgan, has an average discharge of 15 second-feet. Various other water courses lead to the river but carry little or no water. Kiowa Creek, which heads on the plains east of Palmer Lake, is roughly 100 miles in length and its arroyo at the river near Orchard has apparently carried no water whatsoever for a number of years, irrigation and storage along its course having absorbed its entire flow. Cedar Creek, below Sterling, enters from the north and discharges approximately 15 second-feet, all of which is seepage and waste water. The map, Plate 1, of the lower South Platte Valley, shows the general course of the river as well as the extent of the canals and reservoirs of this part of the valley.

TABLE 2.—Mean Velocity of South Platte River at points between Kersey and Julesburg.

Station	Date	Discharge Sec. Ft.	Area Sq. Ft.	Mean Velocity Ft. per Sec.	Means
Kersey	3/20/20	352.2	156.2	2.25	
Kersey	4/27/20	1487.0	503.92	2.95	2.23
Kersey	5/ 5/20	3600.0	1553.5	2.32	
Kersey	9/20/20	219.9	123.25	1.78	
Orchard	7/19/20	312.16	144.9	2.15	
Orchard	4/29/20	939.3	369.3	2.54	2.43
Orchard	5/ 6/20	2879.0	917.3	3.14	
Orchard	9/ 5/20	193.18	101.34	1.91	
Fort Morgan	4/ 8/20	208.06	87.27	2.38	
Fort Morgan	4/29/20	997.27	388.52	2.55	2.49
Fort Morgan	5/ 8/20	3155.4	1068.8	2.95	
Fort Morgan	6/25/20	374.2	178.72	2.09	
Balzac	4/27/20	465.44	207.39	2.24	
Balzac	5/24/20	1382.0	531.7	2.60	2.37
Balzac	5/ 7/20	2143.3	813.5	2.65	
Balzac	9/21/20	184.70	93.07	1.98	
Beetland	4/28/20	660.05	271.45	2.43	
Beetland	5/ 9/20	2219.0	769.7	2.88	2.47
Beetland	8/ 1/20	186.65	89.53	2.08	
Beetland	10/27/20	390.32	156.85	2.49	
Crook	4/26/20	888.0	362.48	2.44	
Crook	6/15/20	195.86	119.94	1.63	1.97
Crook	8/31/20	382.34	177.44	2.16	
Crook	6/ 1/20	224.68	137.75	1.63	
Julesburg	2/18/20	226.31	127.15	1.78	
Julesburg	4/25/20	1496.0	575.34	2.60	2.23
Julesburg	5/11/20	2490.5	1013.95	2.46	
Julesburg	9/14/20	471.95	226.78	2.08	

The South Platte River bottom is confined between bluffs of moderate elevation. These bluffs in that part of the valley between the mouth of the Cache la Poudre river and Sterling are, in general, of a sandy nature, and in many places, especially on the north side of the river, the bluffs are almost pure sand. The river channel is of varying widths, ranging from 800 to 2,000 feet, including that occupied by sand bars and islands, while for extremely high water the overflow area may occupy a width of one and one-half miles. Fig. 2 is a view of the valley near Fort Morgan and shows the character of the river channel.

For the most part the bed of the river is sand of varying degrees of fineness, but nearer to the mountains are found coarse sand and gravel. The river channel, particularly below Kersey, owing to the comparatively flat grade and wide bottom, is broken into a number of streams and only in a few places is the whole stream found in a single channel. Due to the sandy bottom of varying depth, and the scouring action of the current, the channel shifts, and unfortunately this characteristic of the river rendered it difficult to obtain sections that were constant from a hydrographic standpoint. From the mouth of the Cache la Poudre to the Nebraska state-line, only two points are known where bedrock appears in the channel, these points being just west of Fort Morgan near the head of the Upper Platte and Beaver Canal, and at the Narrows.

The grade of the river is quite uniform, and from Kersey to Balzac, a distance of approximately 70 miles, the fall is 7 feet per mile; while from Balzac to Julesburg, approximately 80 miles, the grade is 8 feet per mile. These values have been determined from the relative elevations above sea level of bench marks established by the U. S. Geological Survey. Table 2 shows the mean river—velocity at various points as determined by measurements made at the river stations maintained during the investigation. It will be observed that the mean velocity of the river between Kersey and Balzac is greater than between Balzac and Julesburg. The average slope as determined by elevations is greater east of Balzac, which might appear to be inconsistent. This, in part at least, is explained by the smaller, average discharge in the lower section of the river.

Robert J. Wright* states,

"As an explanation for the apparent reduction of velocity in the stretch of the river from Balzac to Julesburg, more water is required to raise the underflow in this section than from Kersey to Balzac because the gravel beds underlying the valley are much wider. It is believed that the return water ceases to increase the flow of the river while this rising of the underflow is being affected, and that in some places the river may

* Irrigation engineer and Superintendent of Prewitt Reservoir, Sterling, Colorado.

actually lose water into its bed until this rise of water-table has been accomplished. Generally speaking, the average water prism or cross-section has a much less wetted perimeter and a greater average depth between Kersey and Balzac than from Balzac to Julesburg for the same flow, and more especially for the larger discharges. The greater depth of channels from Kersey to Balzac would be a stronger factor for increased velocities than the slightly greater fall per mile existing from Balzac to Julesburg."

During the high water of May, 1920, it was possible to follow with some degree of certainty the rise and crest of the flood as it passed down the valley. The records of the water-stage recording instruments at the various river stations are the basis of compiling Table 3, and it was found that these data resulted in a smooth curve relation.

TABLE 3.—Velocity of Flood Crest in miles per hour, May 1 to 7, 1920, between Kersey and Julesburg.

Station	Miles	RISE Date	RISE Hour	CREST Date	CREST Hour	Disch. in Sec. Ft.	Velocity miles per hour Rise	Velocity miles per hour Crest
Kersey	25.5	5/1	12 p. m.	5/5	9 a. m.	4100		
Orchard		5/2	1 p. m.	5/5	10 p. m.	3000		
Interval in hrs.			13		13		1.95	1.95
Orchard	18.5	5/2	1 p. m.	5/5	10 p. m.	3000		
Ft. Morgan		5/2	12 p. m.	5/6	9 a. m.	3240		
Interval in hrs.			11		11		1.68	1.68
Ft. Morgan	20.7	5/2	12 p. m.	5/6	9 a. m.	3240		
Balzac		5/3	2 p. m.	5/6	12 p. m.	2050		
Interval in hrs.			14		15		1.48	1.38
Balzac	12.0	5/3	2 p. m.	5/6	12 p. m.	2050		
Beetland		5/3	12 p. m.	5/7	12 a. m.	2375		
Interval in hrs.			10		12		1.20	1.00
Beetland	35.5	5/3	12 p. m.	5/7	12 a. m.	2375		
Crook		5/5	7 p. m.	5/9	9 a. m.	2350		
Interval in hrs.			43		45		0.83	0.79
Crook	30.5	5/5	7 p. m.	5/9	9 a. m.	2350		
Julesburg		5/7	3 p. m.	5/12	6 a. m.	2550		
Interval in hrs.			44		69		0.69	0.44

It is to be observed that from Kersey to Julesburg the velocity of both rise and crest decreased, which appears to be consistent with actual, observed velocities at the river stations. The velocity is reduced not only by the nature of the channel, but also by the diversions which make a reduction in the discharge of the stream as it passes down the valley.

The water of the river carries more or less silt during the spring and early summer months, but along the lower reaches the water is usually clear, and only at high-stage periods is the whole stream muddy. This condition results because many of the main diversions are above Sterling and the lower stream bed carries only waste and seepage waters.

ORGANIZATION AND HYDROGRAPHIC MEASUREMENTS

The investigation of the return of seepage water to the lower South Platte River in Colorado was made possible by a cooperative agreement in which the Irrigation Division of the Bureau of Public Roads, U. S. Dept. of Agriculture, the Colorado Agricultural Experiment Station, the State Engineer of Colorado, and the various counties of Water Districts 1 and 64 were interested. These two districts assumed the salaries of their respective deputy water commissioners, who not only assisted the commissioners in their respective districts but also acted as assistant hydrographers in connection with the investigation. The Irrigation Division of the Bureau of Public Roads, the Experiment Station and State Engineer's office contributed approximately equal amounts for salaries and general expenses. The general headquarters were located at the office of the Colorado Agricultural Experiment Station at Fort Collins and two field offices were maintained, one at Fort Morgan and the other at Sterling. At the Fort Morgan office were deposited the field data, where the original computations of hydrographic data were made. It was at first thought possible to reduce and put in proper form the data which would be applicable to the actual immediate conditions of discharge for all the stations under observation, but it soon became apparent that the corps of assistants was inadequate to accomplish this part of the investigation.

The field work was carried on continuously from about July 1, 1919, to November 15, 1920. During the colder portion of the winter the register floats were frozen in the still wells, making observations rather difficult as well as uncertain. About November 10, 1919, very severe weather occurred, and until about January 1, the records were not of sufficient reliability to warrant basing conclusions upon them; therefore, this period has been omitted from the tabulated data. More or less difficulty was experienced throughout the winter and spring months because of the inability to travel by automobile. The field schedule required that each week the recording instruments be visited, the record chart removed and blank chart replaced. Practically three days each week were required for changing these instrument charts, one or two days for current-meter gagings, while the remaining portion of the time was spent in the office. During the investigation from about July 1, 1919, to November 10, 1920, 860 gagings with the current meters were made, and 2,500 weekly, register charts for the river and canal stations were obtained.

The hydrographic equipment used during the investigation consisted of various types of water-stage recording instruments, Gurley-Price current meters and other necessary minor equipment. The investigation was begun during the spring of 1919, at a time when prices were much above the average, and this factor greatly influenced the plans of the organization as well as the item of equipment. A reconnoissance of the section of the river to be studied brought out the facts that the matter of transportation for the field men could only be met by the use of automobiles, and that the number of registering instruments needed would greatly exceed the available supply. At the beginning there were four recording instruments already established which could be used in the investigation, leaving approximately 55 additional instruments to be provided. About 30 registers were available from various sources, making it necessary to obtain 25 more to satisfy the requirements. The cost of these additional instruments made it quite impossible to purchase new ones and plans for constructing 25 instruments according to a new design were adopted. These new instruments were built at the hydraulic laboratory of the Colorado Agricultural Experiment Station at Fort Collins, at a cost of approximately one-half of that asked for factory-made recorders, and field experience has demonstrated the practicability of this new design. Various kinds of recording instruments were installed, and of the total number, 9 different types were used with varying degrees of success.

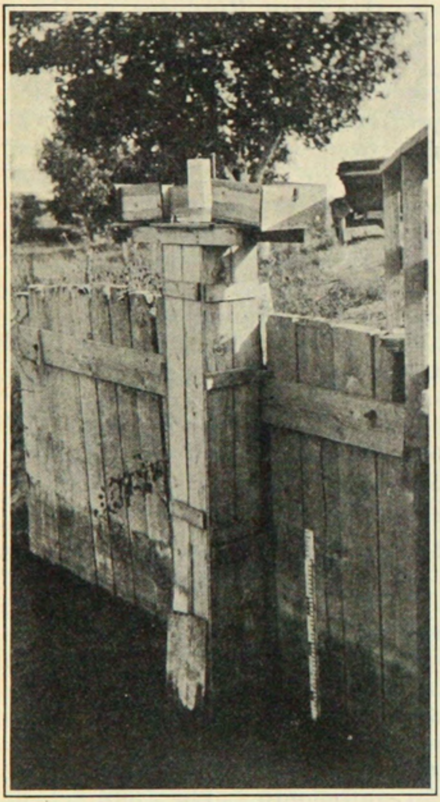

Fig. 3.—Register installation at the Beetland river station. New type of instrument and wooden gage rod with copper bars. Box mounted on approach of bridge, down stream side.

At each register station there was installed a gage, graduated in feet and tenths. Painted metal strips were first tried but the chemical action of the water soon destroyed the graduations. Wooden strips, painted white with copper bars fastened with brass pins at the tenth-points, and special copper disks to indicate the foot-marks, replaced the painted metal gages. This type of gage was very satisfactory and was always easily read. Fig. 3 shows a typical installation of the recording instrument and the new type of gage at the Beetland river station.

The current meter was used for the determination of the velocity of the flowing streams, the method of measurement depending upon the conditions found at the respective section. For the river gagings the six-tenths method was most generally used, either with the cable or rod suspension, and ordinarily these measurements were made by wading the channel except in time of high water, and then the observations were taken from bridges using the cable suspension. The ditch or canal measurements were made in rating flumes

TABLE 4.—Comparisons showing the variations in current-meter measurements by different methods and observers.

Date	Canal	Gage Height	Discharge Sec. Ft.	Method	Observer	Remarks
7/12/19	Meadow Farm	1.78	15.8	Ver. Int.	Grosback	In rating flume
7/12/19	Meadow Farm	1.78	16.3	Ver. Int.	Hemphill	In rating flume
7/12/19	Meadow Farm	1.78	15.3	0.2 & 0.8	Grosback	In rating flume
7/12/19	Meadow Farm	1.78	17.4	0.6	Grosback	In rating flume
7/12/19	Meadow Farm	1.78	15.8	0.7	Grosback	In rating flume
7/12/19	Meadow Farm	1.78	15.8	Mult. Pt.	Grosback	In rating flume
4/16/20	Up. Pl'te & B'vr	1.51	85.3	0.6	Hemphill	In rating flume
4/16/20	Up. Pl'te & B'vr	1.51	78.7	Ver. Int.	Hemphill	In rating flume
5/18/20	Up. Pl'e & B'vr	2.16	157.6	Ver. Int.	Parshall	In rating flume
5/18/20	Up. Pl'e & B'vr	2.16	155.9	Ver. Int.	Parshall	In rating flume
5/18/20	Up. Pl'te & B'vr	2.15	147.1	0.2 & 0.8	Hemphill	Below rat'g flume
4/ 5/20	Trowel	0.67	13.1	Ver. Int.	Hemphill	Earth Section
4/ 5/20	Trowel	0.67	12.7	0.6	Hemphill	Earth Section
5/25/20	A. A. Smith	1.55	14.0	0.6	Hemphill	In rating flume
5/25/20	A. A. Smith	1.55	13.6	Ver. Int.	Hemphill	In rating flume
5/25/20	A. A. Smith	1.55	14.0	Ver. Int. mid points	Hemphill	In rating flume
1/28/20	Riverside Inlet	2.45	229.3	Ver. Int.	Snyder	In rating flume
1/28/20	Riverside Inlet	2.46	226.6	0.6	Snyder	In rating flume
6/12/20	Pawnee	1.57	133.2	Ver. Int.	Hemphill	In rating flume
6/12/20	Pawnee	1.57	136.5	0.6	Hemphill	In rating flume
5/21/20	Putnam	0.82	8.0	Ver. Int.	Hemphill	In rating flume
5/21/20	Putnam	0.82	8.1	0.6	Hemphill	In rating flume
2/ 8/20	South Platte	0.94	127.3	0.6	Snyder	Earth Section
2/ 8/20	River at Orchard	0.94	130.0	Ver. Int.	Snyder	Earth Section
2/ 1/20	No. Sterling Inlet	2.45	172.2	Ver. Int.	Snyder	In rating flume
2/ 1/20	No. Sterling Inlet	2.45	170.6	0.6	Snyder	In rating flume
6/25/20	Lower Pl'te & B'r	0.90	47.3	Ver. Int.	Parshall	In rating flume
6/25/20	Lower Pl'te & B'r	0.90	47.4	0.6	Parshall	In rating flume
7/17/20	Lower Platte &	1.67	188.0	Ver.Int.	Parshall	In rating flume
7/21/20	Beaver	1.65	187.1	Ver. Int.	Northrup	In rating flume

TABLE 4.—(Continued)

Date	Canal	Gage Height	Discharge Sec. Ft.	Method	Observer	Remarks
2/5 /20	Jackson Lake In't	2.98	281.9	0.2 & 0.8	Snyder	In rating flume
2/5 /20	Jackson Lake In't	2.98	280.8	Ver. Int.	Snyder	In rating flume
2/ 9/20	Harmony No. 1	1.11	115.8	0.2 & 0.8	Lightburn	In rating flume
2/ 9/20	Harmony No. 1	1.11	123.8	Ver. Int.	Lightburn	In rating flume
2/19/20	Harmony No. 1	0.65	43.9	0.6	Hemphill	In rating flume
2/19/20	Harmony No. 1	0.65	48.5	Ver. Int.	Hemphill	In rating flume
6/ 5/20	Deuel & Snyder	0.43	7.9	0.7	Hemphill	In rating flume
6/ 5/20	Deuel & Snyder	0.43	8.2	Ver. Int.	Hemphill	In rating flume
6/ 7/20	Deuel & Snyder	0.74	13.5	Ver. Int.	Hemphill	In rating flume
6/ 7/20	Deuel & Snyder	0.73	13.7	0.6	Hemphill	In rating flume
6/ 9/20	Duel & Snyder	1.80	37.4	Ver. Int.	Hemphill	In rating flume
6/ 9/20	Deuel & Snyder	1.81	38.0	0.2 & 0.8	Hemphill	In rating flume
6/17/20	Blair	2.23	39.6	Ver. Int.	Northrup	In earth section
6/17/20	Blair	2.23	42.2	0.6	Northrup	In earth section
4/21/21	Jackson Inlet L.	1.82	116.8	0.6	Lightburn	In earth section
4/22/21	Jackson Inlet L.	1.84	118.3	0.6	Parshall	In earth section
4/22/21	Jackson Inlet U.	1.42	129.6	0.6	Parshall	In rating flume
4/22/21	Jackson Inlet U.	1.42	129.8	0.6	Lightburn	In rating flume
4/30/21	Empire, lower	2.59	296.8	0.6	Lightburn	In earth section
4/30/21	Empire, lower	2.58	298.9	0.6	Parshall	In earth section
4/30/21	Empire, upper	4.37	440.8	0.6	Parshall	In earth section
4/30/21	Empire, upper	4.37	433.2	0.6	Lightburn	In earth section
5/ 6/21	Empire, lower	2.31	245.0	0.6	Lightburn	In earth section
5/ 6/21	Empire, lower	2.29	240.6	0.6	Lightburn	In earth section

L=Lower Station
U=Upper Station

where available, and here the integration method was most generally used, the two-and-eight-tenths method being frequently used, however, as a check. Table 4 shows the consistency of the various methods used, as well as the agreement between two observers using the same method. The last few ratings in this table were made on the Empire and Jackson Lake Inlet canals to determine approximately the canal losses. The six-tenths method was used here to establish consistency in the ratings, and also because sections chosen for the stations were not well adapted to the integration method.

The current meters used during the investigation were of the Gurley pattern, which could be used either as rod- or cable-suspension type, as the case required. These meters were calibrated at the hydraulic laboratory at Fort Collins, where they were tested at the beginning and end of each season's work. No important change was detected in the equation of any of the meters as is shown by the following tabulation:

METER	RATED	EQUATION
Gurley 15188	June 7, 1919	V=2.20R+0.03
Gurley 15188	Nov. 24, 1919	V=2.21R+0.02
Gurley 15188	Nov. 26, 1920	V=2.20R+0.05
Gurley 1109	March 21, 1920	V=2.23R+0.04
Gurley 1109	Nov. 26, 1920	V=2.23R+0.05
Gurley 1434	June 7, 1919	V=2.19R+0.05
Gurley 1434	March 21, 1920	V=2.20R+0.04
Gurley 1434	Nov. 26, 1920	V=2.18R+0.06
Gurley 1081	Nov. 25, 1918	V=2.38R+0.05
Gurley 1081	Nov. 24, 1919	V=2.38R+0.06

Meter 1081 was of the small, Gurley type, designed for rod suspension only, and was used but a short time during the first season.

The computations were all based on the rod-meter equations, but calibrations with the meter suspended by cable with standard torpedo weight attached were also made. The following comparisons are given to show the relative error caused by using one rating table for both rod and cable observations:

Gurley 15188	"Rod"	V=2.20R+0.03 (mean)
	"Cable"	V=2.22R+0.02
Gurley 1109	"Rod"	V=2.23R+0.04 (mean)
	"Cable"	V=2.21R+0.07
Gurley 1434	"Rod"	V=2.19R+0.05 (mean)
	"Cable"	V=2.20R+0.03

At one revolution per second, which is approximately an average field condition, it is observed that the calculated velocities are different by approximately one-half of one percent; however, other conditions entering into gagings which necessitate the use of the cable, involve errors much greater than that resulting from the use of one equation for both types of meter suspension.

