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Seepage or Return Waters from Irrigation.

Approved by the Station Council.

ALSTON ELLIS, President.

FORT COLLINS, COLORADO.

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SEEPAGE OR RETURN WATERS FROM IRRIGATION.

BY L. G. CARPENTER.

For convenience of reference, the principal paragraphs are numbered:

§ 1. In countries where irrigation is practiced, it is often the case that, though streams may be drained dry by the diversion of the waters into canals, not far below the stream will again be of considerable size, and this without the inflow of visible tributaries.

§ 2. This may become of considerable economic importance, as it already has in the valleys whose measurements are here reported. In the valley of the Poudre, the seepage water is worth, at prices at which sales have already been made, from $300,000 to $500,000 at the least, and the waters of the Platte from two to three million dollars. It is of corresponding importance in the valleys of Clear Creek, St. Vrain, and others. Of such importance already, it promises, if the deductions of the bulletin are correct, to be of still greater importance in the future and in the development of the State. Certainly it is true that the value of water will steadily increase.

The experience of all irrigation countries shows that their prosperity is largely bound up in the water question—in the certainty of water, in the security of their rights, and the freedom from abuse. They have found themselves often bound by customs and laws, now become fixed, formed as the practice developed gradually. We are in danger of such here, mostly from lack of knowledge of the conditions. This bulletin is a contribution toward a better knowledge of one condition of water supply, which has already given rise to much vexatious litigation, to some harmful divisions, and to some unrest among those affected one way or another.

§ 3. The increase which is found in such rivers is attributed to the inflow from innumerable springs fed and supplied by the water which has been applied in irrigation upon the higher lands. In irrigation, more water is applied than the crop uses. Of that applied, some is used by the crop and stored in its tissues; more is transpired in the process of growth; some is evaporated from the soil; a portion is usually lost by surface run-off; a certain amount passes down into the ground and disappears. This varies in amount and depends upon various conditions. Usually concurrent observations show that this water passes directly downwards, with little or no lateral movement except capillary imbibition, until reaching an impervious stratum, when, filling the interstices, it gradually rises in the subsoil, and passes laterally with a slow movement due to the slope of the water surface which is thus formed. When the passage takes place through the interstices of the soil the movement is very slow, much slower than is ordinarily supposed by those first encountering the subject. It is faster as the material is coarser. Where there are perceptible channels, the movement may be relatively rapid.

§ 4. One of the first effects noted in irrigation where the soil is pervious, is in the filling of the subsoil. The first evidence is found in the gradual rising of the water in the wells which may have been sunk. Throughout the United States where irrigation is practiced, the evidence is ample, for as the application has been made within a single generation, the changes which have ensued from the application of water are within the memory of hosts of living observers. In many places in the Poudre valley, where it was originally forty or fifty feet to water, water now stands from ten to twenty feet from the surface, the subsoil having been filled to a depth of twenty to forty feet.

There is sometimes a lowering during some seasons of the year, due to the lateral passage of the water. The lateral passage has had the effect in some places of filling in the ground until in some places the water shows on the surface, water-logging or seeping the ground, rendering it unfit for cultivation and capable of growing only sedges, cat-tails, and other water-loving plants. Sometimes on the evaporation of the water, a deposit of alkali is left, rendering the land unfit for cultivation without draining. These effects are found underneath the lines of ditches, so that many companies insert clauses in their contracts for water or for right-of-way freeing the company from liability for damage of such nature. In other cases where contracts do not prevent, it has given rise to suits for damage from such cause.

The water usually first appears near the canal, and progressively further away year by year.

§ 5. The phenomenon has been but little studied. The reason has doubtless been that in most countries irrigation is of such age that there is no record with which to compare the condition now and before irrigation, and the changes due to the construction of canals have been lost in the centuries which have elapsed. There is, however, land in Lombardy which is manifestly seeped and water-logged, and has every appearance of being due to irrigation. Pavia Canal, between Milan and Pavia, built in the early part of this century, has damaged much land. There is loss from the canals themselves, as well as from the water which is applied to the soil.

Wherever the conditions before the construction of canals are within the range of memory, the fact has been observed to a greater or less extent.

Year by year the effect is found farther and farther away from the canal, or from the irrigated locality, as the case may be. In course of time, the waters which are percolating through the subsoil reach the thalweg or the depression of a "draw," or a river, and increase the waters passing therein.

It, therefore, happens that the depressions or draws, which in Colorado are usually dry before irrigation is practiced, contain living streams after irrigation has been carried on for some time. While the Poudre river varies during the year from a maximum of 3,000 to 5,000 cubic feet per second to a minimum of 50 to 100 cubic feet per second, or may vary by forty to eighty times the minimun flow, and other streams correspondingly, these seepage waters will not often vary twice their minimum flow. In consequence the water rights in the seepage channels are usually considered more valuable than those in the river waters.

The particular places at which the waters come to the surface will generally be determined by the nearness of the underlying rock. Frequently the water shows in a particular locality, so that there is a localized gathering area. There may be several on some of the channels, so that different seepage ditches may be supplied.

§ 6. The present measures which are reported, include measurements made on the Cache a la Poudre river and on the South Platte, in Colorado. Most of the measurements have been made on the former, and have been for the object of determining the amount of the increase in the stream; the relation between the increase and the amount of water applied; between the increase and the area irrigated; and to collect data which should give the means of studying these facts and other phenomena of the return of the waters. The measures on the Platte have been for the same purpose and in connection with the office of the State Engineer of Colorado. To a greater degree, the measures on the Platte were taken because of the light they might show on certain inter-state questions which have, or may arise, and on some points that could not be decided from the Poudre alone.