The discharge curves of the river and canals were prepared for each season on uniform cross-section sheets, and the standard curve drawn for points of as near uniform condition of channel as was possible. As subsequent gagings were made, the newly plotted points would show the deviations from the standard curve, disclosing approximately the amount of correction for that particular time. A typical curve illustrating the method of correction is shown in Fig. 4. This standard discharge curve was determined by three plotted points where the gagings were all made the same day, and all subsequent observations show less velocity for the same depth, causing the plotted observations to fall above the standard curve. It is obvious that to apply the observation of depth, as given by the instrument chart, to the standard curve, the gage height must be corrected to give the true discharge. This instrument chart is the graphical record of the gage height for a period of one week and forms the basis of computing the discharge at the various stations where these recording instruments were maintained.

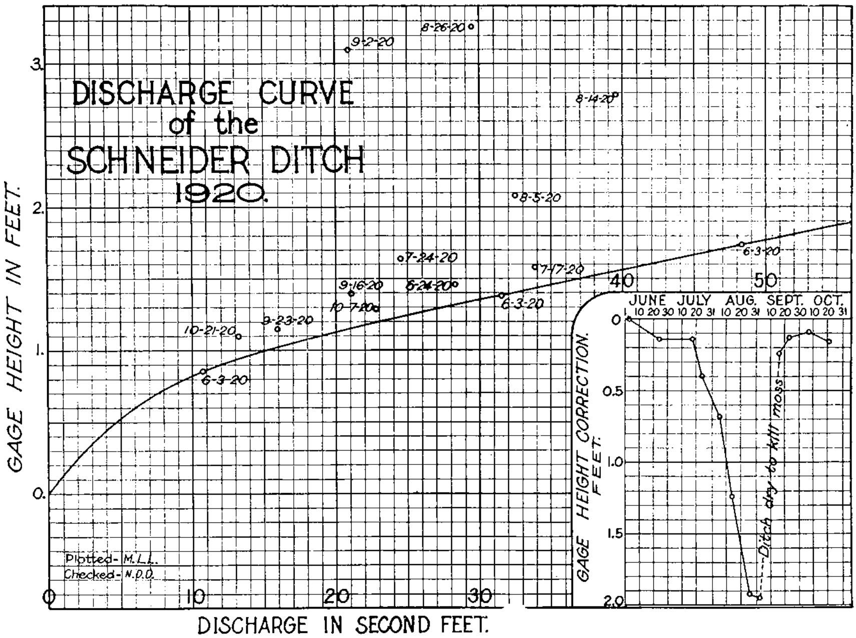

Fig. 4.—Discharge curve of the Schneider Ditch and diagram for correcting heads to the proper discharge.

ECONOMIC IMPORTANCE OF THE INVESTIGATION

The economic value of this investigation is not confined merely to the determination of the extent of the return flow and the practical importance to the river commissioners in the management and distribution of the waters, but has afforded the means of estimating, in a general way, the value of this return water. For a number of years it has been known that the return flow to the river has been exceptional, but only by detailed study has it been possible to approximate its actual amount and distribution along the river. As shown in Table 12, the mean return flow varies from 1.99 to 8.50 second-feet per mile, while for the entire distance, Kersey to Julesburg, approximately 150 miles, the average return flow is 5.26 second-feet per mile, or a total of 751 second-feet.

To determine the value of this return seepage for irrigation it would be necessary to assign a definite value to one second-foot flow, but this is impracticable because of the variation in the condition of delivery, nature of the soil, kind of crops, location of market, and financial situations. The return flow appearing in the river is subject to use or diversion according to the date of appropriation, and a second-foot of return flow diverted into two different canals may not be equal in value because of the canal losses due to the character of the soil, the inefficiency of canal management, the system of distribution of the water or the method of application to the crop.

Variation in market prices of farm products would have an effect upon values of the water rights. During the period of recent high prices of farm products the value of water for irrigation was above normal, but at present, taking into consideration the reduced values of these products, it is reasonable to assume that the value of the water would be less. Values are based largely upon the supply and demand, and as observations show an increase in the return flow to the river, the value of water in this section of the valley should have a tendency to become less because of the greater and better supply, unless canal extensions and increased acreage should counterbalance this tendency. However, on the other hand, it is believed that the factor of having available water for late crops is one of great importance, and from this standpoint alone the return seepage to the river is of great importance.

Various estimates of the value of one second-foot of return flow have been made by engineers familiar with conditions in the lower South Platte Valley. These estimates range in value from $3,000 to $12,000, and do not include the distributing system. John E. Field, former State Engineer of Colorado, estimates the value of the year-round flow of one second-foot of seepage, including the distributing system, to be $5,000, and exclusive of the distributing system to be $3,000. R. J. Wright, Superintendent of the Prewitt Reservoir, estimates the value of one second-foot of seepage water in the Iliff and Platte Valley Ditch to be $3,200, and in the South Platte Ditch to be $3,800. These values include the distributing system but are for the period of direct irrigation only. To assume a value of from $3,500 to $4,000 per second-foot, exclusive of the distributing system, as the average for the lower South Platte Valley, is, in my opinion, too high, and as a conservative estimate I would place the value not greater than $3,000.

The average return flow from Kersey to Julesburg, of more than 750 second-feet for the ten months, January to October, 1920, may be estimated, therefore, to be worth to the farmers of the valley about $2,250,000 on the basis of permanent rights At this time it is not known whether the peak of the return flow has been reached, but it is assumed that it has not and that in later years a greater flow may be expected, which, with other causes, may increase the total value to $3,000,000 or more. The return flow to the river, aside from establishing a value of water rights, has, without doubt, greatly enhanced both general agricultural activities and business affairs of this part of the valley. Fig. 5 shows a part of the accumulation of seepage water in a distance of 25 miles and gives some idea of the economic importance of the return flow to this river.

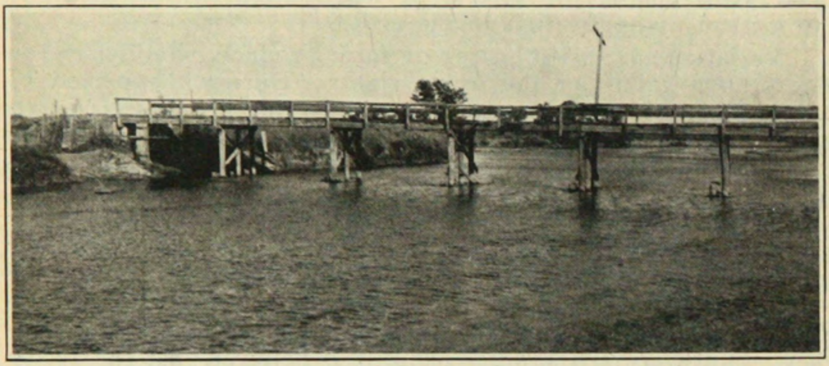

Fig. 5.—Orchard river station showing a flow of 165 second-feet which is all seepage and represents but a part of the accumulation in a distance of 25 miles.

The management and distribution of the water of the lower South Platte, Districts 1 and 64, can only be economically handled by giving due credit and weight to the return flow. This fact may be illustrated by the amount passing the river station at Balzac and the extent of diversions below this point. During the week of September 30-October 6, 1920, the entire flow of the river at Balzac was 2,908 acre-feet, and during this same period there was diverted from the river in District 64, 3,473 acre-feet, with a discharge at Julesburg, at the lower end of the district, of 4,573 acre-feet. The inflow for this period was 1,598 acre-feet, making the total amount available 4,506 acre-feet. The amount diverted plus the quantity passing Julesburg was 8,046 acre-feet, or approximately 79 percent greater than the total inflow for the district. In order to economically distribute the water of the river, it is essential that a careful estimate of the amount of this return flow be made, and it was the ultimate aim of this investigation to determine, with sufficient accuracy for practical purposes, the extent of this return water as a basis for a more efficient management of the water supply.

THE PHENOMENON OF RETURN WATERS

Without exception all of the irrigated valleys of Colorado exhibit, in greater or less degree, the return of percolating water from higher elevations where the water has been applied in the form of irrigation. It is generally accepted that the extent of these returning waters has increased from year to year, due partly to the extension of the irrigation systems which include a larger irrigated area but mostly to the general rise of the water-table over greater areas. From tests made by borings or wells sunk to water-bearing strata during the early stages of the development of irrigation, it has been observed that the then-existing ground-water level was in most cases at a considerable depth below the surface. It has also been noted that the general ground-water level has been raised each year, and in some cases this has been from depths of 100 feet or more to within a few feet of, or even up to the surface. Before the advent of irrigation, this ground-water surface had attained a definite elevation, within small limits, and the only causes affecting this water-table would be the natural absorption of the precipitation, general meteorological changes, or physical and chemical changes of the underground strata. Over a period of a great number of years the mean rainfall and temperature would not change greatly from the actual yearly condition, hence the yearly fluctuations of the water-table would be small. Gravitational force tends to cause this water beneath the ground to assume a level surface, but due to the resistance offered to the movement of the water by the soil particles, it is found that the actual ground-water surface is not level but approximates, in general, the ground surface. It is not uncommon to find places where this water-table actually cuts near or through the ground surface, causing a seeped or water-logged condition, or permitting the accumulation of water in the form of a bog or slough. Due to atmospheric exposure these spots will vary in degree of saturation.

With the artificial application of water to the cultivated fields, this natural condition of equilibrium of the water-table is affected and the yearly application, which was considerably in excess of the precipitation, caused the ground to be filled with water, resulting in a general rise of the water-table. This annual rise and changing slope of the water-table creates a greater pressure on the water beneath, which, in turn, overcomes the normal resistance of the particles of the soil and finally permits the displacement of the water in adjacent areas.

As the practice of irrigation continued and greater areas were affected, it ultimately so increased the pressure that there has resulted, due to the action of gravity, a greater flow through the underground strata; but on account of the great resistance set up by the soil particles, the rate of travel of this underground current is exceedingly slow.

This vast quantity of underground water, adjacent to the river on either side, may be looked upon as a subterranean reservoir of wide expanse, where the water surface is of an undulatory nature, and with a general slope to the river channel, or depression of a water course leading to the main drainage stream. The amount of water added to this underground reservoir by the season's precipitation is not of any great importance, but it is assumed that the water applied to the fields and that lost from ditches and reservoirs contributes the greater part of the return flow coming from this great body of underground water. From the recent studies of these percolating or return waters, it seems evident that they are responsive to the season's application of irrigation water, but the actual water entering the source has the effect only of displacing a comparable amount at some lower level or possibly within the river's bed. The actual water taken in at the higher elevations may require years before it is released finally as return water to the river. This condition may be illustrated by means of a hose completely filled with water; whatever the amount supplied at the upper end, a like amount must be displaced from its lower or outlet end. This condition cannot be literally true, however, because the water stream within the soil is not always confined between impervious strata; consequently, the additional supply added at higher levels only tends to increase the gradient or slope of the water-table.

UNDERGROUND WATER

An attempt was made to show the relation of the rise and fall of the water-table with reference to the filling and emptying of the Riverside Reservoir. This reservoir is located on the north side of the river near Masters, and the crest of the dam on the line of the observation wells is about 8,000 feet from the river channel. The dam is an earth-filled structure extending along the southwest, south and southeast margins of the reservoir site, approximately 6 miles in length and varying in height from 5 to 25 feet. It is composed of very sandy soil and has a concrete facing on the inside. The reservoir basin has an area of about 40 acres at low water stage and of over 3,800 acres, with a capacity of 57,500 acre-feet, at a gage height of 32 feet.

The observation wells were located on the section line running north and south through Masters between the reservoir and the river channel. All the wells were cased with down-spouting, 3 inches in diameter, because of the sandy nature of the soil, and each was protected by a wooden box provided with a hinged cover. The shallow wells near the river were easily dug by means of an ordinary soil auger, while those nearer the reservoir were put down approximately 20 feet, with considerable difficulty, by the use of a soil auger and sand bucket. The depth to the water in the wells was measured from the top of the casing by means of a steel tape to the nearest one-hundredth of a foot. The observations of the depth to water were usually made at frequent intervals, but during the months from January to April it was only possible to secure a few readings.

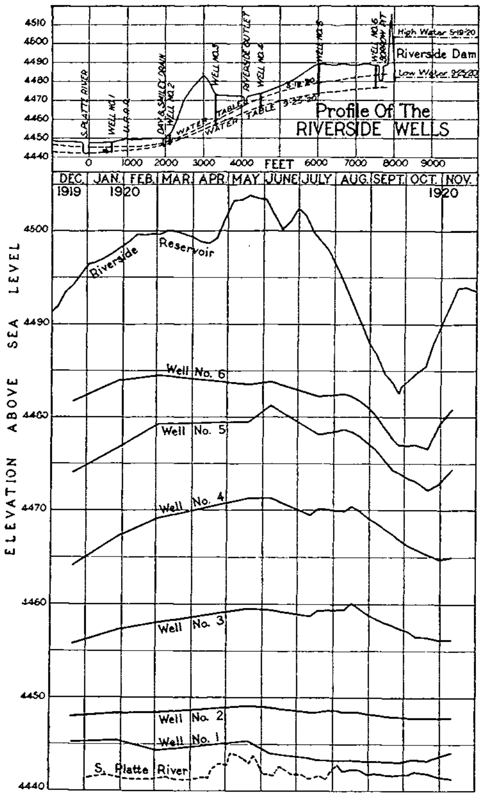

Fig. 6.—Diagram of the fluctuation of the Water Table as affected by the Riverside Reservoir, and also showing the profile of the ground surface on the line of wells from the South Platte River to the reservoir.

Fig. 6 is a graphical representation of the seasonal variation of the water-table at the various wells between the Riverside Reservoir and the river at Masters. A profile is shown giving the relative elevation of the ground surface along the line of wells and the relation between the water surface of the reservoir and its effect upon the wells. The variation of the water-table in wells Nos. 3, 4, 5 and 6 appears to bear a close relation to the change of gage-height in the reservoir, the maximum or peak occurring with very little lag. Well No. 2, which is near the Day and Smiley Drain, is influenced more by the rise and fall of the depth of the water in the drain than by the water-table fluctuations caused by the reservoir. Well No. 1 is within a short distance of the river channel and the ground-water level varies with the change of stage of the river flow, excepting in late October when a divergence of the curves appears. Well No. 6, which is located near the reservoir, does not appear to show the marked relation with the reservoir gage as is evident by the variations in Wells Nos. 3, 4 and 5. The peak of filling in May is shown distinctly in Wells Nos. 4 and 5 and also the effect of increasing the reservoir gage the latter part of June. Wells Nos. 4, 5 and 6 show the effect of filling the reservoir which began late in September.

Another series of wells was established near Snyder on the south side of the river, but the results were not of sufficient importance to warrant the preparation of illustrations. In this series, two deep wells were established on the bench or mesa, while five others of shallow depth were located in the bottom or meadow land adjacent to the river. Well No. 1, which was located 7,900 feet south of the river and 32 feet higher in elevation, did not show a great variation in the water-table. The elevation of this water-table on June 22 was 13.5 feet above a point assumed to be the mean stage of the river, and rose steadily until September 16 when the elevation was 15.5 feet and from this date a gradual decline was observed. This well was located about 400 feet from the Lower Platte and Beaver Canal which carried from 50 to 100 second-feet during the irrigation season. The decline of the water-table in September was not influenced by the canal which drew water from the river until November, and it is thought that the application of the water to the cultivated fields has much more effect on the water-table than the seepage from the ditch. The only peculiarity observed in the wells on the bottom lands was a very decided drop and recovery of the water-table during the first part of July, with a very slight variation after that time. From June 22 to July 2 the stage of the river was falling, and from then until about November 1 remained at practically a constant gage.

The phenomenon of the percolation of water through soil is one of a very complex nature. Many investigators have made measurements of the rate of flow of these underground waters between points which were a relatively short distance apart, by a combination of electrical and chemical methods, and in general they have found this rate of flow rather small. Observations made on the underflow from the Prewitt Reservoir during the litigation over the seepage water from that reservoir indicated that the velocity of flow was less than two feet per day, while the observations of Slichter and Wolff* at Ogallala, Nebraska, showed that the rate of flow through the sand and gravel of the river bed was not more than seven feet per day. The results of the present investigation, however, indicate a much higher velocity. Below the Riverside Reservoir the fluctuations of the water-table and the discharge of the Day and Smiley Drain Ditch, which runs transverse to the underflow from the reservoir and close to the foot of the bluff along the river bottom, follow very closely the changes of elevation of the water surface of the reservoir as shown in Figs. 6 and 7. The close relation of the elevation of the water-table and the discharge of the Day and Smiley Drain Ditch to the reservoir gage shows a rapid transmission of pressure and a rapid equalization by flow to the river and the drain ditch.

Direct determination of the rate of movement of the underground water is very difficult and only an approximation of this

* U. S. Geol. Survey Water Supply Paper No. 184.

rate of flow is possible by the study of the fluctuations of the water-table. By comparisons of the time of the pronounced changes in the reservoir and the wells, as shown in Fig. 6, it is estimated that the underground waters move at a rate of ap-

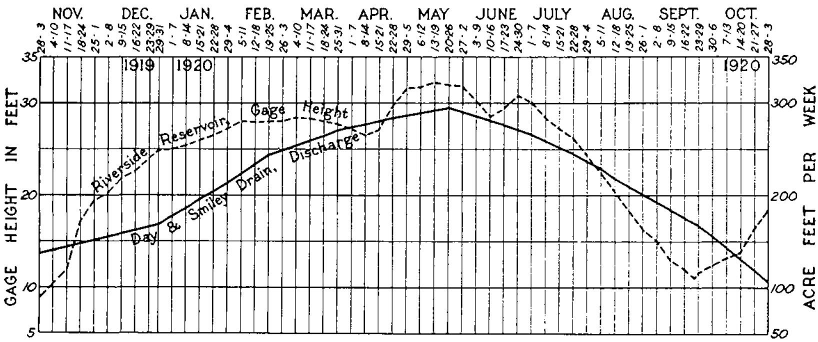

Fig. 7.—Showing the relation of the discharge of the Day and Smiley Drain Ditch in acre-feet per week to the gage height of the Riverside Reservoir.

proximately 100 feet per day, which is far greater than the velocity found by other investigators. The water-table, however, in this case, has a slope or gradient of about 30 feet per mile, and further, because of the porous nature of the soil, there results a rather high velocity of the underflow. The rather sensitive change of the water-table with the variation of the water surface of the reservoir indicates a direct transmission of pressure, and also the immediate transfer or movement of the water as is shown by the relation of discharge of the Day and Smiley Drain Ditch to the gage-height of the reservoir. (See Fig. 7).

This apparently high velocity would indicate that the seepage loss from the reservoir is quite large. The records show that during the period from June to October, 1920, the Riverside Reservoir lost an average of 130 acre-feet, which, when corrected for evaporation, gives about 115 acre-feet per day, or a flow of 57 second-feet as the seepage loss. Of this flow only 16.5 second-feet, or about 30 percent, was intercepted by the Day and Smiley Drain Ditch during the same period. The remaining portion escaped to the river in lower strata and by passing beyond the point where the drain ditch reaches the river channel. As stated elsewhere, the seepage from the various reservoirs was measured as inflow to the river where such measurements were possible, and basing estimates upon the Day and Smiley Drain Ditch it is thought that more than 50 percent of the seepage loss from the reservoirs reached the river as unobserved water.

RETURN FLOW

As previously stated, it is thought that the South Platte River, especially in the valley between the mouth of the Cache la Poudre River and the Nebraska state-line, accumulates more return water than any other stream in Colorado. This return flow to the river at the time when irrigation was first practiced in the late sixties must have been small, and not sufficient to attract the attention of irrigators. Prior to about 1885, the return flow to the South Platte River had assumed such proportions as to cause comment, and was of sufficient importance that new canals were constructed to take advantage of this interesting condition. After the passage of the Irrigation District Law in 1901, a number of projects were proposed for the Platte Valley, and during the period of promotion many experienced engineers looked upon these schemes with considerable apprehension as to the possible water supply. Since their construction it now becomes apparent, however, that in average years there is an ample supply during the growing season. As previously stated, the South Platte River delivers into Nebraska annually about 300,000 acre-feet; or, in other words, approximately one-half of the total supply that is actually used in irrigation. This assumption is based on the approximate irrigated area of Districts 1 and 64 as 200,000 acres and a gross duty of 3 acre-feet per acre. During the extremely high water of June, 1921, it is estimated that not less than 15,000 second-feet flowed across the state-line for a period of at least 10 days, or 300,000 acre-feet which was equal to the approximate annual discharge at this point.

The first detailed seepage measurements were made by E. S. Nettleton, then State Engineer, October, 1885, on the Cache la Poudre River between the mouth of the canyon and a point below the headgate of the Ogilvy Ditch, the last diversion on this river. In this distance of 35 miles there was found to be a gain of 87 second-feet with a 1.6 second-foot gain per mile for the first 7 miles, and 5.4 second-feet gain per mile for the last 6 miles of the entire section of the river investigated.

Subsequent studies made by Prof. L. G. Carpenter during the following ten years also show that the last section near Greeley had a larger return flow per mile than the upper section. The irrigated area adjacent to the river near Greeley is more extensive and the soil of a more sandy nature. This may explain the higher return flow. The early seepage measurements on the South Platte River show a reverse nature; that is, for the lower valley between Crook and Julesburg there was found a loss or very slight gain, while from the mouth of the Cache la Poudre to Hardin or Orchard a very marked gain was observed. Very little irrigation was practiced in the lower valley.

These early seepage determinations were made by Prof. L. G. Carpenter during the period from 1889 to 1895, and averages for the period 1890 to 1894, inclusive, show a gain of approximately 61 second-feet from the mouth of the Cache la Poudre to the Hardin Ditch, while for this same period of years the section from Crook to Julesburg shows a loss of about 20 second-feet. During the period from 1895 to 1918, observations were made by the State Engineer of Colorado, Prof. L. G. Carpenter, R. G. Hosea, and the U. S. Department of Agriculture to determine the amount of return flow. These seepage or return-flow studies were based on one or two series of measurements each year, usually made during October or November, but during this 23-year period a few years are missing because of storms interfering with the measurements, and from 1909 to 1912 the return-flow studies of the South Platte River were abandoned because it was believed to be of little value by the State Engineer, who contended that the theory of these seepage measurements was based upon several questionable assumptions, to-wit:*

"First—An absolutely permanent condition of the stream and its tributaries during the progress of the measurements.

Second—The possibility of differentiating with certainty between the inflow due to surface run-off and that due to the ground-water inflow.

Third—That the ground-water inflow is due entirely to the application of water to irrigated lands.

Fourth—An assumed accuracy of the measurements themselves, which is not justified.

Fifth—The most violent of all assumptions, viz; That the condition found to prevail at the time of the measurements prevails throughout the year."

He concludes:

"None of these assumptions are justified. The river flow is not permanent. The distinction between the surface run-off and the ground-water inflow is not well marked and cannot be accurately defined, and if it were, there is no means of knowing what proportion of the ground-water inflow is due to the application of irrigation water. The differences noted in the seepage tables as gains or losses in a certain distance are frequently less than the probable errors of the measurements themselves. And, lastly, there is no justification for assuming that the conditions prevailing in the fall, when the seepage measurements have been made, are those of the entire year."

The condition of flow of the river and tributaries during the month of October, as a usual thing, is quite constant because of stabilized weather conditions; also the period of demand for irrigation is past and the ditches and canals then drawing have a more or less constant discharge, hence the variation of flow of the main stream should not be great. Exceptions to this have occurred during the month of October when heavy storms have

* 16th Biennial Report of State Engineer of Colorado, page 135.

made measurements impossible. Differentiating between surface run-off and ground-water is not possible without detailed measurements, but as the actual streams flowing into the Platte River between Kersey and Julesburg are relatively few and of comparatively small discharge, the actual return flow can be approximated with reasonable accuracy. The point raised concerning the inflow as a function of the irrigated lands is, in a measure, correct, but certain sections in the valley might be so chosen that return flow from reservoirs could be eliminated; then the return flow to the river would be directly due to canal losses and return from irrigation. Observations show that the storage reservoirs of the lower South Platte Valley lose great quantities of water through seepage and evaporation, and to estimate this seepage loss, let it be assumed that if the six principal reservoirs be filled to capacity each season there would be required approximately 270,000 acre-feet, and if the average efficiency is but 50 percent there would be a loss of 135,000 acre-feet. Taking 10 percent as the average evaporation loss, there would be about 120,000 acre-feet required annually to account for seepage losses. This, reduced to daily loss, would be 330 acre-feet or a flow of 165 second-feet. The accumulation of seepage from the reservoirs into streams flowing to the river was measured and in the aggregate amounted to an average of approximately 100 second-feet. This leaves 65 second-feet returning to the river as unobserved seepage. On this basis the seepage loss from the reservoirs, which was measured as inflow, amounts to 60 percent of the total flow of 165 second-feet. The average return flow from Kersey to Julesburg is approximately 750 second-feet and of this amount 65 second-feet, or about 11 percent, is seepage from the reservoirs. If the 100 second-feet of seepage return from the reservoirs, measured as inflow to the river, be included in the return seepage, then the reservoir loss of 165 second-feet would be approximately 20 percent of the total return flow.

The accuracy of measurements is not absolute but relative, and is very likely to be compensating. Approximations and estimates enter into the final results which, in comparison, do not warrant extreme accuracy in the measurements.

That the conditions prevailing throughout the year are approximately those which obtain during the month of October may be questionable, as shown by Table 5.

The October mean does not show good agreement with the mean return for the 14-months period when taken for the individual or intermediate sections; however, when the entire distance, Kersey to Julesburg, is considered, the October return shows almost an exact agreement.

TABLE 5.—Comparison of the mean return flow for October, 1919, and October, 1920, and the average return flow for a period of 14 months.

Section of River	Mean return flow in sec. ft. for 14 months	Mean return flow in sec. ft. for Oct. 1919 and Oct. 1920	Difference in percent
Kersey to Orchard	184	171	7
Orchard to Fort Morgan	115	148	29
Fort Morgan to Balzac	145	172	19
Balzac to Beetland	102	106	4
Beetland to Crook	145	122	16
Crook to Julesburg	61	37	39
Mean return flow from Kersey to Julesburg	752	756	0

INVESTIGATION OF 1919 AND 1920

Installation of the equipment on the river began late in June, 1919, at Kersey, and it was not until the greater portion of July had passed that the full distance to Julesburg had been covered. It was, therefore, not possible to secure the full month's record for July for the section between Crook and Julesburg. The data as presented in the following tables are compiled from the daily discharges and given in acre-feet per week. During 1919 the investigation was not as satisfactory as the following year because of lack of complete acquaintance with conditions, and also the incompleteness of the organization. The severe weather conditions from November 10, 1919, to about January 1, 1920, did not permit any field work and it was necessary, therefore, to discontinue the records for that period. Between January 1 and about March 1, considerable difficulty was experienced on account of cold weather, especially in District 64. During this period it was necessary to estimate the discharge at some of the river and canal stations. The reservoirs were covered with ice and at this time accurate gage-readings could not be obtained. The river stations in the vicinity of Fort Morgan were open the greater part of the time, but east of Sterling it was not possible to secure dependable records because of ice conditions in the river. (See Fig. 8).

Fig. 8.—Crook river station showing river running slush ice. This flow is all seepage or return water to the river.

The summary of the investigation of the seepage return to the South Platte River during a part of 1919 and 1920 is presented in Tables 6 to 11. These tables cover the entire period of the investigation giving the monthly discharge in acre-feet and the monthly return flow in acre-feet for the various sections of the river from Kersey to Julesburg. There is also given the mean discharge of the return flow in second-feet for the period July 1 to November 10, 1919, and January 1 to November 10, 1920. Considerable variation is to be noted in the return flow. During the winter months this variation is very largely due to weather conditions, freezing and thawing, and partly because of estimated discharges, but during the rest of the year the variations are influenced by the rise and fall of the stage of the river, and other causes. If the return flow is directly due to the application of water to irrigated lands and to the ditches and reservoirs, it does not seem probable that, as the water returns to the stream, it would flow in varying quantities. Resistance to the flow of the percolating waters through the soil is more or less constant, and only two important factors enter which would greatly change this condition; namely, a greater pressure due to a more inclined water-table and the change of temperature of the underground waters. Other factors, such as change of barometric pressure, chemical change of soil, and erosion are of little importance. After the underflow is released as surface water, other factors are operative, such as change of temperature, humidity, winds and stage of river; but the loss due to evaporation, which is much greater in summer than during the winter and which carries away this return flow in varying amounts after it has appeared in the river channel, is no doubt the prime factor in the apparent variation of the return flow during the warmer season of the year. The formation of ice greatly affects the river's flow during the winter and the amount of this variation, due to freezing and thawing, cannot be separated from the actual return flow.

Various investigators have determined that the rate of flow of water through a porous medium is a direct function of the temperature because of the change in the viscosity of the water. It is known that the flow increases with the temperature. Therefore, this factor of temperature will cause a greater return flow in the late summer. Soil temperatures taken at Fort Collins, Colorado, show the annual variation at 6 feet in depth to be approximately 22 degrees, Fahr., while at greater depths the variation would be less. Records taken elsewhere show that at a depth of from 40 to 60 feet the variation in temperature is about 4 degrees. It is not possible to determine the depth of the return-flow water-stratum with any degree of certainty, but it must be at considerably greater depth than 6 feet in many places, and perhaps less in others. The average, annual change

TABLE 6.—Summary of Return Flow, Kersey to Orchard.

	1919					1920										
STATION	July Acre-ft.	August Acre-ft.	Sept. Acre-ft.	Oct. Acre-f.t	Nov. 1-10 Acre-f.t	Jan. Acre-ft.	Feb. Acre-ft.	March Acre-ft.	April Acre-ft.	May Acre-f.t	June Acre-ft.	July Acre-ft.	August Acre-ft.	Sept. Acre-ft.	Oct. Acre-f.t	Nov. 1-10 Acre-ft.
Inflow																
South Platte at Kersey	8434	24816	14819	29162	13248	31995	30990	23541	49818	149962	61528	19921	29992	19203	38972	16760
Crow Creek	260e*	250e	276	0	0	0	0	0	0	921	1159	496	595	958	1016	300e
Meadow Farms Seepage	208e*	124e	71e	105e	60e	245e	230e	245e	240e	260e	295e	430e	370e	160e	310e	90e
Bijou Drain	902e	876e	764	614	177	430	401	430	490	785	830	882	898	859	860	270e
Day and Smiley Drain	729e	649e	568	588	199	810e	924e	1125	1180	1280	1215	1154	1064	810	640	160
Riverside Outlet	1253	1604	1149	0	0	0	0	0	0	0	471	1992	2528	0	0	0
Total inflow	11786	28319	17647	30469	13684	33480	32545	25341	51728	153208	65498	24875	35447	21990	41799	17580
Outflow																
Hoover Ditch	526	576	478	220	44	0	0	0	0	159	655	305	395	687	788	60e
Empire Canal	0	0	0	0	0	6862	15058	20610	17274	6917	8221	1082	0	0	0	0
Riverside Inlet	0	0	0	6026	7094	13286	9557	4959	15343	19222	11073	839	0	5225	20585	9133
Illinois Ditch	972	1020	857	151	132	0	0	0	0	13	876	1234	911	395	91	0
Bijou Canal	5515	7296	4903	17723	5362	0	0	629	551	14780	12559	6358	7794	9480	11285	6613
Mackey Ditch	0	0	0	0	0	0	0	0	0	297	519	331	140	91	6	0
Jackson Lake Inlet	0	0	0	0	0	16504	11888	3143	2538	4502	1680e	0	0	0	0	0
Putnam Ditch	1161	952	649	61	0	0	0	0	0	305	626	1114	696	480	235	63
Weldon Valley Canal	7312	6945	2474	1138	0	0	0	0	0	469	5541	7137	6038	5290	2849	1603
South Platte at Orchard	7622	23037	20248	14644	4216	12006	7037	7759	26528	113920	32806	17540	31466	12592	17445	4015
Total outflow	23108	39826	29609	39963	16848	48658	43540	37100	62234	160584	74556	35940	47440	34240	53279	21487
Summary																
Inflow	11786	28319	17647	30469	13684	33480	32545	25341	51728	153208	65498	24875	35447	21990	41799	17580
Outflow	23108	39826	29609	39963	16848	48658	43540	37100	62234	160584	74556	35940	47440	34240	53279	21487
Return flow	11322	11507	11962	9494	3164	15178	10995	11759	10506	7376	9058	11065	11993	12250	11480	3907
Av. Daily Ret. Acre Ft.	365	371	399	306	316	490	379	379	350	238	302	357	387	408	370	391
Av. Daily Ret., Sec. Ft.	184	187	201	155	160	247	191	191	177	120	153	180	195	206	187	197

e* estimated value.

Net return flow, July 1 to November 10, 1919, acre.-feet. 47,449
Mean daily return flow, acre-feet.......................... 357
Mean daily return flow, second-feet....................... 180

Net return flow, January 1 to Nov. 10, 1920, acre.-feet.. 115,567
Mean daily return flow, acre-feet.......................... 367
Mean daily return flow, second-feet....................... 185

TABLE 7.——Summary of Return Flow, Orchard to Fort Morgan.

STATION	1919 July Acre-ft.	1919 August Acre-ft.	1919 Sept. Acre-ft.	1919 Oct. Acre-ft.	1919 Nov. 1-10 Acre-ft.	1920 Jan. Acre-ft.	1920 Feb. Acre-ft.	1920 March Acre-ft.	1920 April Acre-ft.	1920 May Acre-ft.	1920 June Acre-f.t	1920 July Acre-ft.	1920 August Acre-ft.	1920 Sept. Acre-ft.	1920 Oct. Acre-ft.	1920 Nov. 1-10 Acre-ft.
Inflow																
South Platte at Orchard..	7622	23037	20248	14644	4216	12006	7037	7759	26528	113920	32806	17540	31466	12592	17445	4015
Jackson Lake Outlet.....	8030	5328	4504	1085	0	0	0	0	0	3448	275	8440	9613	4644	1276	0
Shumaker Drain........	1107e	1070e	736e	443e	114e	266	276	326	552	445	593	701	809	645	455	143e
Bijou Creek............	841	842	814	842	271	879e	662e	686	625	775	873	1193	1020	982	1054	358
Ft. Morgan Canal Waste.	0	0	80e	60e	0	0	0	0	132e	1102e	46e	707e	383e	400e	299e	151e
Gt. West. Sug. Co. Fact'y. Waste................	0	0	0	744e	240e	0	0	0	0	0	0	0	0	240	930	300
Total inflow........	17600	30277	26382	17818	4841	13151	7975	8771	27837	119690	34593	28581	43291	19503	21459	4967
Outflow																
Ft. Morgan Canal.......	7907	9223	13032	10573	2949	0	0	0	877	12213	7909	13434	17320	10289	11323	3005
Up. Platte & Beav'r Can'l	6145	8165	5679	4898	1157e	0	0	0	396	6361	6719	5624	9016	7285	7320	2037
Deuel & Snyder Ditch....	674	403	975	96	11	0	0	0	0	148	1075	1299	1091	815	526	0
So. Platte at Ft. Morgan.	10348	22421	16148	11680	3663	17403	13741	14609	30053	113213	22996	13531	18601	10269	11061	3120
Total Outflow......	25074	40212	35834	27247	7780	17403	13741	14609	31326	131935	38699	33888	46028	28658	30230	8162
Summary																
Inflow.................	17600	30277	26382	17818	4841	13151	7975	8771	27837	119690	34593	28581	43291	19503	21459	4967
Outflow...............	25074	40212	35834	27247	7780	17403	13741	14609	31326	131935	38699	33888	46028	28658	30230	8162
Return Flow..........	7474	9935	9452	9429	2939	4252	5766	5838	3489	12245	4106	5307	2737	9155	8771	3195
Av. Daily Ret., Acre-Feet	241	320	315	304	294	137	199	188	116	395	137	171	88	305	283	319
Av. Daily Ret., Sec. Ft....	122	162	159	153	148	69	100	95	58	200	69	86	44	154	143	161

(e) Estimated values

Net return flow, July 1 to Nov. 10, 1919, acre-feet........39,229
Mean daily return flow, acre-feet...................... 295
Mean daily return flow, second-feet.................. 149

Net return flow, January 1 to Nov. 10, 1920, acre-feet....64,861
Mean daily return flow, acre-feet...................... 206
Mean daily return flow, second-feet.................. 104

TABLE 8.—Summary of Return Flow, Fort Morgan to Balzac.

STATION	1919 July Acre-ft.	1919 August Acre-ft.	1919 Sept. Acre-ft.	1919 Oct. Acre-ft.	1919 Nov. 1-10 Acre-ft.	1920 Jan Acre-ft.	1920 Feb. Acre-ft.	1920 March Acre-ft.	1920 April Acre-ft.	1920 May Acre-ft.	1920 June Acre-ft.	1920 July Acre-ft.	1920 August Acre-ft.	1920 Sept. Acre-ft.	1920 Oct. Acre-ft.	1920 Nov. 1-10 Acre-Ft.
Inflow																
South Platte at Ft. M'rgn	10348	22421	16148	11680	3663	17403	13741	14609	30053	113213	22996	13531	18601	10269	11061	3120
Beaver Creek	0	0	934	3552	491	520	512	357	1306	1503	1975	338	103	3457	5095	1542
Total inflow	10348	22421	17082	15232	4154	17923	14253	14966	31359	114716	24971	13869	18704	13726	16156	4662
Outflow																
Lower Platte & B'vr C'nl	2499	7738	6154	4503	566	0	0	10	1245	4201	5046	6413	9454	7239	5154	1233
Tremont Ditch	161	262	1232	818	49	0	0	784	1417	1258	545	52	966	1261	497	12
Snyder Ditch	0	231	249	660	164	0	0	0	312	1092	81	2	275	293	266	107
A. A. Smith Ditch	53	428	478	47	15	0	0	1	1	174	495	134	887	322	570	68
Trowel Ditch	5	78	0	86	55	0	0	120	270	363	183	21	0	0	0	0
North Sterling Inlet	0	0	0	0	2791	9958	13124	14518	13311	24209	7928	781	0	0	0	0
Union Ditch	0	172	128	0	0	0	0	62e	216e	0	24e	0	477e	146e	0	0
Prewitt Reservoir Inlet	0	0	0	0	0	9393	7090	6564	14051	18543	6826	1174	1023	984	1142	302
Johnson-Edwards Ditch	156	323	854	754	228	0	0	0	294e	434e	396e	207e	454e	479e	280e	0
Tetsel Ditch	1242	1466	1024	921	10	0	0	0	0	665	1615	1760	1548	1489	1204	218e
South Platte at Balzac	11316	16082	14881	16939	2486	3604	1356	1219	11067	64714	16361	14670	15420	15214	18737	6138
Total Outflow	15432	26780	25000	24728	6364	22955	21570	23278	42184	115653	39500	25214	30504	27427	27850	8078
Summary																
Inflow	10348	22421	17082	15232	4154	17923	14253	14966	31359	114716	24971	13869	18704	13726	16156	4662
Outflow	15432	26780	25000	24728	6364	22955	21570	23278	42184	115653	39500	25214	30504	27427	27850	8078
Return Flow	5084	4359	7918	9496	2210	5032	7317	8312	10825	937	14529	11345	11800	13701	11694	3416
Av. Daily Ret., Acre-Feet	164	141	264	306	221	162	252	268	361	30	484	366	381	457	377	342
Av. Daily Ret., Sec. Feet	83	71	133	155	112	82	127	135	182	15	244	185	192	231	190	173

(e) Estimated values

Net return flow, July 1 to Nov. 10, 1919, acre-feet.......29,067
Mean daily return flow, acre-feet........................ 219
Mean daily return flow, second-feet..................... 110

Net return flow, January 1 to Nov. 10, 1920, acre-feet....98,909
Mean daily return flow, acre-feet........................ 314
Mean daily return flow, second-feet..................... 158

TABLE 9.—Summary of Return Flow, Balzac to Beetland.