The present and future importance of the inflow was under estimated. In the course of the measures, the facts determined have led to much wider and more useful application than was anticipated during their progress.

METHODS OF GAGING.

§ 7. The points at which gagings were made are scattered over a distance of 200 miles by the river, without following its meanderings. The distance to be traveled by road is much in excess of this; and the distance is made longer for the reason that the highway does not follow the river, and at many points the headgates and places of gaging are not easily accessible. Some roads cross fields and, until an intimate acquaintance is gained with the river and the special by-ways, time is lost in passing from one point to another.

The first measurement on the Poudre was usually made at the gaging station in the Canon, about 12 miles from the College, at the point indicated on the map [page 16]. On the way the ditches on one side of the river would be examined and the in-takes measured. Where the water exceeded more than a few inches in depth in the smaller channels, or where there was sufficient to measure by the current meter, the meter was used to determine the velocity and thus determine the amount entering the canal. In cases where the canal was small and the in-take at the time of gaging was little, surface floats were often used, and the mean velocity determined in this manner. While not overly accurate, the results obtained can usually be depended upon to within a few per cent., and the absolute error where used is too small to make any appreciable effect in the general result.

In gaging the river at the regular gaging station, which is at a point in the Canon above the headgates of all the principal canals, a tape is stretched across the river between points on the masonry side walls and the depth of the water at each one-foot or two-foot interval measured throughout the entire width, which is very nearly 100 feet. Then observations were taken with the current meter, usually at two-foot intervals, sometimes at less, across the stream. As most of these gagings were made at a time of low water in the spring, or low water in the fall, the meter has been held by hand and the gager has waded the stream. At other points on the river where gagings were made the method has been essentially the same, although the cross-sections have not been as favorable as at the gaging station. It is not thought, however, that any material error has crept in from these sources. In the notes on the measurements some individual sources of error are noted.

DESCRIPTION OF THE POUDRE VALLEY, IN WHICH THE MEASUREMENTS WERE TAKEN.

§ 8. The measurements have been made on the Cache a la Poudre river and also on the South Platte. The "Poudre," as it is called, is the river which drains the valley in which the State Agricultural College is located, and is, therefore, the most easy of access for the purpose of this and similar investigations. It has the additional advantage of being one of the largest irrigation streams in the State, and one which has been the best used for irrigation purposes, and where irrigation has been carried on as completely and successfully as in any part of the United States. There is in addition as large a body of land irrigated in one tract as anywhere in the United States. The phenomena observed are, therefore, found under conditions of irrigation on a large scale. They are of great economic importance to this valley, and may be expected to hold true of other valleys under similar conditions, and where irrigation has been practiced as long as it has here.

The map in the inset [page 16] is intended to give an understanding of the conditions which may affect the return waters in this valley. The gaging station is indicated near the left of the map, below the junction of the north Poudre with the main stream. The only canal above this point which needs consideration is the North Poudre canal, shown on the map, irrigating some 4,000 acres, principally in the valley of the Box Elder.

The main trend of the valley is to the southeast. Near the stream the land is low, the bottom land varying in width from one-half to two miles. These bottoms have been occupied in times past by the bed of the stream, which is subject to shifting at times of high water. With the decrease of floods, and with the use of water for irrigation, the changes are less.

As we pass out of the first bottoms, we reach successively tw or three terraces, or mesas, which are generally sandier an stretch back for varying distances. On the north side of the strea the watershed extends many miles, and the streams here indicate as Dry creek, Box Elder creek, Lone Tree creek, and sever smaller channels, are simply ravines or depressions which at tim after storms are filled with water and may become at such perio raging torrents. Ordinarily their beds are sharply marked an have a clear tributary country; they are entirely dry, giving almo no indication whatever of water. After their channels cross th lines of the canals and enter the irrigated country, these strean begin to carry running water.

The lines of the canals, which follow approximately contou lines, indicate by their bends the general character of the countr and the slope. On the north side of the river the land, as a whol is more uniform than on the south side. Nearly all the irrigatio is, therefore, confined to the north side of the river; the exceptio being in the region near Fort Collins, and a little space nea Greeley. Between the two there is a rougher and more broke country on the south side of the stream, not easily reached b canals from the Poudre.

On the south side, the divide which separates the Poudre fro the Big Thompson is but a few miles from the main river, and a we reach range sixty-eight, the location of the divide is indicate closely by the ditch which takes from the stream to the sout Some of the waste of this canal passes into the Poudre river. T the west, the drainage on the south side, even the mountain drain age, does not flow into the Poudre to any great extent, the latera valleys being nearly all tributary to the stream to the south.

The foothills are near the western portion of range sixty-nin following a line a little east of south. The first ranges, generall known as hogbacks, are formed of gray sandstone, and very shortl afterward the granite is met with, forming the foothills of the mai Rockies. The sandstone appears in ridges, and even on the plain for miles the same general appearance may be seen in the burie ridges which traverse the country from north to south, and mad evident on the map by the intermediate valleys, in which flo streams like Dry creek, Box Elder creek, etc., approximately par allel for a long distance and separated by pronounced ridge These ridges sometimes form natural basins, which have bee largely used for storage purposes. As the amount of water ther stored affects, to some extent, the amount of return waters, the prin cipal reservoirs in use are indicated on the map.

§ 9. As the length of time that irrigation has been practice together with the distance of the land from the river, is an import ant element in the amount of seepage, a fuller description of th valley is needed with reference to its irrigation. The crops grown in the valley are principally the cereals, alfalfa, and potatoes. Potatoes have been extensively grown only during the last few years, and the greater part of this crop has been grown near the lower end of the valley. The upper end of the valley is confined almost exclusively to alfalfa and grain, with some market gardens. The distribution of the crops affects the application of the water, both in amount and in time of application. The grains receive water early in the season, and rarely any after July 1. Alfalfa receives from one to three irrigations, commonly two, one often in May. Two will be given, then, and if late water be sufficient, a third in August, after the second cutting; this is by flooding. For potatoes, the ground may be irrigated before plowing. If not, then irrigation will usually be commenced in July or early in August, and is practically over by the end of the first week in September, the active period being confined to five or six weeks. With the crops thus grown, irrigation extends from May to September, with minor quantities applied to orchards and gardens both earlier and later. More water is applied in June than in any other month. Until the development of storage capacity by the construction of reservoirs, the amount of water applied in August was necessarily limited by the stage of the river Since then, more is applied, and this being for potatoes, is largely applied to the section composing the east half of the valley.

§ 10. Of the canals shown on the north side of the river, the Cache a la Poudre No. 2 is the oldest of the large canals, being one of the original Greeley colony canals. The land irrigated under the Cache a la Poudre No. 2 has been almost fully occupied for a number of years. Some of the land near the upper end has become too wet to need water, and the stock representing the water hitherto applied to this land has been sold and the water is now largely applied to land lower down the canal, and largely drains into the Lone Tree creek, which empties into the Platte just below the mouth of the Poudre. The Larimer & Weld comes next in point of time of construction, dating from 1879–81. It is the largest of the ditches, having an appropriation of 720 cubic feet per second, and a capacity still greater for a portion of its length. The amount of land brought under irrigation from this canal has largely increased during the past few years. The Larimer County canal has been still more recently constructed, and waters the country still farther from the river to the extent of something like 16,000 or 20,000 acres. Owing to the later appropriation of this canal, and the low stage of water in the river for some years, this canal has not been able to apply as much water compared with its land as the others mentioned, until within the last few years. Recently, by the development of their system of storage reservoirs, combined with the construction of a canal bringing water from the watershed of the Laramie river, this canal has been able in 1894 and 1895 to secure an amount of water more nearly comparable with the others.

On the south side of the river the canals are mostly small, and have irrigated essentially the same land and the same amount for a number of years.

The other canals of the river have not changed to any great extent in the amount or the distribution of the land irrigated, for eight or ten years. It will be shown later that there is reason to suppose that the water passes through the ground at a very slow rate. Hence the amount of the land irrigated and the time when brought under cultivation will make some difference with the return waters. It seems probable that the seepage due to much of the land under the Larimer & Weld canal, and from the Larimer County, as well as all from the North Poudre canal, has not yet reached the river.

The point where the weir is placed at the canon is in a granite formation inside the foothills. Within a short distance, the Poudre passes out of the granite and cuts across the upturned edges of sandstones of the Jurassic and Cretaceous periods, and its course from this point until it reaches the Platte is across the slightly upturned edges of the strata, which are mostly shale and some sandstone. In some places these form marked ridges across the country, extending slightly northwest. Their effect will be noticed in the map in the case of the drainage on the north side of the Poudre, where many of these small streams extend to the north for a long distance. The canals show the contours approximately as far up as these go.

CHARACTER OF THE STREAM.

§ 11. The character of the stream is essentially that of all our mountain streams, as its source of water supply is in the snows of the mountains. It is low in the spring, increasing from April to the middle of June, when it reaches its highest stage; then decreasing, reaching its low stage again in September. It remains low during the winter. Its maximum discharge may vary from 3,000 to 5,000 cubic feet per second. Its average winter flow is from 50 to 100 cubic feet per second. Its average flow is shown in the following table, the averages being made from records of from three to twelve years for the different months:

TABLE I.

January	110	cubic feet per second.
February	83	" " " "
March	70	" " " "
April	237	" " " "
May	1,245	" " " "
June	2,017	" " " "
July	1,018	" " " "
August	362	" " " "
September	173	" " " "
October	136	" " " "
November	81	" " " "
December	74	" " " "

CONDITIONS AFFECTING ACCURACY.

§ 12. The stream itself is subject to fluctuations, which, however, are more noticeable at times of high water during the summer than at low water, or at the times at which measurements were made. When the snow is melting rapidly the effect of the daily heat is to increase the quantity of snow melted and thus increase the height of water in the river. This makes a very perceptible daily tide, the hour at which it reaches the gaging station varying according to the stage of the river and the distance from which the water comes. When the water is low, the daily rise is later than when the water is high. With high water the greatest height occurs at from 4 to 6 o'clock in the morning; with a low stage of the river it may not be until toward evening. After the principal snow fields are melted the effect of this daily tide is small, so as scarcely to be perceptible upon the self-registering instruments which are located at the gaging station. At the dates at which gagings have been made for the purpose of this investigation, the tide has been very small, the greatest in August, 1894, and has been neglected. Even if not, inasmuch as the greater portion of the river is taken into the canals before many miles, the quantity of return waters found by the measurements would not be affected thereby. It is of small importance, as the greater quantity of the return waters has been found to be near the lower end of the river.