STATION	1919				1920										
	July Acre-Ft.	August Acre-Ft.	Sept. Acre-Ft.	Oct. Acre-Ft.	Nov. 1-10 Acre-Ft.	Jan. Acre-Ft.	Feb. Acre-Ft.	March Acre-Ft.	April Acre-Ft.	May Acre-Ft.	June Acre-Ft.	July Acre-Ft.	August Acre-Ft.	Sept. Acre-Ft.	Oct. Acre-Ft	Nov. 1-10 Acre-Ft.
Inflow																
South Platte at Balzac...	11316	16082	14881	16939	2486	3604	1356	1219	11067	64714	16361	14670	15420	15214	18737	6138
Prewitt Reservoir Outlet	5875	7102	2931	13	0	0	0	0	0	0	2551	6678	12761	3289	0	0
Prewitt Drain..........	2235e	1714	1075	585	160	665e	1288	1680	2077	3082	3419	3038	2434	1365	769	172e
Tetsel Waste...........	0	0	0	0	0	0	0	0	0	0	0	0	0	580e	582e	113e
Total inflow........	19426	24898	18887	17537	2646	4269	2644	2899	13144	67796	22331	24386	30615	20448	20088	6423
Outflow																
South Platte Canal......	2800	3543	2460	1004	704	0	0	0	0	416	2327	3926	3709	1550	3425	0
Pawnee Canal...........	11277	11828	5393	212	0	0	0	0	0	0	6636	10358	9186	5164	1770	8
Davis Bros. Ditch........	778	1256	826	1142	226	0	0	0	0	0	1567	1160	1555	718	745	44
Schneider Ditch.........	1774	1529	811	435	22	0	0	0	0	0	1809	1714	2103	1051	953	198e
South Platte at Beetland.	12282	16457	15250	20907	4011	9010	6933	7444	17766	77347	16826	10698	17656	18435	19933	7761e
Total Outflow......	28911	34613	24740	23700	4963	9010	6933	7444	17766	77763	29165	27856	34209	26918	26826	8011
Summary																
Inflow.................	19426	24898	18887	17537	2646	4269	2644	2899	13144	67796	22331	24386	30615	20448	20088	6423
Outflow................	28911	34613	24740	23700	4963	9010	6933	7444	17766	77763	29165	27856	34209	26918	26826	8011
Return Flow...........	9485	9715	5853	6163	2317	4741	4289	4545	4622	9967	6834	3470	3594	6470	6738	1588
Av. Daily Ret., Acre-Feet	306	313	195	199	232	153	148	147	154	322	228	112	116	216	217	159
Av. Daily Ret., Sec. Ft....	155	158	98	101	117	77	75	74	78	163	115	57	59	109	110	80

(e) Estimated values

Net return flow, July 1 to Nov. 10, 1919, acre-feet........33,533

Mean daily return flow, acre-feet...................... 252

Mean daily return flow, second-feet.................... 127

Net return flow, January 1 to Nov. 10, 1920, acre-feet....56,858

Mean daily return flow, acre-feet...................... 180

Mean daily return flow, second-feet.................. 91

TABLE 10.—Summary of Return Flow, Beetland to Crook.

STATION	1919 Jul. 15-31 Acre-Ft.	August Acre-Ft.	Sept. Acre-Ft.	Oct. Acre-Ft.	Nov. 1-10 Acre-Ft.	1920 Jan. Acre-Ft.	Feb. Acre-Ft.	March Acre-Ft.	April Acre-Ft.	May Acre-Ft.	June Acre-Ft.	July Acre-Ft.	August Acre-Ft.	Sept. Acre-Ft.	Oct. Acre-Feet	Nov. 1-3 Acre-Feet
Inflow																
So. Platte at Beetland....	6782	16457	15250	20907	4011	9010	6933	7444	17766	77347	16826	10698	17656	18435	19933	2761
Pawnee Creek...........	0	0	0	0	0	310e	290e	310e	560e	0	0	0	0	0	0	0
Cedar Creek.............	712	1290	1890	1117	298	1487	1559	1190	2040	1744	1837	1244	1996	2748	1783	126
Ten Foot Drain.........	......	......	......	......	......	1210e	1160e	1240e	1938e	1306e	1062	235	238	682	911	77
Gt. West. Sug. Co. W'ste..	0	0	0	124e	40e	0	0	0	0	0	0	0	0	0	320e	30e
Total inflow........	7494	17747	17140	22148	4349	12047	9942	10184	22304	80397	19725	12177	19890	21865	22947	2994
Outflow																
Springdale Ditch........	1368	2209	1106	335	0	0	0	0	0	19	2032	3091	3032	1594	504	0
Sterling Ditch No. 1......	3022	5380	2712	0	0	0	0	0	0	477	3803	4585	4804	2611	152	0
Batten Ditch............	0	0	0	94e	0	0	0	0	0	0	140e	310e	310e	300e	310e	30e
Sterling Ditch No. 2......	0	432	772	549	0	6			Not in operation during 1920							
Hereford Cattle Co. Ditch	80e	145e	125e	0	0	0	0	0	0	0	0	60e	175e	85e	0	0
Henderson&Smith Ditch.	500	282	1092	1254	506	0	0	373	720	972	496	240	1257	692	450	27
Lowline Ditch...........	818	1216	1402	79	0	00	0	0	0	15	615	1734	1604	873	474	13
Bravo Ditch............	812e	1463	1818	0	0	0	0	0	0	0	2119	1663	3297	2171	1282	33
Farmers Ditch..........	0	119	36	0	0	0	0	0	0	92	24	105	548	98	35	0
J. B. Ditch...............	67	115	433	691	220	0	0	0	0	591	321	305	354	646	356	12
Iliff & Platte Val. Canal..	1758	2726	1098	0	0	0	0	0	0	2470	2317	2411	2244	862	45	0
Blair Ditch..............	......	......	......	......	......	0	0	0	0	9	730	679	332	0	0	0
Lone Tree Dich..........	364e	668e	582e	519	86	0	0	0	0	310	755	1011	805	253	412	31
Powell Ditch............	198	187	62	0	0	0	0	0	0	0	180	126	0	0	0	0
Harmony Ditch No. 2....	33	5	42	0	0	0	0	0	0	0	0	63	101	0	0	0
Ramsey Ditch...........	427	247	86	0	0	0	0	0	0	0	13	170	37	0	0	0
Chambers Ditch.........		379	0	0	0				0	324	563	687	339	84	0	0
Harmony Ditch No.1.....	403	3644	864	221	72	6645e	6845e	2451	2166	2011	7335	3315	2365	3292	7152	854
South Platte at Crook....	2150	4898	12715	25739	7447	10710e	10124e	14736	29190	78666	13356	4279	8904	19861	19368	1589
Total outflow.......	12000	24115	24945	29481	8331	17355	16969	17560	32076	85956	34799	24834	30508	33422	30540	2589
Summary																
Inflow..................	7494	17747	17140	22148	4349	12047	9942	10184	22304	80397	19725	12177	19890	21865	22947	2994
Outflow................	12000	24115	24945	29481	8331	17355	16969	17560	32076	85956	34799	24834	30508	33422	30540	2589
Return Flow...........	4506	6368	7805	7333	3982	5308	7027	7376	9772	5559	15074	12657	10618	11557	7593	......
Av. daily Ret. acre-feet..	265	205	260	237	398	171	242	238	326	179	502	408	343	385	245	......
Av. daily Ret. sec. ft.....	134	104	131	120	201	86	122	120	165	90	254	206	173	194	124	......
Loss, second-feet.......																68

(e) esimated values.

Net return flow, July 15 to Nov. 10, 1919, acre-feet......29,994
Mean daily return flow, acre-feet...................... 252
Mean daily return flow, second-feet.................... 127

Net return flow, January 1 to Nov. 3, 1920, acre-feet....92,136
Mean daily return flow, acre-feet...................... 299
Mean daily return flow, second-feet.................... 151

TABLE 11.—Summary of Return Flow, Crook to Julesburg.

STATION	1919 July22-31 Acre-Ft.	1919 August Acre-Ft.	1919 Sept. Acre-Ft.	1919 Oct. Acre-Ft.	1919 Nov. 1-10 Acre-Ft.	1920 Jan. Acre-Ft.	1920 Feb. Acre-Ft.	1920 March Acre-Ft.	1920 April Acre-Ft.	1920 May Acre-Ft.	1920 June Acre-Ft.	1920 July Acre-Ft.	1920 August Acre-Ft.	1920 Sept. Acre-Ft.	1920 Oct. Acre-Ft.	1920 Nov. 1-3 Acre-Ft.
Inflow																
South Platte at Crook..	1436	4898	12715	25739	7447	10710e	10124e	14736	29190	78666	13356	4279	8904	19861	19368	1589
Moore's Creek..........	..	..	..	..	..	1772e	1656e	1772e	3199	2216	2123	915	2860	2513	896	146
Lodgepole Creek........	100e	355	877	445	202e	975e	866	1773	2507	1735	1077	583	862	1989	927	100
Total inflow........	1536	5253	13592	26184	7649	13457	12646	18281	34896	82617	16556	5777	12626	24363	21191	1835
Outflow																
Settlers' Ditch..........	51	1750	3435	93	0	0	0	0	0	1038	2817	2718	4463	2476	734	342
Long Island Ditch.......	10	46	95	213	0	0	0	0	6	28	0	79	187	168	185	0
Red Lion Ditch..........	35	111	162	34	0	0	0	0	22	58	386	44	517	80	186	0
Peterson Ditch..........	40	1769	3184	0	0	0	0	916	31	203	3084	1503	2851	480	613	0
South Reservation Ditch.	48	822	125	0	0	0	0	0	0	46	176	600	452	149	174	0
Liddle Dich.............	357e	1086e	48	0	0	0	0	0	0	0	42	193	431	35	0	0
Carlson Ditch...........	0	0	0	0	0	0	0	0	0	0	412	0	97	0	0	0
Cox Ditch...............	..	..	..	..	..	..	..	..	..	..	600e	664e	686e	0	0	0
So. Platte at Julesburg...	152	750	7869	28448	8719	16856e	15752e	21991e	42061	88937	19059	5543	4174	22305	21291	1813
Total outflow.......	693	6334	14918	28788	8719	16856e	15752e	22907e	42120	90310	26576	11344	13858	25693	23183	2155
Summary																
Inflow..................	1536	5253	13592	26184	7649	13457	12646	18281	34896	82617	16556	5777	12626	24363	21191	1835
Outflow................	693	6334	14918	28788	8719	16856	15752	22907	42120	90310	26576	11344	13858	25693	23183	2155
Return flow............	..	1081	1326	2604	1070	3399	3106	4626	7224	7693	10020	5567	1232	1330	1992	320
Av. daily ret., Acre-feet..	..	35	44	84	107	110	107	149	241	248	334	180	40	44	64	107
Av. daily Ret. sec. ft.....	..	18	22	42	54	56	54	75	122	125	169	91	20	22	32	54
Loss, second feet.......	42															

(e) Estimated values

Net return flow, July 22 to Nov. 10, 1919, acre-feet.......5,238
Mean daily return flow, acre-feet.............................. 47
Mean daily return flow, second-feet.......................... 24

Net return flow, January 1 to Nov. 3, 1920 (acre-feet)....46,509
Mean daily return flow, acre-feet.......................... 151
Mean daily return flow, second-feet....................... 76

of temperature of the percolating water would probably not be greater than 15 degrees and would occur between the months of March and September. On account of the change in viscosity, this increase in temperature would tend to increase the return flow by approximately 20 percent. The recent investigation shows the mean return flow, Kersey to Julesburg, for September, 1919 and September 1920, to be 830 second-feet, and the return flow for March, 1920, to be 690 second-feet; or the return flow in September to be 20 percent greater than in March. The change may be due entirely to the effect of temperature, but some other factors, such as the change in the slope of the ground water surface and the variation in the amount of irrigation water applied, probably also exert considerable influence on the amount of the return flow.

In the compilation of these data shown in the summary, Tables 6 to 11, a distinction has been made between the inflow and return seepage. All streams of practical importance that emptied into the river channel were accounted for as inflow, but in some cases may be looked upon as seepage. The Day and Smiley, Bijou, and Shumaker drains may be included as purely seepage, with the exception of the latter which carried waste water from the Weldon Valley Canal. Cedar and Moore's creeks also carried seepage and waste water, and Lodgepole contributed some of both.

Fig. 9.—View looking up Prewitt Drain Ditch from a point near the outlet end of the drain at river.

The Prewitt Drain ditch near Merino (see Fig. 9) carried the seepage from the Prewitt Reservoir with possibly a small amount of waste water from the South Platte Canal. To make a distinction between the kinds of water, it was decided to classify all these streams as inflow and the seepage as that returning to the river channel in the form of small streamlets and unobserved waters, such as springs and submerged flows. During 1919 the Ten Foot Drain and Moore's Creek, in District 64, were not included as inflow to the river because records were not obtained on these

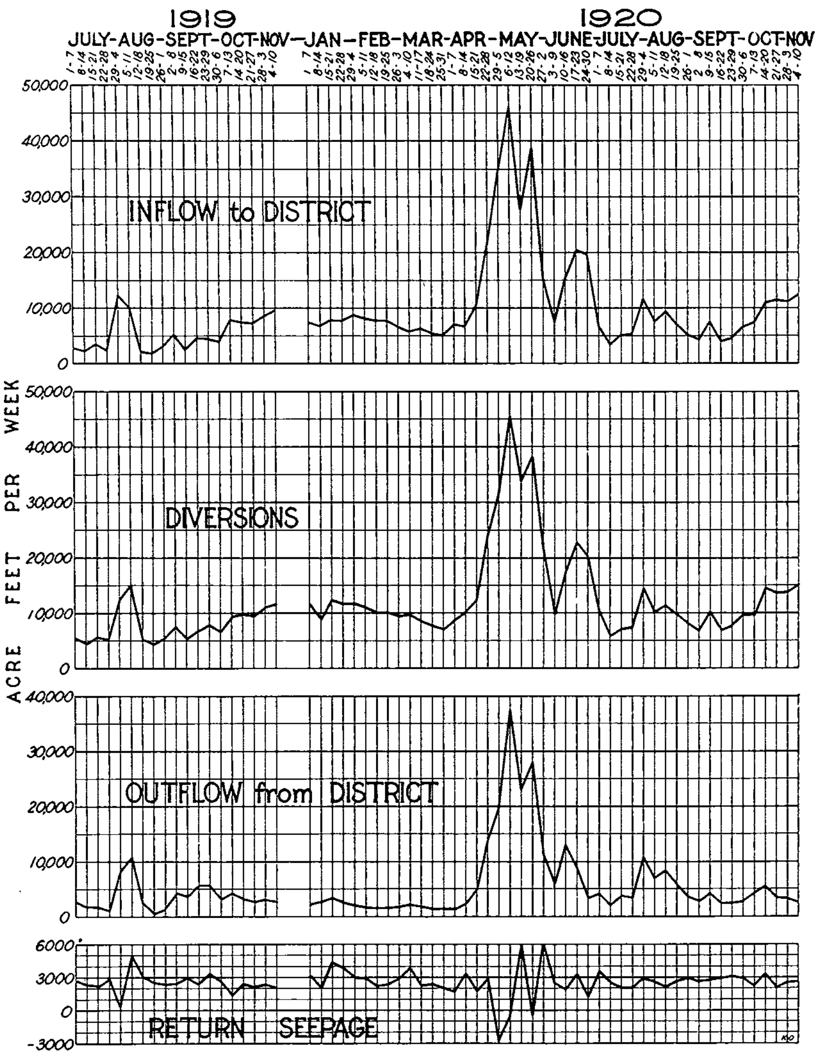

Fig. 10.—Diagram showing the relation of inflow, diversions, outflow and return seepage for the district Kersey to Orchard.

two streams. Hence this flow was included in the seepage return. Accounting for these streams as inflow during that year, the apparent return flow from Beetland to Julesburg would have been reduced by approximately 6 percent when based on the period of January to October, 1920.

The summary of the data is shown in graphical form in Figs. 10 to 15 inclusive. These charts show the weekly variation of the inflow in the district, the diversions, outflow from dis-

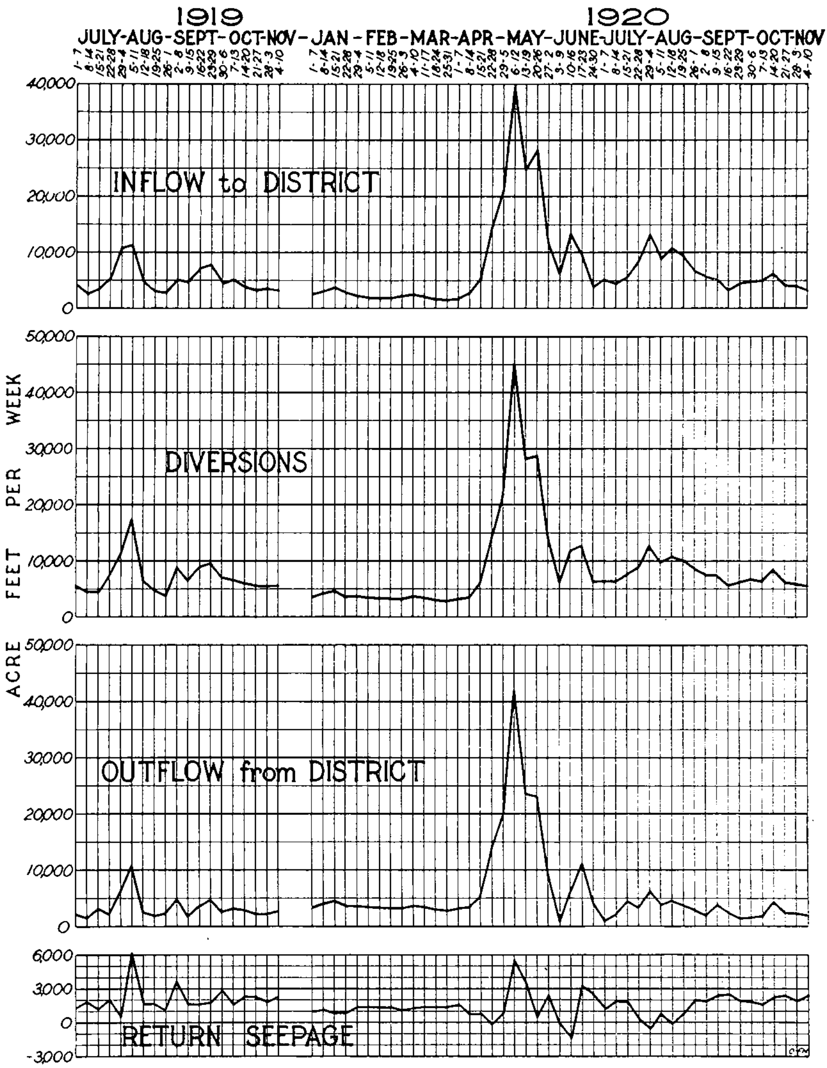

Fig. 11.—Diagram showing the relation of inflow, diversions, outflow and return seepage for the district Orchard to Fort Morgan.

trict and the return seepage, all in acre-feet per week. The effect of the rise of the river is well marked in the extent of the return flow, and in some cases there has been an actual loss instead of a gain. The return-flow seepage curves in general show an increase when the stage of the river is falling, this being attributed to the water being absorbed by the sands of the

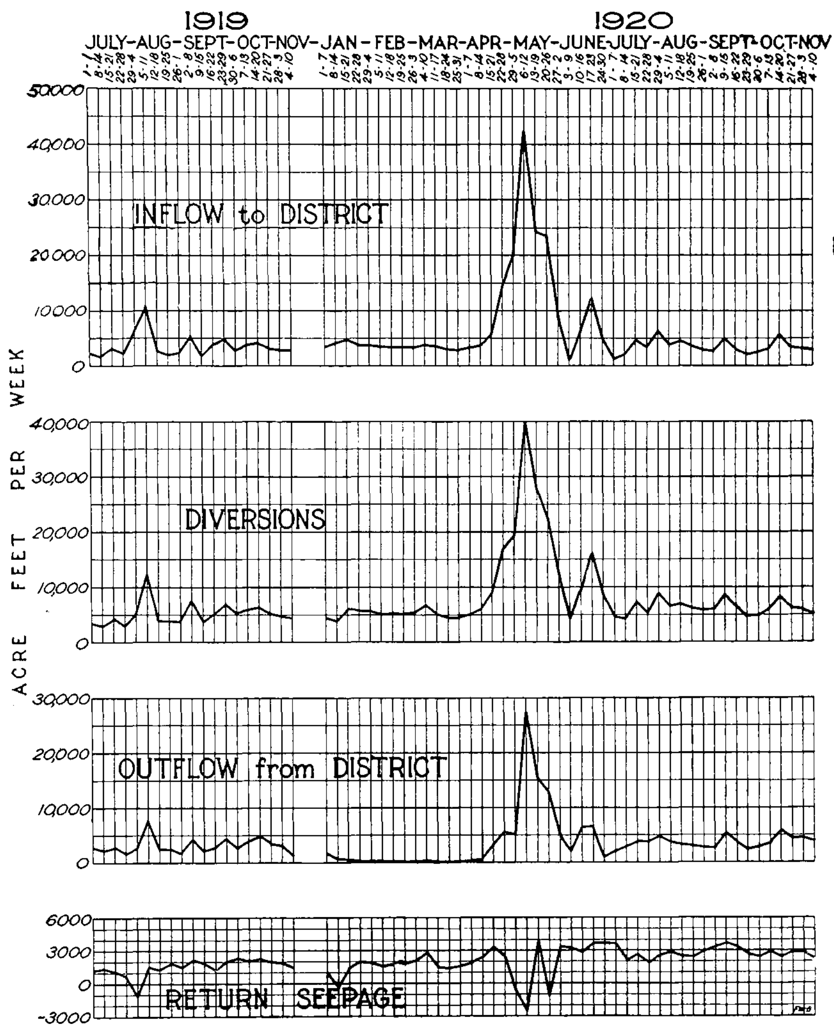

Fig. 12.—Diagram showing the relation of inflow, diversions, outflow and return seepage for the district Fort Morgan to Balzac.

river bed at high stage and then released as the flow of the river decreases.