Errors in gaging might introduce some errors in the results, but the relative values should remain the same. The meters, however, have been rated in still water, and the constants determined often enough to indicate that the constants have been nearly the same. The meter usually used has been the "Lallie Meter," made in Denver, Colo. Sometimes a meter made by Messrs. Buff & Berger, of Boston, Mass., has been used.

The omission occasionally of some of the ditches drawing water from the stream would induce an error, but it is not believed that such an error has been committed.

If a portion of the returns by the various creeks and sloughs were waste water instead of seepage water, the quantity found would be reduced correspondingly. The amount found in these streams is here given in parenthesis (though not counted), and the effect can be easily seen.

Without having determined the actual origin of the water in every case, it is believed that in no case is any of the water derived from above the ditches.

§ 13. The diagram, Fig. 1, shows graphically the amount of return waters as found in the different measurements. The horizontal distances, or abscissæ, give the distances in miles from the gaging station. The vertical distances, or ordinates, indicate the amount of return waters in cubic feet per second. The vertical lines are drawn at the principal points of measurement. The distances have been measured, not along the curves of the river, but on the map, taking generally a straight course across the bottoms, because it is thought that the amount of inflow will not be increased by the curves of the river, but rather will depend upon the straight course of the river, other things being equal. The different lines indicate the different measurements. It is evident that there is a general agreement between them. There are some marked exceptions, which it is difficult to entirely account for. The small amount of inflow in the first ten miles is noticeable in the eighth and ninth measurements, while in all previous ones it had been considerably greater. A decrease between the seventeenth and twentieth miles is noticed twice, and once between the seventeenth and thirty-second mile. Notwithstanding the minor discrepencies, there is a general agreement, especially during the last portion. It may be seen that the total inflow does not vary much.

Several of the measurements were not carried beyond the Ogilvy ditch, which is several miles from the north of the river, and, therefore, the values found are less than had they been continued to the mouth.

§ 14. Table II. shows the rainfall in connection with the gaging, so as to give the means of judging as to the effect of the rainfall of the previous and the current year upon the amount of inflow. The headings of the columns sufficiently indicate the quantities given. Thus, column 3 gives the amount of rain which fell during the calendar year up to the first of the current month of gaging, and the fifth column is the amount of precipitation during the month and previous to the time of gaging. There does not seem to be any particular connection between the wet and dry seasons and the amount of return waters.

With a high river, the amount of water applied is more than when the river is low, because in the latter case there is stinting of water and much land does not secure enough for the needs of the crops, far less than enough to satisfy the owners; hence, we may

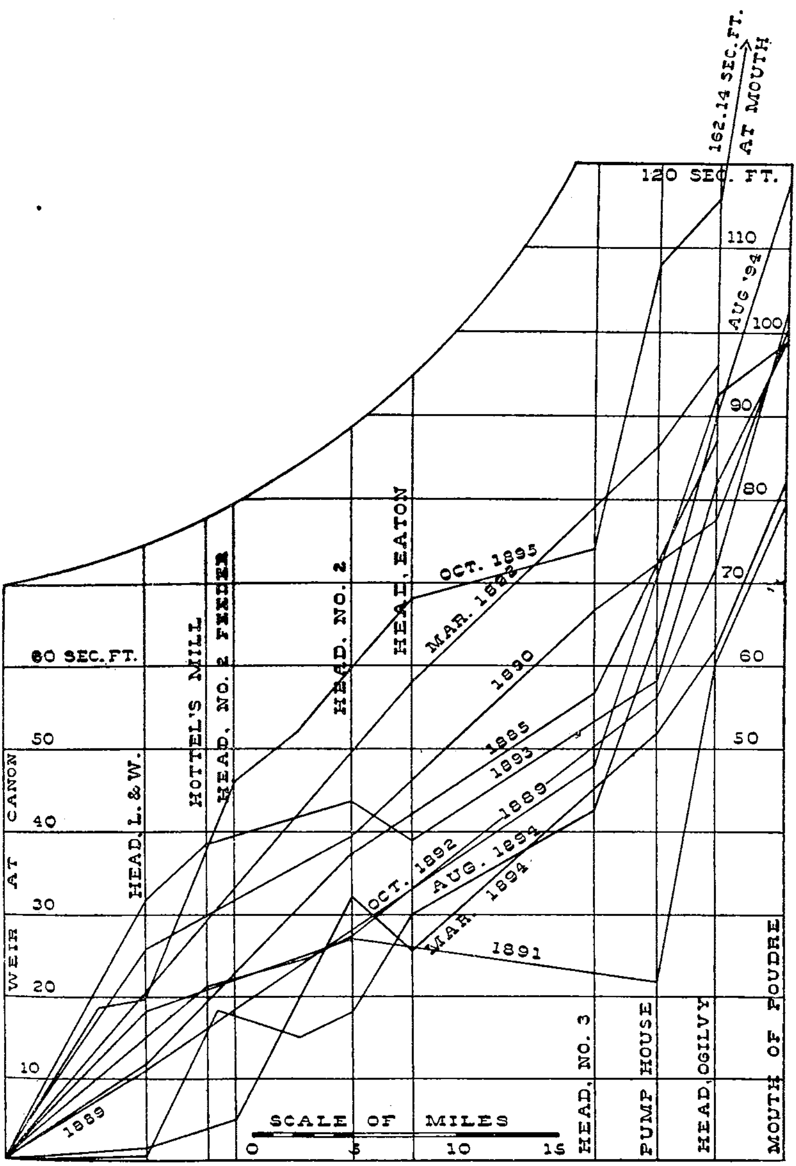


FIG. 1.—Seepage Increase of the Cache a la Poudre River.

expect that the high years of the river will tend to increase the amount of water that is applied, and likewise the amount of water that returns in the form of seepage.

TABLE II.

YEAR.	Rainfall of Previous Calendar Year.	Rainfall to Time of Gaging, first of Month.	Rain During Current Month.	Rain Immediately Before Gaging.	Rain During Gaging.
1884	15.07	....	....	....	....
1885	15.95	....	....	....	....
1889	9.79	10.88	3.16	0.34	.09
1890	14.48	12.42	0.70	0.70–week before gaging	....
1891	13.58	14.43	0.20	0.19–3 weeks " "	0
1892, March	15.69	1.89	1.52	0.83- week " "	0
1892, October	15.69	13.94	0.93	None	0
1893	15.45	6.28	0.16	None	0
1894, March	7.11	0.85	0.67	None	0
1894, August	7.11	9.17	1.53	.08	0
1894, October	....	11.46	T.	None	0
1895	12.36	16.60	1.06	None	0

In the measurement of August, 1894, irrigation was still being carried on quite extensively, especially for potatoes, the most of which are raised toward the lower end of the valley. At this measurement, it is noticed that the total increase is greater than at any previous one, amounting to 118 cubic feet per second. This would seem to show either that a considerable portion of the water returns in a comparatively short time to the river, or that there is some waste which returns directly. During the past few years, there has been an active increase in the use of seepage water for irrigation by the construction of drainage ditches, which in some cases extend back a number of miles. The effect of this is in most cases to cause the water to be applied to the ground nearer the river than where it is cut, and thus the water is developed and hastened in its journey to the river. In some cases the ditches are constructed and deliver the water directly to the river, so that the water returns sooner than it otherwise would. We should expect in consequence a greater development of the inflow during the period immediately succeeding irrigation, and less during the spring following.

NOTES ON THE MEASUREMENTS.

§ 15. The first measurement of the river was made by Mr. E. S. Nettleton, when State Engineer, in 1885, with the aid of Hon. B. S. LaGrange, then Water Commissioner of this district. The measurement was made in October, 1885.

This was at a time when most use of water for irrigation had ceased. A special attempt was made to get all ditches to shut their headgates for the period of the measurement, which had been done very generally by the ditches, so that the amount entering them was only the leakage that passed the gates. No account was made of the water entering the stream by the small channels, which is given in the later measurements. The assumption was made in this, as in several subsequent measurements, that this water was all seepage water, as, in fact, the investigations of later years have seemed to show.

The second measurement was made in October, 1889, under the direction of Mr. E. S. Nettleton, then Supervising Engineer for the U. S. Geological Survey, and Mr. J. S. Greene, State Engineer.

The inflow determined by this measurement was 99 cubic feet per second in the distance from the gauging station to the mouth of the Poudre. This is a little greater distance than measurement No. 1.

Measurement No. 3, was made in October, 1890, by Mr. L. R. Hope and Mr. E. C. Hawkins, representing J. P. Maxwell, State Engineer, and Col. Nettleton, of the U. S. Department of Agriculture. The total amount of inflow is very nearly the same as in the second measurement.