Fig. 16 was compiled from the following data to give some idea of the yearly increase of the return flow for the South Platte River from Kersey to Julesburg. To have presented these data for each year would have resulted in a series of broken lines which would not be easy to interpret; therefore, for the sake of simplicity, the years were grouped in periods of three to five years and mean values determined. The curve, 1890 to

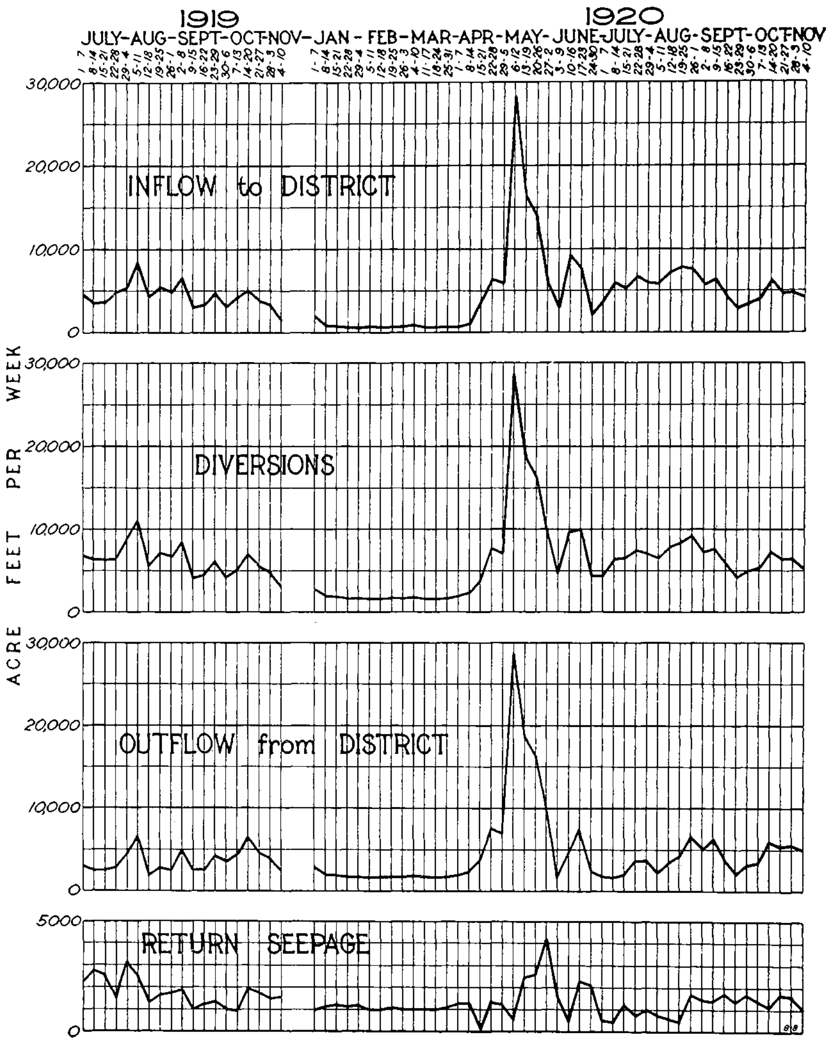

Fig. 13.—Diagram showing the relation of inflow, diversions, outflow and return seepage for the district Balzac to Beetland.

1894, represents the data collected by Prof. L. G. Carpenter; the curves, 1895 to 1908, are based on the data taken from the biennial reports of the State Engineer of Colorado, and the curve, 1916, 1917 and 1918, represents the average values as determined by R. G. Hosea. The 1919-1920 curve, cooperative investigation, is based on data taken for a continuous period while the other curves were determined by data obtained by the series method. In this diagram it is observed that there is apparently

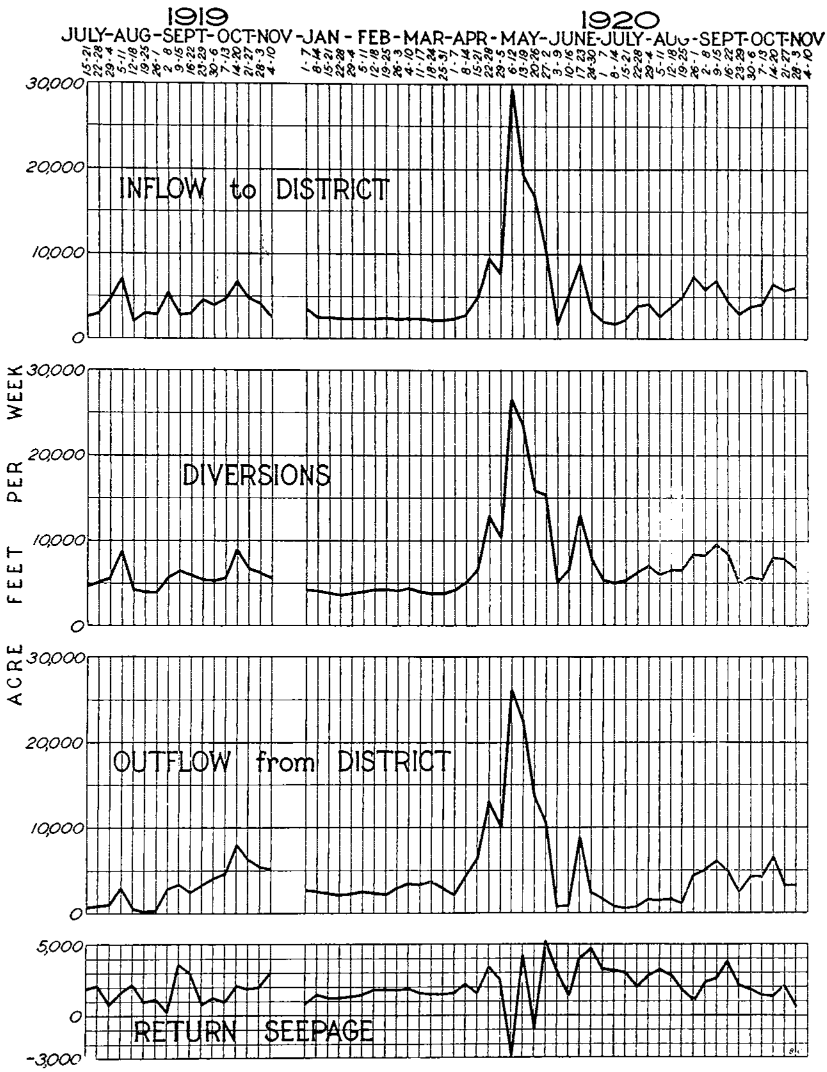

Fig. 14.—Diagram showing the relation of inflow, diversions, outflow and return seepage for the district Beetland to Crook.

while the broken dotted-line, 1919-1920, is based on values where a yearly increase in the return seepage and that the results of the investigation made during 1919 and 1920 show the return flow less than for the period 1916, 1917 and 1918. This deviation is because the several inflows, such as the Meadow Farms, Day and Smiley, Bijou, Shumaker and other drainage streams, were accounted for as return flow for the period 1916 to 1918,

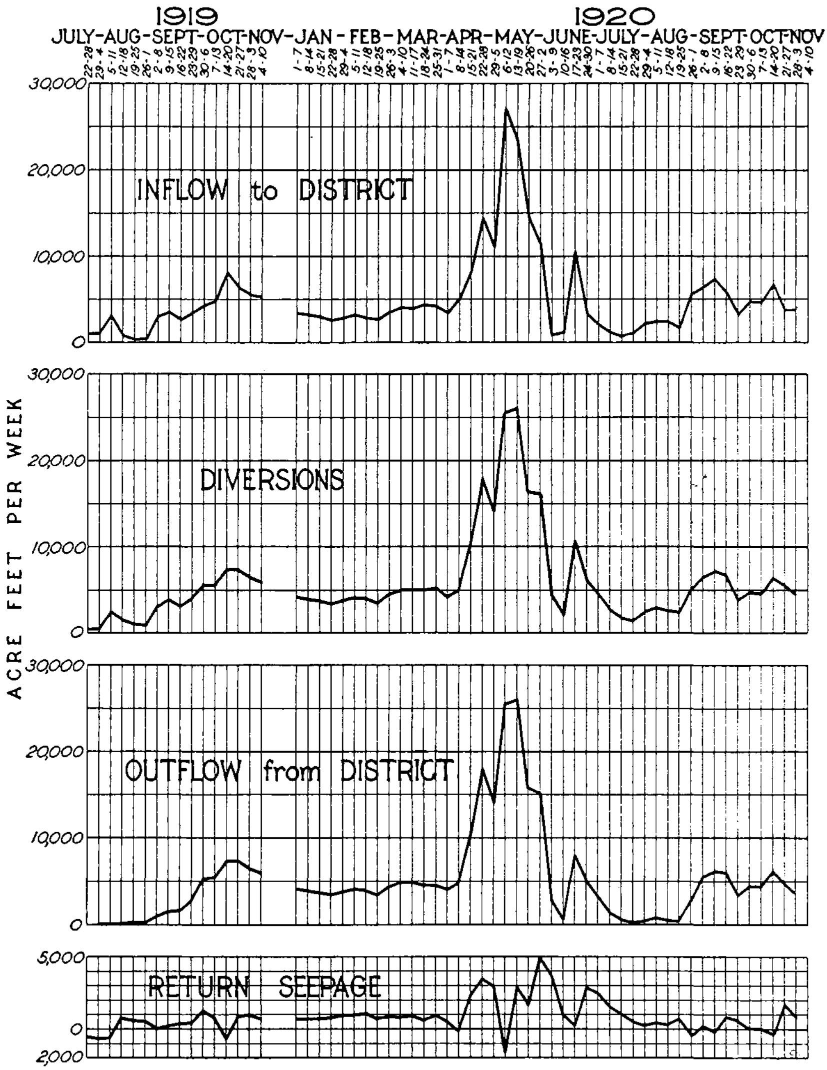

Fig. 15.—Diagram showing the relation of inflow, diversions, outflow and return seepage for the district Crook to Julesburg.

the main, drainage-inflow streams are considered as direct inflow, which results in a decrease in the total return flow.

The summary, Table 12, is based on the average return flow in second-feet per month for the various sections of the river from Kersey to Julesburg, and also the average return flow in second-feet per mile. This table further shows the average re-

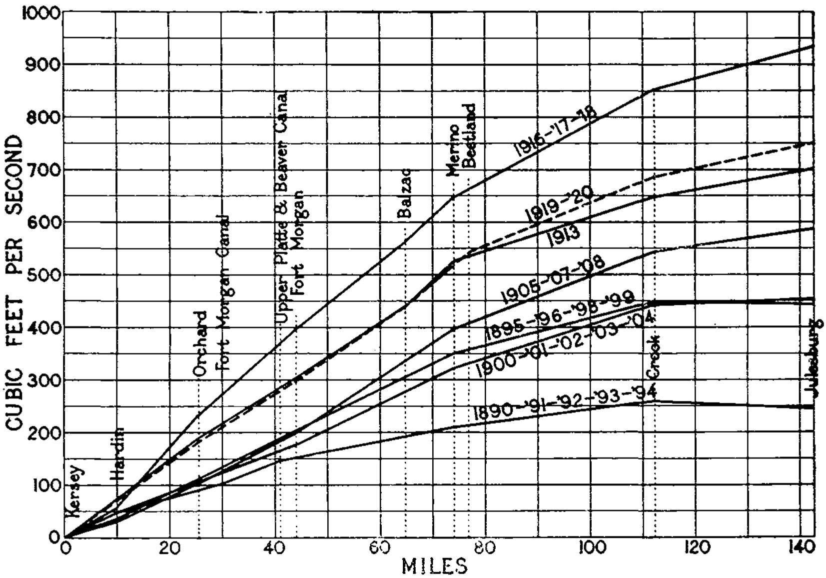

Fig. 16.—Curves showing the gain of return flow in second-feet to the South Platte River for the various periods of years from 1890 to 1920 for the points between Kersey and Julesburg.

turn flow in second-feet for the entire distance, Kersey to Julesburg, and also the average return per mile per month during the period of the investigation.

The previous seepage studies on the South Platte River were usually made during the months of October and November, where discharge measurements were made beginning at the uppermost station on the river and proceeding down stream at approximately the same rate as the flow of the river. A special series of seepage measurements were made in August, 1921, to determine the extent of the return water at that time by observing the discharge at all the river stations previously maintained between Kersey and Julesburg, as well as all the diversions and inflows between these points. The return flow was thus determined by the difference between the inflow and diversions, plus the amount of water in the river at the next succeeding down-stream station. Prof. L. G. Carpenter for a number of years carried out such a study between the mouth of the Poudre and Julesburg.* It is evident from the conclusions of these studies that, for a period of years, the return flow was not constant; however, it is very clearly indicated that the gain is quite marked and greatest in the upper part of the river val-

* The results of these studies may be found in Bulletin 33, Colorado Agricultural Experiment Station.

TABLE 12.—Summary of return flow in second-feet by months and the return flow in second-feet per mile.

		Kersey to Orchard 25.5 miles	Orchard to Fort Morgan 18.5 miles		Fort Morgan to Balzac 20.7 miles		Balzac to Beetland 12 miles		Beetland to Crook 35.3 miles		Crook to Julesburg 30.5 miles		Kersey to Julesburg 142.7 miles	
1919 Month	Av. Return Sec.-Feet	Sec.-Feet per mile	Average return sec.-feet	Sec.-Feet per mile	Average return sec.-feet	Sec.-Feet per mile	Average return sec.-feet	Sec.-Feet per mile	Average return sec.-feet	Sec.-Feet per mile	Average return sec.-feet	Sec.-Feet per mile	Average return sec.-feet	Sec.-Feet per mile
July	184	7.21	122	6.60	83	4.01	155	12.91	134	3.78	0e	.00e	678	4.75
August . .	187	7.33	162	8.76	71	3.43	158	13.16	104	2.93	18	0.59	700	4.91
September	201	7.88	159	8.60	133	6.43	98	8.16	131	3.59	22	0.72	744	5.21
October ..	155	6.08	153	8.27	155	7.49	101	8.41	120	3.38	42	1.38	726	5.09
1920														
January .	247	9.69	69	3.73	82	3.96	77	6.41	86	2.42	56	1.84	617	4.33
February.	191	7.48	100	5.40	127	6.14	75	6.24	122	3.44	54	1.77	669	4.67
March ...	191	7.48	95	5.14	135	6.52	74	6.16	120	3.38	75	2.46	690	4.83
April	177	6.94	58	3.14	182	8.80	78	6.50	165	4.65	122	4.00	782	5.48
May	120	4.70	200	10.81	15	0.73	163	13.59	90	2.54	125	4.10	713	5.00
June	153	6.00	69	3.73	244	11.79	115	9.59	254	7.15	169	5.54	1004	7.05
July	180	7.06	86	4.65	185	8.94	57	4.75	206	5.80	91	2.98	805	5.64
August ..	195	7.64	44	2.38	192	9.27	59	4.91	173	4.87	20	0.66	683	4.78
September.	206	8.07	154	8.33	231	11.17	109	9.09	194	5.46	22	0.72	916	6.42
October...	187	7.33	143	7.73	190	9.18	110	9.17	124	3.49	32	1.05	786	5.51
Mean	184	7.21	115	6.23	145	6.99	102	8.50	145	4.06	61	1.99	751	5.26

TABLE 13.—Special Observations, South Platte River, Kersey to Julesburg, August 8-12, 1921.

Station	Inflow Second-Feet	Outflow Second-Feet	Return Second-Feet
River at Kersey	690		
Hoover Ditch		10	
Crow Creek	5		
Boxelder Creek	5		
Empire Canal		290	
Riverside Canal		Dry	
Illinois Ditch		Dry	
Meadows Farms Drain	10		
Bijou Canal		120	
Corona Ditch		Dry	
Putnam Ditch		5	
Riverside Outlet Ditch	Dry		
Day & Smiley Drain	15		
Jackson Lake Inlet Ditch		Dry	
Weldon Valley Canal		115	
Bijou Drain	15		
River at Orchard		560	
Total	740	1100	
Return flow Kersey to Orchard			360
Mean return flow for this section	July 1 to Nov. 10, 1919		180
Mean return flow for this section	Jan. 1 to Nov. 10, 1920		188
River at Orchard	560		
Jackson Lake Outlet	Dry		
Shumaker Drain	10		
Fort Morgan Canal		175	
Bijou Creek	15		
Upper Platte & Beaver Canal		220	
Deuel & Snyder Ditch		20	
River at Fort Morgan		315	
Total	585	730	
Return flow Orchard to Ft. Morgan			145
Mean return flow for this section	July 1 to Nov. 10, 1919		150
Mean return flow for this section	Jan. 1 to Nov. 10, 1920		108
River at Fort Morgan	315		
Brown & Pyott Ditch		Dry	
Lower Platte & Beaver Canal		180	
Tremont Ditch		40	
Wild Cat Creek	Dry		
Gill & Stevens Ditch		Dry	
Snyder Ditch		Dry	
Trowel Ditch		Dry	
A. A. Smith Ditch		10	
North Sterling Inlet Ditch		Dry	
Union Ditch		Dry	
Big Beaver Creek	10		
Prewitt Inlet Ditch		Dry	
Johnson & Edwards Ditch		Dry	
Tetsel Ditch		15	
River at Balzac		370	
Total	325	615	

TABLE 13.—(Continued)

Station	Inflow Second-Feet	Outflow Second-Feet	Return Second-Feet
Return flow Ft. Morgan to Balzac.			290
Mean return flow for this section	July 1 to Nov. 10, 1919		110
Mean return flow for this section	Jan. 1 to Nov. 10, 1920		169
River at Balzac	370		
South Platte Canal		35	
Pawnee Canal		110	
Prewitt Reservoir Outlet Canal....	Dry		
Prewitt Drain	40		
Davis Bros. Ditch		30	
Schneider Ditch		35	
River at Beetland		380	
Total.........................	410	590	
Return flow Balzac to Beetland....			180
Mean return flow for this section	July 1 to Nov. 10, 1919		127
Mean return flow for this section	Jan. 1 to Nov. 10, 1920		91
River at Beetland	380		
Springdale Ditch		60	
Batton Ditch		Dry	
Pawnee Creek	Dry		
Sterling Ditch No. 1		80	
Sterling Ditch No. 2		Dry	
Hereford Cattle Co. Ditch		Dry	
Henderson & Smith Ditch..........		Dry	
Lowline Ditch		35	
Cedar Creek	30		
Bravo Ditch		25	
Farmers Ditch		Dry	
Lone Tree Ditch		10	
Iliff & Platte Valley Canal.........		65	
J. B. Ditch		Dry	
Blair Ditch		Dry	
Powell and Dillon Ditch		Dry	
Powell Drain	5		
Harmony Ditch No. 1		225	
Ten Foot Drain	15		
Chambers Ditch		10	
River at Crook		140	
Total.........................	430	650	
Return flow Beetland to Crook....			220
Mean return flow for this section	July 15 to Nov. 10, 1919		127
Mean return flow for this section	Jan. 1 to Nov. 10, 1920		151
River at Crook	140		
Settlers Ditch		45	
Long Island Ditch		Dry	
Red Lion Ditch		Dry	
Moore's Creek	Dry		
Peterson Ditch		140	
South Reservation Ditch		Dry	
Carlson Ditch		Dry	
Lodgepole Creek	10		
Liddle Ditch		5	

TABLE 13.—(Cincluded)

Station	Inflow Second-Feet	Outflow Second-Feet	Return Second-Feet
Cox Ditch		25	
River at Julesburg		135	
Total	150	350	
Return flow Crook to Julesburg			200
Mean return flow for this section	July 22 to Nov. 10, 1919		23
Mean return flow for this section	Jan. 1 to Nov. 3, 1920		76

ley. Later, R. G. Hosea conducted an extended series of seepage measurements on this river along much the same line as those just mentioned, and his studies also show marked increases for the upper sections of the valley between Kersey and Julesburg.

These special observations were made for the purpose of comparing the method of taking individual measurements in the various sections and the mean or average results obtained by continuous records. No great reliance can be placed upon these comparisons because the return flow is very greatly affected by the stage of the flow and also because of changes in the river channel. On a rising stage a greater area of river bottom is covered, which apparently has the effect of absorbing or holding back the return flow, while on a falling stage the water held in the sands adjacent to the stream is relieved and readily finds its way into the flowing channel. Table 13 shows the results of this special series of measurements which were taken during a falling stage of the river. During the previous June a large flood passed down the valley and so changed the conditions of the river channel that some variation from the results obtained during the two previous years might be expected. It is believed, however, that the falling stage of the river occurring while the measurements were being made is the principal reason for the excessive return flow shown by these special observations.

Dr. Fortier* made a series of seepage measurements on the Bitter Root River in Montana in 1903 which show the effect of absorption or infiltration during a period of high water and the excessive return flow which occurred during the following low stage of the river.

"The first series of measurements was made from June 11 to 15, 1903, and consisted of a measurement of the river at Grantsdale and a measurement of each of the 39 tributaries, as well as five diversions through irrigation canals. The results of the first series of measurements, expressed in cubic feet per second, are as follows:

*Irrigation in Montana, by Samuel Fortier, U. S. Dept. of Agri., O. E. S., Bul. 172, pp. 91.

"Return Seepage, Bitter Root River, June 11-15, 1903

Discharge of river at Grantsdale, Mont.	9111.3	
Inflow from 39 tributaries	5764.2	
Total inflow		14875.5
Discharge of river at Buckhouse bridge	12660.6	
Diversions through canals	313.5	
Total outflow		12974.1
Loss in 48 miles		1901.4

"The second series was made about a month later, between July 9 and 14, after the spring floods had subsided. The results of the second series of measurements, expressed in cubic feet per second, are as follows:

"Return Seepage, Bitter Root River, July 9-14, 1903

Discharge of river at Grantsdale, Mont.	2320.9	
Inflow from tributaries	1623.8	
Total inflow		3944.7
Discharge of river at Buckhouse bridge	4221.7	
Diversions through canals	161.7	
Total outflow		4383.4
Gain in 48 miles		438.7

"The third series was made from August 7 to 14, at a time when the discharges of the river and the various tributaries was quite low. The results of the third series of measurements, expressed as before, are as follows:

"Return Seepage, Bitter Root River, August 7-14, 1903

Discharge of river at Grantsdale, Mont.	325.5	
Inflow from tributaries	209.5	
Total inflow		535.0
Discharge of river at Buckhouse bridge	1536.8	
Diversions through canals	111.8	
Total outflow		1648.6
Gain in 48 miles		1113.6

"The foregoing figures show that a large volume is held back during the flood period, when all the natural channels are full, and that much of the water which is temporarily stored in this way returns to the channel of the river to augment the flow during the latter part of the season. According to the measurements, a volume of 1901 cubic feet per second was retained on June 11 to 15. The only way to account for this loss is by infiltration in the soils and subsoils of the valley. It is probable this process went on over 480 square miles of open, gravelly soil, and if this is so, it is not surprising that a stream of nearly 4 cubic feet per second on an average should be absorbed by each section of land. This process of absorption or infiltration of water, if one considers the entire area affected, terminated about July 6. After this date there is a gain instead of a loss. This gain is small at first, but at the end of 37 days increases to 1,113 cubic feet per second. The conditions found between August 7 to 14 are remarkable.

The total discharge of the stream at Grantsdale is only 325.5 and that of all the tributaries 209.5, or 535 cubic feet per second in all. At the same time there is an available flow of 1,648.6 cubic feet per second at a point 48 miles farther down the stream. In other words, the increase is more than double the ordinary flow of the stream."

SEEPAGE LOSSES FROM CANALS

Only two canals, the Empire Inlet and Jackson Lake Inlet, were investigated for seepage losses, and unfortunately the records obtained on the Jackson Lake Inlet were of such short duration that little or no dependence can be placed upon the results.

It was not until April, 1921, that this matter was given attention, and at that time the Jackson Lake Reservoir was practically filled, which caused the closing down of the canal. On this canal two registers were installed, one at the rating flume near the diversion from the river, and the other near Orchard, 9 miles below the rating flume and about 1½ miles from the reservoir. Records were obtained for a three-day run, April 22 to 24, which show an average loss of 7.8 second-feet, or approximately 1 second-foot per mile for a head of about 145 second-feet. This canal is located through a sandy-soil region where a greater loss would be expected, but this channel has been used for 18 years, during which time the interior surface has become well silted. The section of the canal at the lower station had a bottom width of 27 feet, side slopes of approximately 3 to 1, and a depth of 3.2 feet. The 9-mile section of canal investigated had but one waste way, which, during the test, discharged a constant stream of 0.90 second-feet, which was applied as a correction to the total passing the upper station.

Observations on the Empire Inlet Canal began April 28 and continued without interruption until May 25, a period of 28 days. During this time the average daily loss was 19.3 second-feet or about 1 second-foot per mile when carrying an average of approximately 250 second-feet. Two gaging stations were established on this canal, one at the rating flume near the head and the other one down stream where the section line south from Masters intersects the canal. At each of these stations there was installed a new-type register which gave a continuous record of the gage-height. The distance between stations was 19.7 miles by way of the alignment of the canal. This canal was constructed through a sandy material and for the first 5 miles below the rating flume the bottom of the canal is in quite coarse gravel. The present section of the canal is about 30 feet wide on the bottom with side slopes of 1 to 1, and it has a capacity of approximately 450 second-feet. The canal has been in use since about 1906, and like the Jackson Lake Inlet canal, has accumulated a covering of silt which has materially lessened the seepage losses. The Empire Canal is well suited

TABLE 14.—Seepage losses on Empire and Jackson Lake Inlet Canals.

Date 1921	Upper Station Rating Flume Acre-Feet	Lower Station Masters Acre-Feet	Seepage Loss Acre-Feet	Loss in Sec. Ft.	Gain due to drop in Gage-Height Acre-Feet	Gain in Sec. Ft.
Apr. 28	575.5	104.1	471.4	237.6	......	......
Apr. 29	712.2	634.1	78.1	39.3	......	......
Apr. 30	938.9	614.3	324.6	163.6	......	......
May 1	634.6	724.9	.....	.....	90.3	45.6
May 2	744.4	540.5	203.9	102.8	......	......
May 3	762.4	681.4	81.0	40.8	......	......
May 4	835.0	732.0	103.0	51.9	......	......
May 5	768.6	800.2	.....	.....	31.6	15.9
May 6	428.4	555.8	.....	.....	127.4	64.2
May 7	223.0	317.3	.....	.....	94.3	47.5
May 8	136.4	243.4	.....	.....	107.0	53.9
May 9	55.0	133.3	.....	.....	78.3	39.4
May 10	158.6	99.2	59.4	29.9	......	......
May 11	634.8	373.0	261.8	131.9	......	......
May 12	749.9	618.3	131.6	66.3	......	......
May 13	748.7	647.6	101.1	50.9	......	......
May 14	775.0	658.4	116.6	58.7	......	......
May 15	799.3	715.0	84.3	42.5	......	......
May 16	823.1	751.7	71.4	35.9	......	......
May 17	813.2	741.8	71.4	35.9	......	......
May 18	792.3	779.4	12.9	6.5	......	......
May 19	249.4	551.0	.....	.....	301.6	152.0
May 20	30.7	213.2	.....	.....	182.5	92.0
May 21	51.6	127.9	.....	.....	76.3	38.4
May 22	39.7	47.6	.....	.....	7.9	3.9
May 23	27.8	50.5	.....	.....	22.7	11.4
May 24	17.8	14.9	2.9	1.4	......	......
May 25	19.8	0.0	19.8	9.9	......	......
Totals...	13546.1	12470.8	2195.2	1105.8	1119.9	564.2

EMPIRE INLET CANAL

Total inflow, April 28-May 25............................13546.1 Acre-Feet
Total outflow, April 28-May 25...........................12470.8 Acre-Feet
Total net loss, April 28-May 25.......................... 1075.3 Acre-Feet
Average daily loss....................................... 38.4 Acre-Feet
Average daily loss in second feet........................ 19.3

JACKSON LAKE INLET CANAL

Total inflow, April 22-24.................................887.5 Acre-Feet
Total outflow, April 22-24................................840.9 Acre-Feet
Total loss, April 22-24.................................. 46.6 Acre-Feet
Average daily loss....................................... 15.5 Acre-Feet
Average daily loss in second feet........................ 7.8

for the investigation of seepage losses, having only one wasteway between the points of discharge measurements, and during the period of the observations there was less than 0.1 second-foot leakage at this point.

The summary of the data concerning the seepage losses of these canals is given in Table 14. These losses, when expressed in percentage of the discharge at the upper station, were 8.0 percent for the Empire Canal when carrying an average of approximately 250 second-feet, and 5.2 percent for the Jackson Lake Inlet Canal when carrying an average of approximately 145 second-feet. These losses, when expressed in percent per mile, are 0.40 for the Empire Canal and 0.58 for the Jackson Lake Inlet Canal.

DAILY FLUCTUATIONS

At various places along the river it was observed that there was a very noticeable daily variation in the flow of the water in the canals and ditches and also the river at Julesburg. Evidence of this daily rise and fall of the river stage was noted in the upper district, but it was much more pronounced from Balzac to Julesburg. The Schneider Ditch, near Merino, shows a very pronounced fluctuation with approximately 0.20 foot range of head, or a variation in the flow of about 8 second-feet, which was most noticeable during September. The Prewitt Drain also shows a similar variation where a change of 0.15 foot in gage amounts to approximately 4 second-feet. The most marked daily change of flow was observed on the South Reservation Ditch near Julesburg, when the ditch was taking at its headgate practically all the water in the river. A record of this variation (Fig. 17) shows a daily change of more than 0.30 foot on the gage, or about 5 second-feet variation in the discharge. The register on the South Platte River at Julesburg indicated, during the latter part of July when the flow of the river was small, approximately 0.1 foot daily variation of the stage of the river.

The diversions from the river in the lower area, District 64, during this time when these variations were most noticeable, were made when the flow of the river was entirely seepage water. This periodic change in the flow of the river is no doubt due to the evaporation losses from the warm shallow streams of water and also from the warm sands of the river bed. Assuming that the South Reservation Ditch drained the river at its headgate, which is located about 15 miles above the Julesburg river station, and that the average exposed width of the river bed for this distance is 500 feet, there would be some 900 acres that were contributing to the evaporation loss. This loss of 20 second-feet in twelve hours from this area results in one forty-fifth of a foot as the evaporation, or about one-fourth inch. The Prewitt Drain (Fig. 9), which catches the seepage from the Prewitt Reservoir, is approximately three miles in length and about 20 feet wide, and numerous ponds are directly connected with this ditch, which, in the aggregate, has an exposed area of

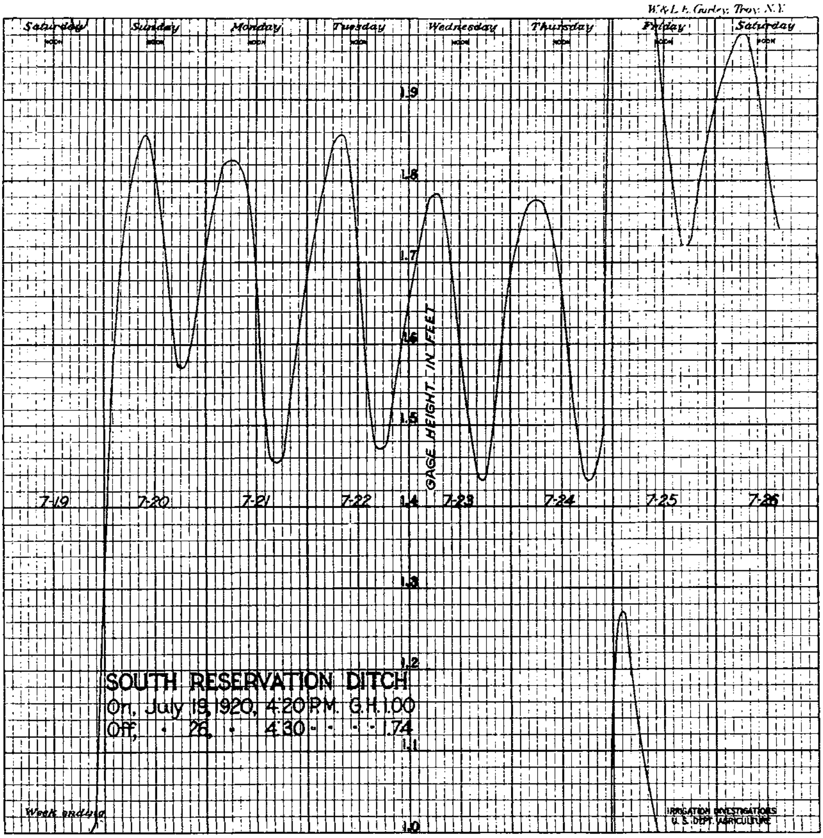

Fig. 17.—Reproduction of the actual instrument record of the South Reservation Ditch which shows a daily variation of the gage height of more than 0.30 foot.

80 acres, more or less, depending upon the depth of water in the reservoir. The variation of flow of approximately 4 second-feet in 12 hours is about 4 acre-feet, or a loss of nearly five-eighths of an inch on the basis of 80 acres as the exposed area.

CANALS AND IRRIGATION SYSTEMS OF THE VALLEY

The first ditch to have acquired a right to divert water from the South Platte River was the Brantner Ditch near Brighton, Water District No. 2, with an appropriation of 29.77 second-feet, dated April 1, 1860. In District No. 1, the Hoover Ditch appropriated 15 second-feet April 20, 1869, and in the lower river, District No. 64, the South Platte Ditch appropriated 22.5 second-feet on May 1, 1872.

These first ditches were comparatively short in length and served but a few hundred acres along the bottom lands of the valley. The return flow to the river from these early ditches must have been of little importance, due to the small amount of water diverted from the river. Historical records indicate that at about this time the supply of water for irrigation was at times completely exhausted. Enlargements and extensions were made later on some of the early ditches, while in other cases new ditches were created covering larger areas, these additional diversions taking advantage of the spring and early summer flow which was sufficient to supply all these ditches. These first efforts in building irrigation systems were made largely through co-operative action on the part of the farmers, and not until after the adoption of the Colorado Irrigation District Laws in 1901 was there concerted action on a relatively large scale to bring about larger irrigation systems. At this time the return flow to the river had increased in sufficient proportions to warrant further irrigation development. In this development under the irrigation act of 1901 it appears that the South Platte Valley was greatly favored in the successful promotion of irrigation districts, especially in Water Districts 1 and 64. A report of the Colorado Irrigation District Finance Commission to the Twenty-third General Assembly of Colorado gives, in part the following facts concerning the irrigation districts of the Lower South Platte Valley:

Name of District	Date of Organization	Acres	Bonds issued	Remarks
Fort Morgan	1903	12,200	$ 186,000	Operating
Julesburg	1904	20,000	615,000	Operating
Bijou	1905	26,000	1,075,000	Operating
Hillrose	1905	11,460	70,000	Operating
Green City	1906	2,400	46,000	Operating
North Sterling	1907	47,000	2,080,000	Operating
Riverside	1907	40,000	1,047,500	Operating
Iliff	1910	13,600	225,000	Operating
Logan	1910	13,600	480,000	Operating

These irrigation districts at present are all in successful operation, drawing their supply from the South Platte River and maintaining large storage reservoirs which greatly augment the natural flow of the river during the latter part of the irrigation season. At the time of building these irrigation systems, the direct-flow rights in the river were not sufficient to accommodate the acreage under ditch, and to take advantage of the return flow during the winter months together with the run-off during the spring and early summer, these large reservoirs were constructed for the purpose of conserving this water for use when the river flow was insufficient to meet the demand for direct irrigation. All these districts have storage supplies and their success is largely dependent upon the return flow to the river. The greater part of the filling of these reservoirs is during the fall and winter months, when the flow is practically all return water, and during the spring rise the "topping out" or last filling is made. Due to wind during the early spring months, the wave action on the embankments is very pronounced, and if the reservoirs do not have ample freeboard at this time, there is danger of breaking the dykes by water being carried over the top by these waves. As a usual practice, the last of the filling is withheld until after the period of high winds, and during the rise in the river which usually occurs in May or early June, the reservoirs are filled to capacity. The nature of the season has much to do with this filling, and at times the reservoirs are brought to capacity at an early date, drawing from then on only sufficient water to balance the seepage and evaporation losses.

To make use of these stored waters, which are largely derived from return seepage, an efficient system of exchange with the river flow has been developed where it has been possible to put into practice such a scheme. All the storage reservoirs of the lower South Platte Valley do not operate under the exchange system because of the lack of a direct outlet from the reservoir back to the river. The Fort Morgan District has acquired ample rights in Jackson Lake which is suitably located to deliver water into the river above the headgate of the Fort Morgan Canal. The Julesburg District has its own reservoir at sufficient elevation to cover practically the entire district with storage water. This reservoir is not used in the exchange of water with the river. The Bijou District has two reservoirs, the Empire and Bijou No. 2, which command the entire district but are not used in exchange with the river's flow. The North Sterling District also has a large reservoir known as the Point of Rocks, which supplies the entire district with storage water. This district is the largest in the lower valley and has no direct-flow rights in the river. The Riverside District is on the north side of the river, near Fort Morgan, and here too, their reservoir, known as the Riverside Reservoir, supplies the district with storage water. This district, like the North Sterling, has no direct-flow rights in the river and must depend upon river supply during the non-irrigation season. Other rights are owned in this reservoir which require exchange with the river's flow, and in order to take care of this exchange the outlet from this reservoir divides at a point about one mile below the outlet gates, where one branch leads to the district and the other to the river. The Iliff and Logan districts are dependent upon the Prewitt Reservoir which discharges directly into the river. The Green City District is located near Masters and has rights in the Riverside Reservoir. The Hillrose District is located on the south side of the river and is served by the lower Platte and

Beaver Canal. This district is served both by Jackson Lake and Riverside storage. The general map of the lower South Platte Valley (Plate 1) gives the location of these several principal storage reservoirs.