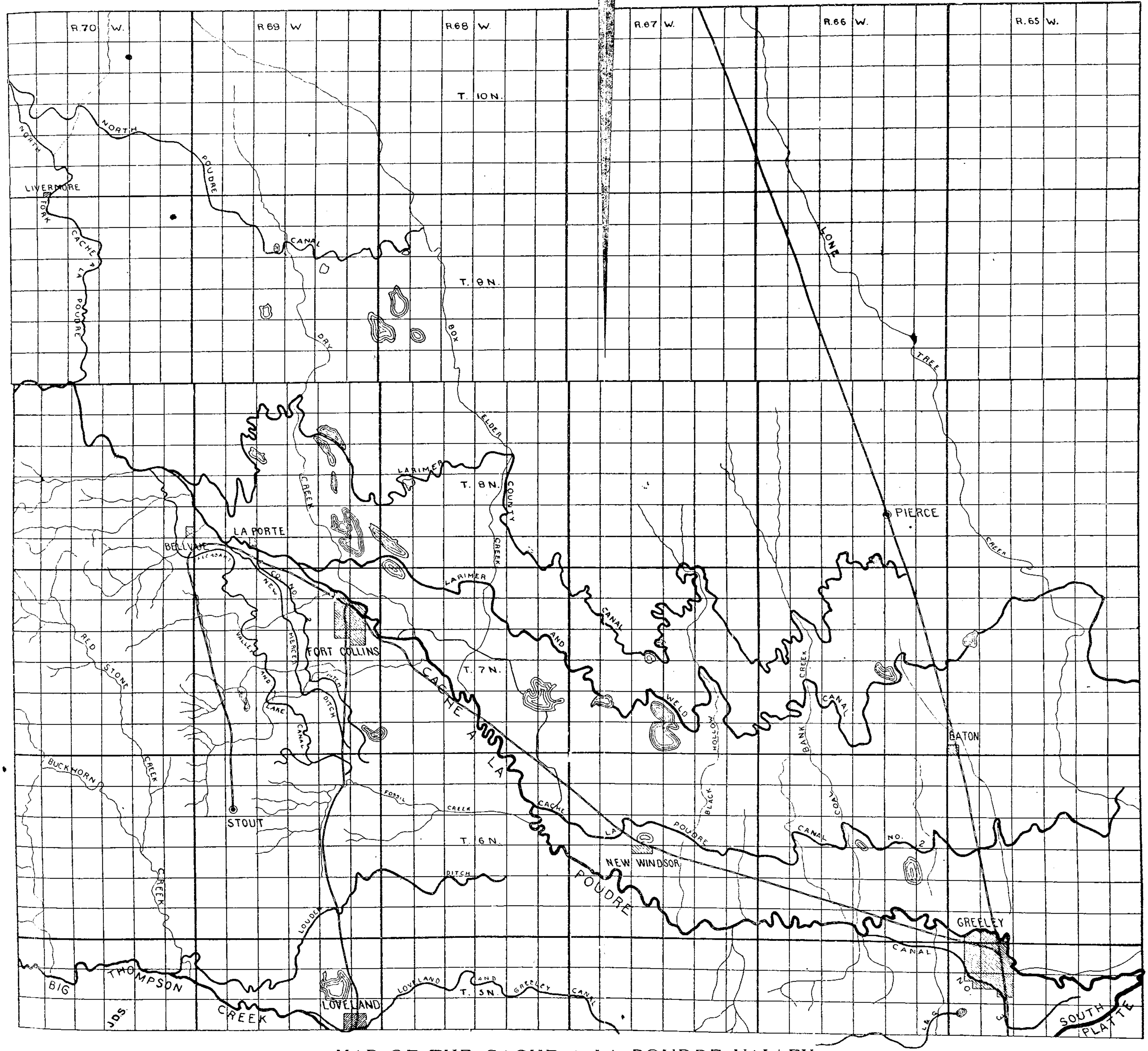
The fourth measurement, made in the latter part of October, 1891, was made by this Section in co-operation with the State Engineer's measurements of the Platte river, with which the Section also co-operated. During the first day Mr. Trimble assisted and then joined Mr. Hope at Greeley, helping him take the measurement of October 29th, from Greeley to the mouth of the Poudre, and thence going down the Platte, assisting in making these measurements. In this and the subsequent measurements which have been made by this Section, each measurement has shown some features which it has been desirable to avoid, but which it has not been possible to do. In order not to interfere with the use of water for irrigation, in this and the subsequent measurements no attempt was made to regulate the ditches themselves. The time, however, was chosen so that the use of water in any ditch was nearly constant during the few days devoted to the gaging, and the irregularity, if any, is so small as not to affect the results derived from the measurements. There is one measurement, however, to which an exception may be made. This is No. 6, of 1892, during which time the river was constantly affected because of the trading of water between the Larimer & Weld canal and a mill at Fort Collins. Each had some claims to the water, but not to the full amount, hence it became mutually convenient to the two parties to alternate the water, so that the mill used the water during the day and the canal took the water at night for storage. This, therefore, caused fluctuations in the streams at points below the Larimer & Weld headgate, and hence caused some of the discrepancies which are evident in this measurement. Thus, on October 6th, at three o'clock p. m., the river below Strauss's bridge had fifty-four second feet, while the next morning, at 11 o'clock a. m., it had but twenty-one. This is due to the water entering the canal during the night, and the day water in use by the mill has not yet reached this point. It is not thought that this fluctuation materially affects the indicated inflow at lower points on the river at that date.

The measurements made up to this time indicated that the inflow was approximately the same. Inasmuch as the measurements had been made at only one period of the year, it seemed desirable to know whether or not the amount of return waters was the same at other seasons of the year; hence, beginning with the measurement of 1892, gagings have been made during the spring, when the conditions were favorable, as well as in the fall.

The fifth measurement was made in March, 1892, at a time before the canals had used much water for irrigation, but still when most of them were drawing some water, either for domestic purposes or for irrigating fruit and garden lands. All streams or ditches which contained water were measured and are indicated in this table, as in subsequent ones. In case the streams were bringing water to the river which seemed to be derived from seepage water, thus finding a way to the stream, the amount of the gaging is inclosed in parenthesis, and is not counted in the summation, as it is considered only another way of the water returning to the stream. The source of these waters has not at every gaging been investigated, but, in several cases, and at different times, we have traced these sloughs and creeks to their crossing with the outermost ditches, finding in every case that there is not a stream above the ditch. In some instances the quantity here given may include some waste waters. In general, the amount is insignificant, although in the measurements of August, 1894, there may be some to be thus considered.

In some cases the out-takes of ditches are inclosed in parenthesis. These are cases where the water returned almost immediately to the river. Frequently the measurement was made, and the fact of the water returning was discovered afterwards as we passed down the stream.

In several measurements, as in 1895, it was not possible to complete the gagings without intermission. In these cases the increase was found for each section. In several cases wherever seepage water had been collected in a lateral channel or drainage ditch and was found running into the river, it was measured and noted as a matter of record, and is found inclosed in single parentheses. Where this was caught in another channel, and did not reach the river, it is inclosed in two sets of parentheses. The water is thus found coming from the Big Thompson creek.