The return flow to the river, which has been increasing from year to year, has made possible the irrigation expansion in the valley, and in this development certain types of river structures have been built, some of crude and inexpensive design, while in other cases very substantial concrete construction has been provided, as for example in the Prewitt, North Sterling, Riverside and Fort Morgan systems. (See Fig. 18). The diversion

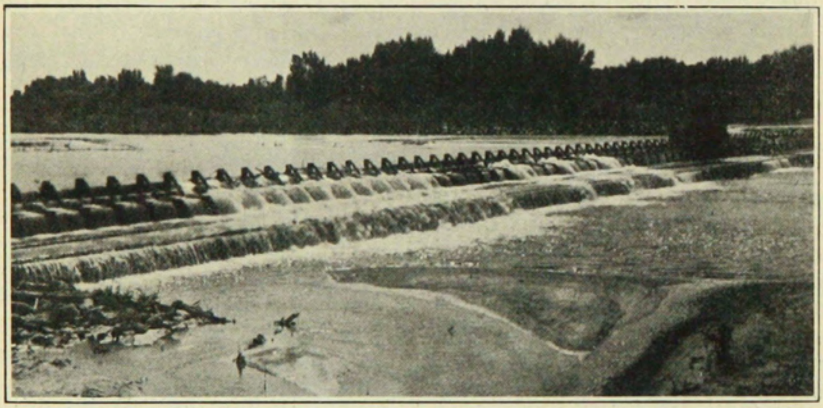

Fig. 18.—Prewitt diversion dam, flashboard type, with angle iron posts. The discharge passing over the dam is all return seepage to the river.

dams in the river are of various designs, but where a rise of two to three feet is sufficient, the more common and substantial ones are of the flashboard type. The panels are from 4 to 8 feet long, and in most cases the dams are from 200 to 400 feet in length. These flashboard dams have aprons provided on the down-stream side, either of concrete or timber, placed on lines of piling driven in the bed of the river.

The North Sterling dam, near Cooper, has the radial gate regulation. The gates are mounted between concrete piers. This type of regulation has proved very satisfactory, but at times during the winter, ice has interfered with the operation, due to the small clearance between the radial arms of the gate and the walls of the abutments.

The brush and sand dams are intended only as temporary expedients and are easily constructed at little cost, but are always at the mercy of high water. Due to the extreme depth of the sand bed of the river in most places, permanent structures can only be installed at considerable cost.

The headgates of the canals and ditches are of both the steel-gate and screw-lift type, and the wooden-gate and lever-lift type. The more recent headgates were built of concrete placed on pile foundations and are provided with a number of panels or openings in which the metal gates are raised by a large hand wheel working on the gate stem with a small-pitch thread. Waste ways are of similar construction.

The studies of the return flow, forming the basis of this bulletin, required the constant measurement of the diversions from the river where the amount flowing was determined by calibrating standard rating flumes. The rating flumes of the canals, in most cases, were built of timber and a number of them were in a bad state of repair, but just prior to the begin-

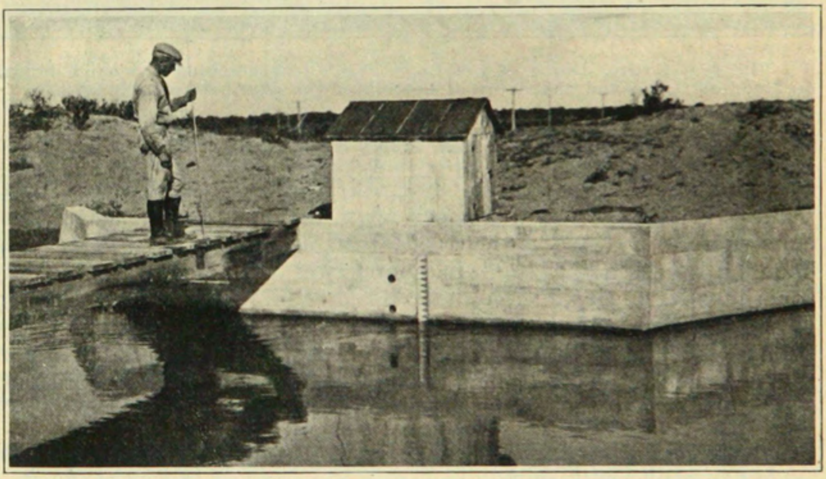

Fig. 19.—View of concrete flume on Weldon Valley Canal showing instrument shelter and 3-inch tubes through wall into float well.

ning of these seepage studies several new flumes, both concrete and timber, were installed, which aided greatly in the efficiency of the field work. About fifteen concrete rating flumes are in use along the river between Kersey and Julesburg, where both the rectangular and trapezoidal sections may be found.

A typical concrete rating flume with rectangular section is shown in Fig. 19. Due to the sand carried in many of the canals, the floor of the flume is not infrequently found to be covered, more or less, and in some cases this sand has been observed to accumulate to a depth of one and one-half feet. With such a deposit a flume is little better than a well-chosen earth section, and it is needless to say that distribution under such conditions is highly unsatisfactory. Fig. 20 shows a wooden rating flume with a moderate accumulation of sand on the floor.

Fig. 20.—Rating flume of the Lone Tree Ditch showing the sand deposit on floor of flume and character of bottom of the channel beyond.

RESERVOIRS OF THE LOWER PLATTE VALLEY

The first large storage reservoir built in the Lower Platte Valley for irrigation purposes was Jackson Lake, which was constructed in 1903. Since this date a number of others have been built, all being used in connection with the water supply for the several irrigation districts in the valley. The Prewitt Reservoir was the last storage provided, being constructed in 1911 1912. The following table shows the larger reservoirs of the Lower Platte Valley in the order of their date of construction:

TABLE 15.—Characteristic Features of the Larger Storage Reservoirs of the Lower South Platte Valley.

Reservoir	Constructed	Contour Feet	Capacity Acre-Feet	Area at H. W. line, acres	Max. H'gt of dam in feet
Jackson Lake	1903	30.2	35,400	2546	20
Julesburg	1905	47.0	28,200	1560	50
Empire	1906	30.0	37,700	2842	40
Riverside	1909	32.0	57,500	3595	25
Point of Rocks	1911	90.0	81,300	3081	87
Prewitt	1912	28.0	32,800	2431	37

All the storage reservoirs of this part of the valley were constructed in natural basins adjacent to the river, and almost without exception required long shallow earth-fills as dams, which have been provided, in most cases, with concrete facings on the inside slope as a protection against wave action. The Riverside, Jackson Lake, Empire and Prewitt reservoirs are all located in a region of sand hills, and owing to the nature of the soil there has resulted a material loss in seepage. The soil conditions at the Jackson Lake reservoir site may be somewhat modified in this respect, as an inspection of the outlet ditch from this reservoir indicates that a stratum of clay or heavy soil underlies this basin which would reduce the seepage losses.

The Prewitt Reservoir affords, perhaps, the best example of seepage losses from any of the storage basins in the valley. This reservoir, having a capacity of about 33,000 acre-feet, has an artificial embankment extending one-third of the length of the high-water-line contour. The material used in the construction of this embankment was fine sand with a small percentage of loam, the entire basin being of the same material. The reservoir is located near the river and the entire loss of water by seepage finds its way to the river channel, either through the sand or by way of the drain ditch. Soon after the first filling of the reservoir, much of the area immediately below the dam began to show signs of seepage, and to alleviate this condition an open drain was constructed below the reservoir paralleling somewhat the axis of the dam.

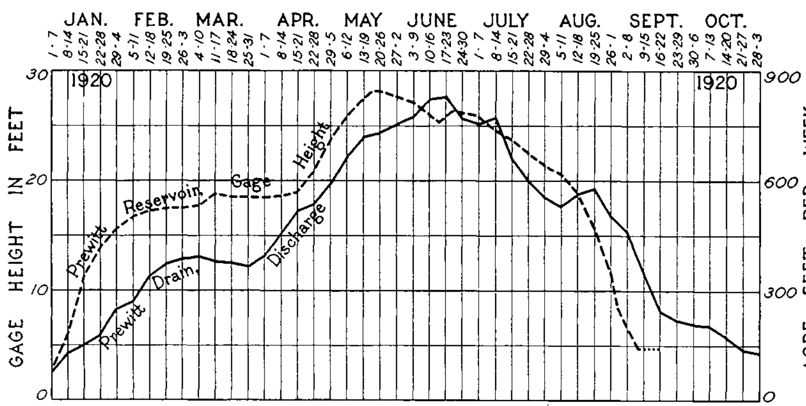

Fig. 21.—Diagram showing the relation of the discharge of the Prewitt Drain Ditch in acre-feet per week to the gage height of the Prewitt Reservoir.

This ditch is approximately 3 miles in length, and at the lower end discharges more than 60 second-feet when the reservoir is filled. Fig. 21 illustrates the relation between the discharge of this drain ditch in acre-feet per week, and the stage of the reservoir. As stated in the Eighteenth Biennial Report of the State Engineer of Colorado, the Prewitt Reservoir lost by evaporation approximately 16,200 acre-feet of water in the 35 months from December, 1912, to October, 1915, or 463 acre-feet per month as an average. The open drain carried an average of 600 acre-feet per week from January 1 to November 10, 1920, or about 2400 acre-feet per month. This amount added to the loss due to evaporation is about 2860 acre-feet, or the gross loss.

TABLE 16.—Table showing the gross loss in acre-feet per month for the Prewitt Reservoir.

Period	Days Run	Gage	Capacity Acre-Feet Begin	Capacity Acre-Feet End	Gain or Loss in Reservoir	Acre-Feet Diverted from River	Loss in Transit 2 percent	Acre-Feet delivered to Reservoir	Diverted from Reservoir to River	Loss in Acre-Feet
1919										
Oct. 1 to Oct. 31..	0	3.2- 3.1	650	620	— 30	.....	.....	.....	.....	30
Nov. 1 to Nov. 30.	0	3.1- 3.0	620	600	— 20	.....	.....	.....	.....	20
Dec. 1 to Dec. 31.	0	3.0- 2.9	600	590	— 10	.....	.....	.....	.....	10
1920										
Jan. 1 to Jan. 31.	27	2.9-15.3	590	8220	+7630	9390	190	9200	.....	1570
Feb. 1 to Feb. 29.	29	15.3-17-5	8220	11160	+2940	7090	140	6950	.....	4010
Mar. 1 to Mar 31.	31	17.5-18.5	11160	12690	+1530	6560	130	6430	.....	4900
Apr. 1 to Apr. 30.	30	18.5-22.6	12690	19870	+7180	14050	280	13770	.....	6590
May 1 to May 31	31	22.6-27.6	19870	31700	+11830	18540	370	18170	.....	6340
June 1 to June 30	12	27.6-26.1	31700	27690	—4010	5800	120	5680	2550	7140
July 1 to July 31	2	26.1-21.5	27690	17800	—9890	430	10	420	6680	3630
Aug. 1 to Aug. 31	0	21.5-10.8	17800	3920	—13880	.....	.....	.....	12760	1120
Sept. 1 to Sept. 30	0	10.8- 4.8	3920	1000	—2920	.....	.....	.....	3290	370*
Total........				350				60620	25280	34990

$$\text{Efficiency} = \frac{25280 + 350}{60620} = \frac{25630}{60620} = 42\%$$

$$\text{Avg. loss per month } \frac{34990}{12} = 2916 \text{ acre-feet}$$

$$\text{Avg. loss per day } \frac{2916}{30} = 97 \text{ acre-feet}$$

Table 16 gives the average loss per month from this reservoir to be 2916 acre-feet, which is based upon inflow and outflow records. The close agreement between the loss of the reservoir determined by the drain ditch, plus the evaporation and the mean value given in the table, would indicate that the drain ditch intercepts a very large percentage of the underflow. Messrs. Weiland and Bishop, formerly State Engineer and Deputy State Engineer, respectively, of Colorado, and Olds determined in 1913 to 1917, a period of five years, that the open drain ditch carried off 65 percent of the reservoir loss, leaving the remaining portion of the loss to reach the river channel as underflow.

An attempt was made to determine the losses for the Riverside and Jackson Lake reservoirs, as well as for the Prewitt. Due to adverse weather conditions, it was not possible to determine accurately the inflow to these reservoirs during a part of the filling season, but the estimated flow is thought to be

* Gain.

reasonably close. Register records were obtained on all inflows and outflows with the exception of the diversion from the Riverside Reservoir to the district. This particular information was obtained from J. M. Dille, superintendent of the Riverside District. The gage heights for the reservoirs were obtained from the superintendents of the companies and are assumed to be correct. The results of losses from the Jackson Lake and the Riverside reservoirs, together with the average monthly loss in acre-feet and the approximate daily loss expressed in acre-feet, are given in Tables 17 and 18.

TABLE 17.—Table showing the gross loss in acre-feet for Jackson Lake.

Period	Days Run	Gage	Capacity Acre-Feet Begin	Capacity Acre-Feet End	Gain or Loss in Reservoir	Acre-Feet diverted from River	Loss in Transit 5 percent	Acre-Feet delivered to Reservoir	Diverted from Reservoir to River	Loss in Acre-Feet
1919										
Nov. 1 to Nov. 30..	0	13.0-13.0	3500	3500	(Repairing outlet tubes and gates)					
Dec. 1 to Dec. 31..	20	13.0-17.3	3500	8070	+ 4570	5500	280	5220	......	650
1920										
Jan. 1 to Jan. 31..	31	17.3-24.5	8070	21920	+13850	16500	820	15680	......	1830
Feb. 1 to Feb. 29.	29	24.5-29.0	21920	32440	+10520	11890	590	11300	......	780
Mar. 1 to Mar. 31.	31	29.0-29.6	32440	33920	+ 1480	3140	160	2980	......	1500
Apr. 1 to Apr. 30.	15	29.6-30.1	33920	35130	+ 1210	2540	130	2410	......	1200
May 1 to May 31.	22	30.1-30.1	35130	35130	00	4500	220	4280	3450	830
June 1 to June 30	13	30.1-30.2	35130	35440	+ 310	1680	80	1600	270	1020
July 1 to July 31.	0	30.2-26.5	35440	26430	— 9010	.....	....	.....	8440	570
Aug. 1 to Aug. 31.	0	26.5-22.0	26430	16570	— 9860	.....	....	.....	9610	250
Sept. 1 to Sept. 30	0	22.0-19.2	16570	11170	— 5400	.....	....	.....	4640	760
Oct. 1 to Oct. 31..	0	19.2-17.7	11170	8670	— 2500	.....	....	.....	1280	1220
Totals........				5170				43470	27690	10610

$$\text{Efficiency} = \frac{27690 + 5170}{43470} = \frac{32860}{43470} = 76\%$$

$$\text{Avg. loss per month } \frac{10610}{11} = 965 \text{ acre-feet}$$

$$\text{Avg. loss per day } \frac{965}{30} = 32 \text{ acre-feet}$$

The gage on the Jackson Lake Reservoir is located within the gate chamber and when water is being withdrawn from the reservoir, the gage height cannot be read with certainty; therefore, to get accurate readings, it is necessary to close the outlet gates and allow the water to rise to the reservoir level. During the time water was being turned out from the reservoir, only a few dependable readings on the gage were available which made it necessary to interpolate, in some cases, to determine the gage reading for the last or first day of the month. Because of these interpolated values a few of the gage height

TABLE 18.—Table showing the gross loss in acre-feet per month for the Riverside Reservoir.

Period	Days Run	Gage	Capacity Acre-Feet Begin	Capacity Acre-Feet End	Gain or Loss in Reservoir	Acre-Feet diverted from River	Loss in Transit 5 percent	Acre-Feet delivered to Reservoir	Diverted from Res. Dist.	Diverted from Res. River	Loss in Acre-Feet
1919											
Oct. 13 to Oct. 31	19	6.0*- 8.9	2050	4150	+ 2100	6030	300	5730	......	......	3630
Nov. 1 to Nov. 30	30	8.9 -19.7	4150	20800	+16650	24770	1240	23530	......	......	6880
Dec. 1 to Dec. 31	31	19.7 -24.8	20800	33860	+13060	16360	820	15540	......	......	2489
1920											
Jan. 1 to Jan. 31	31	24.8 -26.8	33860	39910	+ 6050	13290	670	12620	......	......	6570
Feb. 1 to Feb. 29	29	26.8 -28.0	39910	43730	+ 3820	9560	480	9080	......	......	5260
Mar. 1 to Mar. 31	16	28.0 -27.7	43730	42770	— 960	4960	250	4710	......	......	5670
Apr. 1 to Apr. 30	19	27.7 -30.5	42770	52180	+ 9410	15340	770	14570	......	......	5160
May 1 to May 31	31	30.5 -32.0	52180	57520	+ 5340	19220	960	18260	3950	......	8970
June 1 to June 30	13	32.0 -30.8	57520	53630	— 3890	11070	550	10520	9360	470	4580
July 1 to July 31	2	30.8 -24.8	53630	33860	—19770	840	40	800	12090	1990	6490
Aug. 1 to Aug. 31	0	24.8 -16.4	33860	14220	—19640	......	......	......	13990	2530	3120
Sept. 1 to Sept. 30	10	16.4 -12.0	14220	7490	— 6730	5220	260	4960	9650	......	2040
Oct. 1 to Oct. 31	27	12.0 -18.5	7490	18230	+10740	20580	1030	19550	5600	......	3210
Totals				16180				139870	59630		64060

*Approximately.

$$\text{Efficiency} = \frac{59630+16180}{139870} = \frac{75810}{139870} = 54\%$$

$$\text{Avg. loss per month } \frac{60430}{12} = 5040 \text{ acre-feet}$$

$$\text{Avg. loss per day } \frac{5040}{30} = 168 \text{ acre-feet}$$

readings shown in Table 17 are only approximately correct; however, the results are believed to be reasonably close.

This study of the reservoirs was made for the purpose of approximating their efficiency. The values determined are shown in these tables, where the efficiency is based on the ratio of the amount actually diverted from the reservoir for useful purposes plus the amount in excess at the end of the season over the amount in the reservoir at the beginning, to the amount delivered to the reservoir from the river after deducting a certain percent for loss in transit. This statement may be expressed as follows: $E = \frac{Q + e}{K D}$, where E is the efficiency, Q the quantity diverted from the reservoir, *e* the excess or deficiency, as the case may be, D the total diversion from source of supply, and K the factor for canal loss to reservoir. The results of this study show that the older reservoir, Jackson Lake, has the highest percentage of efficiency and the Prewitt the lowest. The silt carried into these basins has a marked influence upon the leakage, which in a measure may be illustrated by the following experiences: The register float wells on both the Riverside and Empire inlets were set vertically into the bank of the canal, inside slope, and were both provided with a horizontal tube leading from the well into the channel at a low elevation. The tube of the Empire float well was thoroughly flushed by pouring water into the well, and after mounting the instrument and beginning the records, it was observed that the recorded gage height was less than the staff gage.

This same trouble was experienced on the Riverside Canal at the rating flume, and to investigate this condition it was necessary to dig down between the well and the waterline in canal to provide an opening into the float well. (See Fig. 22). This hole was dug with a shovel to a depth of 3 feet in almost pure sand, leaving a section about 6 inches thick at the top of the excavation between the edge of the water and the edge of the pit, and under these conditions the bottom of the pit was free from water. The horizontal tube to the float well was not tested in this case but was supposed to have been clogged with sand and silt. The depression of the water surface in these wells below the surface in the canal is thought to be due to the rapid percolation from the well, causing an error in the recorded gage height. The instruments used on these two canals were the new type registers, which were designed and built for this seepage investigation.

Further trouble of this nature was experienced on the Snyder Ditch, near Snyder, where the register indicated a lower gage than the staff reading. Here a Gurley recorder with metal tape from float to cylinder, with no chance of slipping, indicated that the water surface within the well was less than the staff

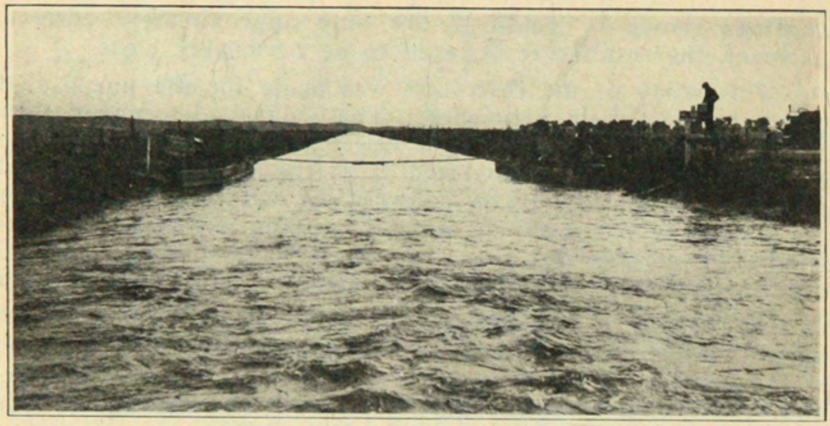

Fig. 22.—Riverside Inlet Canal at rating flume. Register installed on bank with tube leading into box, slope gage at water surface. Canal carrying 325 second-feet.

reading. This float well, like the others mentioned, was constructed of wood without a bottom and was set in the bank of the ditch in very sandy soil. The Snyder ditch at the point where the register was installed was quite heavily silted and the seepage loss perhaps was not great, but when this crust was broken, as occurred by installing the box, the loss due to percolation through the bottom of the well was quite marked.

RELATION OF RETURN FLOW TO IRRIGATION

The early agriculture of the valley was confined largely to the upper parts and the tributaries. This early development occurred in these parts for two reasons; first, because of a better water supply for irrigation; and, second, because the market for the crop was found largely in the mining centers of the mountain regions. This nearness to market and a water supply sufficient to mature crops of moderate area made a favorable combination for the beginning of irrigated agriculture. Natural grass meadows and grain first constituted the principal crops, but at this time garden vegetables and potatoes commanded a good price and found a ready market. The irrigation of the meadows and the grain was by direct flow from the streams, no storage water being available, and as the cereals could be matured early there was little need for late water. The meadow land was confined to the immediate stream valley, and much of the water applied as irrigation soon reached the stream again as return flow, which was available for further application.

The area of irrigated agriculture spread down the valley, as is evident by the dates of the first appropriations for water along the river. In District No. 2 the Brantner Ditch, near Brighton, has the earliest right, being established in 1860, while in District No. 1 the first appropriation was granted in 1869 to the Hoover Ditch near Greeley, and not until 1872 was the first appropriation made in District No. 64 to the South Platte Ditch near Merino. In these early days of irrigation the supply during the growing season was at times small and the extent of the irrigated crops was necessarily limited, but because of the improving water supply the outlook was promising though the condition at first was discouraging. Crops requiring late irrigation were at first grown only in limited and favorable areas because of the meager water supply, and to provide a more dependable supply the winter and spring run-off was stored in artificial reservoirs and used for supplementing the river flow during the late summer.

The storage of water for irrigation purposes is of great importance and because of the present return flow in the lower valley, both the direct flow and storage rights in the upper valley have been very materially improved. The law of appropriation requires the senior rights to be first satisfied, and since the return flow which accumulates in the river in the lower valley is sufficient to supply a large portion of the ditches there, it is not necessary to pass such amounts from the upper valley, as was formerly the case, to provide for the earlier appropriations in the lower sections of the stream. This return flow has also, in its present amount, greatly assisted in supplying water for late irrigation and at the same time made more certain the dependability of the storage reservoirs. At the time of the construction of the storage reservoirs of the lower South Platte Valley, the supply available for all of them was at the time believed to be questionable; however, it has since been proved that the river flow has been adequate and there have been years recently when the Julesburg Reservoir has not been of great value for storage because of the river

Fig. 23.—River station at Beetland showing a discharge of 300 second-feet which is all seepage or return flow to the river.

being able to furnish practically all the water needed by the irrigation district growing season. Fig. 23 shows the rating section at the Beetland river station where the discharge is being measured by means of the current meter. The 300 second-feet passing is all return flow to the river.

The South Platte Valley, because of its favorable summer weather, fertile soil, and in normal years an adequate irrigation supply, is capable of producing crops of great variety. The principal irrigated crops grown in the order of their acreage are: Alfalfa, sugar beets, cereals, natural grasses, and miscellaneous crops. The successful growing of alfalfa and sugar beets, which constitute the greater percentage of the crops grown, requires late irrigation which depends upon the storage of water and the return flow to the river; however, these two crops are successfully grown in the lower valley and depend altogether upon the return seepage-water supply.

Irrigation practice in the valley is not essentially different from that of the tributary valleys, with the exception of what is locally known in the lower valley as winter irrigation or soil storage. In the vicinity of Fort Morgan and Sterling it is not uncommon to irrigate quite copiously after the crops have been

TABLE 19.—Acreage of Crops Irrigated, District No. 1, 1920.

CANAL	Alfalfa	Natural Grasses	Cereals	Orchards	Market Gardens	Potatoes	Sugar Beets	Other Crops	Tot. Acreage Irrigated	Acre-Feet of Water Used	Gross Duty Acre-Ft. per Acre
Hoover Ditch	100	200	60	....	....	80	100	70	610	3043	4.98
Riverside Inlet	8000	....	6000	....	....	800	6000	3000	23800	54640	2.30
Illinois Ditch	100	700	160	....	....	....	120	80	1160	3518	3.03
Mackey Ditch	100	500	....	....	....	....	80	80	760	1391	1.83
Putnam Ditch	400	600	300	....	....	80	600	100	2080	3519	1.69
Weldon Valley Canal	2400	400	1800	....	....	400	1500	1000	7500	28927	3.86
Ft. Morgan Canal..	4000	....	2500	....	....	....	5300	1000	12800	74428	5.82
Up. Platte & B'vr D'h	2300	1000	3000	....	....	500	5000	200	12000	44756	3.74
Deuel-Snyder Ditch	400	400	300	....	....	....	700	200	2000	4967	2.48
L'wr Pl'te & B'r D'h	4000	2000	3000	....	....	....	5000	1000	15000	39995	2.66
Tremont Ditch	400	300	500	....	....	....	400	400	2000	6790	3.39
Snyder Ditch	300	400	300	....	....	....	200	300	1500	2428	1.62
A. A. Smith Ditch..	200	100	100	....	....	....	500	100	1000	2652	2.65
Trowel Ditch	500	300	160	....	....	....	400	....	1360	957	0.70
Union Ditch	300	150	200	....	....	....	200	100	950	925	0.97
Johnson & Ed'w D'h	500	800	600	....	....	....	200	200	2300	2544	1.10
Tetsel Ditch	400	200	300	....	....	....	600	....	1500	7224	4.81
Totals..........									88320	282704	
Mean...........											3.20

Note:—The records for the Bijou System were not available for estimating the gross duty in acre-feet per acre.

harvested. This fall or winter irrigation, together with the amount applied during the growing season, tends to raise the water table causing a greater return flow from the irrigated area.

As a general statement it may be said that the soil is less sandy as one proceeds down the valley; however, sand areas occur throughout the whole of the lower valley but heavy lands are not uncommon. The soil on the north side of the river, between Proctor and Julesburg, is rather heavy and in some localities approaches the adobe type, while on the south side of the river throughout this area it is rather sandy and irrigation is confined to the river-bottom lands. (See Plate 1). Because of

TABLE 20.—Acreage of Crops Irrigated, District No. 64, 1920.

CANAL	Alfalfa	Natural Grasses	Cereals	Orchards	Market Gardens	Potatoes	Sugar Beets	Other Crops	Tot. Acreage Irrigated	Acre-Feet of Water Used	Gross Duty Acre-Ft. per Acre
South Platte Canal	1280	953	2070	17	....	60	1380	240	6000	15355	2.56
Pawnee Canal	4500	700	4000	200	100	300	4000	500	14300	33118	2.32
Davis Bros. Ditch .	700	600	700	5	....	3	140	52	2200	5779	2.63
Schneider Ditch ...	1000	400	406	12	2	10	541	110	2481	7823	3.15
Springdale Ditch ..	2200	200	600	100	175	35	900	290	4500	10272	2.28
Sterling Ditch No. 1	1176	670	1182	20	20	....	2515	602	6185	16432	2.66
Batten Ditch	80	....	30	....	....	....	....	40	150	1400	9.32
Her'fd Cattle Co. D'h	45	....	5	....	....	8	30	22	110	320	2.91
So. Side D. & Res. Co.	220	160	50	....	2	2	....	75	......	......	....
He'drsn & Smith D'h	150	400	75	....	....	....	70	200	1404	5227	3.72
Lowline Ditch	760	620	213	....	7	....	627	....	2227	5330	2.39
Bravo Ditch	470	150	575	....	....	20	250	....	1465	10564	7.20
Farmers Ditch	60	....	100	....	....	3	100	20	283	902	3.19
J. B. Ditch	170	420	165	....	....	....	50	....	805	2585	3.21
Iliff & Pl'te Val. C'nl	2500	2400	1100	....	....	2	2500	....	8502	12099	1.42
Blair Ditch	Acreage of crops included under Iliff and Platte Valley										
Lone Tree Ditch ..	100	700	100	....	1	3	20	400	1324	3577	2.70
Powell Ditch	300	900	125	1	....	....	225	....	1551	306	0.20
Harm'y Ditch No. 2	500	400	....	....	....	....	300	400	1600	164	0.10
Ramsey Ditch	300	600	....	....	....	....	50	....	950	220	0.23
Chambers Ditch ...	150	....	75	....	....	½	....	....	225	1997	8.87
Harm'y Ditch No. 1	875	1000	350	....	....	8	940	....	3173	10690	3.37
Settlers Ditch	1600	1550	1800	....	....	360	1600	90	7000	14588	2.08
Long Island Ditch .	410	....	....	....	....	....	40	....	450	654	1.45
Red Lion Ditch ...	375	500	....	....	....	....	100	....	975	1293	1.32
Peterson Ditch	3400	202	3500	18	....	700	1900	280	10000	9681	0.97
So. Reserv'n Ditch	65	600	....	....	....	....	120	50	835	1597	1.91
Liddle Ditch	60	200	300	....	....	....	300	500	1360	701	0.51
Carlson Ditch	40	400	150	....	....	....	....	....	590	509	0.86
Cox Ditch	....	665	....	....	....	....	....	....	665	1950	2.93
Totals..........									81310	175133	
Mean...........											2.15

the more extended irrigation systems, including the storage reservoirs, wide expanse of area irrigated and possibly a more porous soil, together with a lower duty in District No. 1, a larger return flow results in this part of the lower valley.

Records of the diversions from the river were practically complete for the season of 1920, and these data, together with the Water Commissioners' reports for Districts 1 and 64 give the basis of estimating the gross duty in this part of the South Platte Valley. Tables 19 and 20 give in detail the approximate irrigated areas of the various crops served by the several ditches in the two districts, total acreage irrigated, acre-feet of water used and the gross duty in acre-feet per acre. The Batten Ditch in District 64 has a very low duty resulting from the small area served and the high percentage of waste water. The amount diverted from the river by this ditch was estimated by the Water Commissioner and is probably too great. As given in these tables, the gross duty of water in District 1 is 3.20 acre-feet per acre and in District 64 is 2.15 acre-feet per acre; and also from Table 12 it is found that the approximate, average, return flow for these two districts is 7 and 4 second-feet per mile respectively. In this it will be noted that the ratio of the gross duty in these two districts compares favorably with the ratio of the return flow in second-feet per mile for these two sections of the valley.

A definite statement as to the actual relation existing between the amount of return flow and the area irrigated cannot be made. The return flow to the river has its source of supply from the irrigated lands, seepage loss from canals and reservoirs and a small amount possibly from rain fall. To actually segregate these parts and determine the amount of return flow from the strictly irrigated area is not possible. Only a very general and approximate relation of the return flow to the area actually irrigated can be determined, and in Table 21 may be found the average number of irrigated acres required for each second-foot return flow. This table is based on acreages of Districts 1 and 64 as reported by the State Engineer in his biennial reports, and the return flow for the period of years indicated was approximated from the values shown in Figure 16. There does not appear to be any consistency in the acres required per second-foot return, but as an approximate average it may be said that about 275 acres of irrigated area are required to account for each second-foot gain in the river from Kersey to Julesburg.

RECOMMENDATIONS

The purpose of the hydrographic work of this seepage investigation was two-fold. It was primarily for the purpose of establishing records of discharge of the various river stations and canals, and, secondarily, to fix the calibration of the rating flumes of the canals and ditches in Districts 1 and 64. This investigation provided data for revising and issuing rating cards to date, and it is believed that the distribution made upon these gagings was, on the whole, quite satisfactory. As many as fifteen gagings have been made on a single canal to properly adjust the season's calibration, while observations made throughout the irrigation period served as a means of knowing the con-

TABLE 21.—Irrigated Acres Required for each Second-Foot of Return Flow.

Year	ACRES IRRIGATED Dist. No. 1	Dist. No. 64	Total	Total seepage Ret. sec. Ft.	Acres req'd per sec. Ft.
1890	11000	11000	22000	......	......
1891	.....	......	......	......	......
1892	44000	12000	56000	......	......
1893	.....	......	......	......	......
1894	26300	13100	39400	......	......
Mean	.....	......	39100	195	200
1895	79000	37000	116000	......	......
1896	51000	31000	82000	......	......
1897	.....	......	......	......	......
1898	48300	40900	89200	......	......
1899	70000	36000	106000	......	......
Mean	.....	......	98300	409	240
1900	145000	44000	189000	......	......
1901	72000	110000	182000	......	......
1902	66500	43600	110100	......	......
1903	.....	......	......	......	......
1904	.....	......	......	......	......
Mean	.....	......	160000	404	400
1905	82000	58000	140000	......	......
1906	44000	65000	109000	......	......
1907	46000	73000	119000	......	......
1908	58000	72000	130000	......	......
1909	87000	104000	191000	......	......
Mean	.....	......	138000	555	250
1910	76000	120000	196000	......	......
1911	41000	106000	147000	......	......
1912	76000	90000	166000	......	......
1913	90000	87000	177000	......	......
1914	94000	89000	183000	......	......
Mean	.....	......	174000	700	250
1915	95000	102000	197000	......	......
1916	88000	107000	195000	......	......
1917	99000	118000	217000	......	......
1918	100000	110000	210000	......	......
Mean	.....	......	205000	881	230
1919	84000	131000	215000	......	......
1920	110000	119000	229000	......	......
Mean	.....	......	222000	750	300

Note:—This table compiled from the Biennial Reports of the State Engineer of Colorado.

stancy of the rating. In some cases it was observed that the capacity of the canals or ditches decreased during the irrigation season, while in other cases an increase was found.

The canals and ditches are all more or less affected by shifting sand, and in some instances the sand has accumulated in the flumes to a depth of more than one foot, while in other cases the velocity has been found to increase, due to the cutting action of the current. Such varying conditions require constant attention to keep the errors in the rating of the ditch within reasonable limits. Canal ratings established in the spring have shown nearly 75 percent error when applied later in the season. This, however, may be considered an exception rather than the rule.

Table 22 gives comparisons of gage heights and discharges for different times of the season.

TABLE 22.—Table showing the effect of moss growth on discharge and error introduced by basing discharge on rating card effective during the early part of the season.

Ditch	Date	Gage Height	Disch. Sec. Ft.	Date	Gage Height	Disch. Sec. Ft.	Percent Diff'nce
Snyder	5/7/20	1.59	39.9	8/18/20	1.59	18.5	54
Snyder	5/7/20	1.41	31.6	9/15/20	1.41	11.8	63
Davis Bros.	6/3/20	1.45	41.7	9/16/20	1.45	11.9	71
Schneider	6/3/20	3.26	115.0	8/26/20	3.26	29.5	74
Hen. & Smith	4/6/20	0.84	29.0	9/30/20	0.84	8.7	70
Iliff & P. Valley	5/18/20	2.22	95.0	9/11/20	2.22	43.5	54

It was thought at the time of the beginning of this investigation that it would be possible to continue the method of keeping up the calibration of the ditches and canals and also to keep in operation a large number of water-stage recording instruments. The principal idea was to maintain a condition of a more equitable distribution and a permanent record of flow, and, further, to establish a feeling of good will and harmony between the water users of the two water districts of the lower valley. Perhaps some scheme, possibly not as elaborate as carried out during the investigations, could be successfully undertaken where sufficient gagings could be made to establish the correct calibration of the rating flumes and to operate the more important instrument stations and maintain a just and equitable division of the stream. From the standpoint of economy to the farmer, it is worth while to have the water diverted that is rightfully his, and assuming that a ditch with a normal capacity of 50 second-feet is deficient 10 percent would cause a decrease of 5 second-feet, and with water valued at even $1000 per second-foot this would be sufficient to warrant the employment of assistants to correct faulty measurements. The loss in value to one canal, in some cases, would be worth more than the salary and expense of a special hydrographer to protect the interests of the whole district.

SUMMARY

No attempt has been made to distinguish between seepage and return waters in the investigation.

The return flow to the South Platte River is phenomenal and is due largely to the liberal use of water, the nearness of the irrigated area to the river and the favorable condition of soil and underground strata.

The diversions from the river after the spring floods have subsided are practically all from seepage or return water and only during summer floods or freshets is the river flow increased.

The mean, annual discharge of the South Platte River at Julesburg is sufficient to warrant further construction of storage reservoirs and development of irrigation systems.

The normal velocity of flow of the river varies from 2 to 2½ feet per second, or from 33 to 41 miles per day. The rate of travel of a flood or rise in the river is about 30 miles per day.

The return flow to the South Platte River varies from 2 to 8½ second-feet per mile for various sections of the river from Kersey to Julesburg, and the average return flow between these two points, a distance of 143 miles, is 5¼ second-feet per mile, or a total of about 750 second-feet.

The value of one second-foot of return water is believed to be about $3000, and on this basis the total return flow is worth more than $2,000,000 to the farmers of the valley.

The rate of the underflow from the Riverside Reservoir to the river is approximately 100 feet per day. The average velocity of the return water to the river between Kersey and Julesburg is perhaps considerably less than this amount.

The annual discharge of the river at Julesburg is equal to one-half the total amount used for irrigation in the lower South Platte Valley, Districts 1 and 64.

The reservoirs in the valley contribute about 20 percent to the return flow.

There is a greater return flow in September than in March.

There is a yearly increase in the seepage return. The average seepage return for the years 1919-20 is apparently less than for the years 1916 to '18 because of the exclusion of certain seepage streams from the seepage return in 1919-'20.

The return seepage increases as the river falls and decreases as the river rises.

The seepage losses from the Empire and Jackson Lake Inlet canals are approximately one second-foot per mile, or 0.40 and 0.58 percent per mile respectively.

Due to the evaporation there is a marked daily variation of the flow of the river, especially in District 64.

The average efficiency of the large storage reservoirs of the lower South Platte Valley is about 50 percent.

The ratio of return seepage to irrigated area is approximately 1 second-foot to 275 acres.

The ratio of the seepage return in Districts 1 and 64 is about the same as the ratio of the gross duty of water in these two districts.

The distribution of water through calibrated rating flumes has been found, in some cases, to be more than 50 percent in error where the amount is based upon the calibration made during the first part of the season.

ACKNOWLEDGEMENTS

I desire to record my thanks and appreciation to Mr. A. H. Cutler, Water Commissioner of District No. 1, of Fort Morgan, and also to the officers of the North Sterling Irrigation District of Sterling, who have very materially assisted in this investigation by the donation of office quarters and conveniences. I am also indebted to the officials of the Prewitt Reservoir System who assisted in the field work by permitting the use of three water-stage recording instruments installed on their canals, and to the officers of the several reservoir and ditch companies of the lower Platte Valley for giving information and records of their operation. I wish to acknowledge the able assistance of Mr. R. G. Hemphill, who for a part of the time directed the field work of the investigation, Mr. M. L. Lightburn, who was in immediate charge of the investigation in District 64, and to Mr. A. B. Crosley who prepared the illustrations appearing in this bulletin. To Messrs. J. E. Field, A. L. Fellows and Carl Rohwer I am indebted for their kindly assistance and valued criticisms.