MAP OF THE CACHE A LA POUDRE VALLEY.

GAGINGS OF THE CACHE A LA POUDRE RIVER.

(In cubic feet per second.)

MEASUREMENT No. 1—Made by E. S. Nettleton, October 12–15, 1885.

Place of Measurement.	Out-take.	Remainder.	River	Gain.	No. of Miles.	Gain per Mile.
River at Gaging Station	......	....	127.609	....	....	....
Pleasant Valley & Lake canal	1.75	....	....	....	....	....
Larimer County canal	0.58	....	....	....	....	....
Jackson ditch	0.266	....	....	....	....	....
Little Cache la Poudre ditch	1.00	....	....	....	....	....
Larimer County No. 2 canal	0.534	....	....	....	....	....
New Mercer canal	0.228	....	....	....	....	....
Fort Collins canal	1.14	....	....	....	....	....
Sum	5.498	122.111	....	....	....	....
River, 2½ miles above Fort Collins	......	....	133.973	11.862	7.25	1.64
Larimer & Weld canal	1.731	....	....	....	....	....
Pioneer ditch	2.60	....	....	....	....	....
Ames ditch	0.69	....	....	....	....	....
Lake canal	1.248	....	....	....	....	....
Cache la Poudre No. 2	3.216	....	....	....	....	....
Sum	9.485	124.488	....	....	....	....
River at the dam below No. 2	......	....	149.985	25.497	10.10	2.52
The Whitney ditch	1.583	....	....	....	....	....
Greeley No. 3 canal	5.870	....	....	....	....	....
Sum	7.453	142.532	....	....	....	....
River, ¼ mile below No. 3	......	122.908	161.863	19.331	12.25	1.58
Ogilvy ditch	38.955	....	....	....	....	....
River, ⅓ mile below Ogilvy ditch	....	....	153.117	30.209	5.6	5.39
Totals	......	....	....	86.90	35.0	2.48

MEASUREMENT No. 2—Made by L. R. Hope and E. C. Hawkins, under direction of E. S. Nettleton, October 14–17, 1889.

River at Gaging Station	......	....	68.723	....	....	....
Pleasant Valley & Lake canal	14.781	....	....	....	....	....
Larimer County canal	.818	....	....	....	....	....
Jackson ditch	5.288	....	....	....	....	..
Little Cache la Poudre ditch	6.968	....	....	....	....	....
Taylor and Gill	2.577	....	....	....	....	....
Larimer County No. 2 canal	12.425	....	....	....	...	....
Fort Collins Water Works	.875	....	....	....	....	....
Arthur Irrigating Co. canal	.650	....	....	....	....	....
Larimer & Weld canal	3.040	....	....	....	....	....
Sum	47.422	21.301	....	....	....	...
River, below L. & W. dam	......	....	32.571	11.270	7.25	1.55
Pioneer ditch	1.746	....	....	....	....	....
Josh Ames ditch	1.378	....	....	....	....	....
The Lake canal	1.500	....	....	....	....	....
The Arthur canal	1.497	....	....	....	....	....
Box Elder ditch	6.555	....	....	....	....	....
Cache a Poudre Canal No. 2	55.184	....	....	....	....	....
Sum	67.860	-35.289	....	....	....	....
River, below No. 2 dam	......	....	1.500	36.789	10.10	3.64
Whitney ditch	2.285	....	....	....	....	....
Eaton ditch	.300	....	....	....	....	....
Greeley Canal No. 3	9.835	....	....	....	....	....
Ogilvy ditch	30.098	....	....	....	....	....
Sum	42.518	-41.018	....	....	....	....
River, below Ogilvy dam	......	....	3.480	44.498	17.50	2.54
River, near mouth	......	....	9.887	6.407	3.75	17.09
Totals	157.800	....	....	98.964	38.60	2.56

GAGINGS OF THE CACHE A LA POUDRE RIVER.

(In cubic feet per second.)

MEASUREMENT No. 3—Made by L. R. Hope and E. C. Hawkins, October 16–18, 1890.

Place of Measurement.	Out-take.	In-flow.	Remain-der.	River.	Gain.	No. of Miles.	Gain per Mile.
River, at Gaging Station	......	....	....	80.776	....	....	....
Canon ditch	.975	....	....	....	....	....	....
Larimer County canal	2.849	....	....	....	....	....	....
Jackson ditch	4.125	....	....	....	....	....	....
Little Cache la Poudre canal	4.016	....	....	....	....	....	...
Taylor and Gill ditch	.700	....	....	....	....	....	....
Fort Collins Water Works	.383	....	....	....	....	....	....
Larimer & Weld canal	16.401	....	....	....	....	....	....
Sum	29.449	....	51.327	....	....	....	....
River, below Larimer & Weld dam	......	....	....	77.117	25.79	7.25	3.56
Riddle ditch	.106	....	....	....	....	....	....
Josh Ames ditch	1.000	....	....	....	....	....	....
The Lake canal	1.040	....	....	....	....	....	....
Coy ditch	.973	....	....	....	....	....	....
Box Elder ditch	5.730	....	....	....	....	....	....
Cache la Poudre Canal No. 2	79.867	....	....	....	....	....	....
Sum	88.716	....	-11.599	....	....	....	....
River, below No. 2 canal	......	....	....	2.060	13.66	10.10	1.35
River, above Greeley (Pump House)	.....	....	....	19.308	17.25	15.0	1.15
River, at Ogilvy ditch	......	....	....	40.180	20.87	2.00	10.43
Ogilvy ditch	36.675	....	....	....	....	....	....
River, near mouth	.....	....	....	32.729	23.22	4. (?)	5.80
Totals	......	....	....	......	100.79	38.35	2.63

MEASUREMENT No. 4—Made by L. G. Carpenter and R. E. Trimble, October 28, and by L. G. Carpenter and J. D. Stannard, October 29–30, 1891.

Place of Measurement.	Out-take.	In-flow.	Remain-der.	River.	Gain.	No. of Miles.	Gain per Mile.
River at Gaging Station	......	....	....	97.58	....	....	....
Canon ditch	.03	....	....	......	....	....	....
Pleasant Valley & Lake canal	6.99	....	....	......	....	....	....
Jackson ditch	0	....	....	......	....	....	....
Little Cache la Poudre ditch	5.21	....	....	......	....	....	....
Taylor and Gill ditch	2.16	....	....	......	....	....	....
Larimer County canal	1.00	....	....	......	....	....	....
New Mercer canal	0	....	....	......	....	....	....
Fort Collins Water Works	0.30	....	....	......	....	....	...
Larimer County No. 2 canal	.64	....	....	......	....	....	....
Arthur ditch	1.82	....	....	......	....	....	....
Larimer & Weld canal	43.30	....	....	......	...	....	....
Sum	61.45	....	36.13	......	....	....	....
River, below L. & W. canal	......	....	....	54.39	18.26	7.25	2.52
Pioneer ditch	0.0	....	....	......	....	....	....
Josh Ames ditch	.50	....	....	......	....	....	....
The Lake canal	.24	....	....	......	....	....	....
Coy ditch	1.60	....	....	......	....	....	....
Box Elder ditch	3.78	....	....	......	....	....	....
Cache la Poudre No. 2 canal	.50	....	....	......	....	....	....
Sum	6.62	....	47.77	......	....	....	....
River, at head of No. 2	......	....	....	56.48	8.71	10.10	0.86
Whitney ditch	0.0	....	....	......	....	....	....
Eaton ditch	1.42	....	....	......	....	....	....
Jones ditch	(8.126)	....	....	......	....	....	....
Greeley No. 3 canal	32.24	....	....	......	....	...	....
Boyd and Freeman ditch	2.42	....	....	......	....	....	....
Sum	36.08	0	11.69				
River, near Pump House	......	....	....	15.3	—5.1	15.0	....
Poudre below Greeley	......	....	....	53.56	38.26	2.1	2.24
Ogilvy ditch	18.12	....	....	......	....	....	....
Waste	......	5.88	....	......	....	....	....
River, near mouth	......	....	....	60.72	19.40	4.25	4.56
Totals	......	....	....	....	84.63	38.7	2.19

River at Gaging Station Nov. 3. 107.01 cu. ft.

GAGINGS OF THE CACHE A LA POUDRE RIVER.

(In cubic feet per second.)

MEASUREMENT No. 5—Made by L. G. Carpenter and J. D. Stannard, March 10, and by L. G. Carpenter and F. DeVotie, March 11-12, 1892.

Time.	Place of Measurement.	Out-take.	In-flow.	River.	Gain.	No. of Miles.	Gain per Mile.
	MARCH 10.						
....	River at Gaging Station	......	....	65.02	....	....	....
....	Lew Stone creek	......	0.50	......	....	....	....
....	Canon ditch	0	....	......	....	....	....
....	Pleasant Valley canal	4.38	....	......	....	....	....
....	Jackson ditch	2.07	....	......	....	....	....
....	Little Cache la Poudre ditch	1.08	....	......	....	....	....
....	Taylor and Gill ditch	0.59	....	......	....	....	....
....	Fort Collins Water Works	0.22	....	......	....	....	....
....	Larimer County ditch	0	....	......	....	....	....
....	Larimer County No. 2	10.10	....	......	....	....	....
....	New Mercer	0.28	....	......	....	....	....
	MARCH 11.						
....	Larimer & Weld canal	0.72	....	......	....	....	....
....	Pioneer ditch	0	....	......	....	....	....
....	Lake canal	0	....	......	....	....	....
....	Coy ditch	(2.47)	....	......	....	....	....
....	Dry Creek ditch	......	(1.25)	......	....	....	....
....	Ames slough	......	(7.00)	......	....	....	....
....	Cooper slough	......	(2.43)	......	....	....	....
....	Box Elder creek	......	(2.16)	......	....	....	....
....	Spring creek	......	(6.04)	......	....	....	....
....	Box Elder ditch	0.75	....	......	....	....	....
....	Fossil creek	......	(2.72)	......	....	....	....
....	Near Whitney ditch	......	(0.81)	......	....	....	....
	MARCH 12.						
....	Eaton ditch	0.10	....	......	....	....	....
....	Whitney ditch	0	....	......	....	....	....
	Sum	20.29	0.50	......	....	....	....
....	River, near Eaton ditch	......	....	102.54	57.31	20.35	2.82
....	Near Fulton bridge	......	1.15	......	....	....	....
....	Inflow above Briggs	......	(2.25)	......	....	....	....
....	Inflow near Whitney ditch	......	....	......	....	....	....
....	Jones ditch	0	....	......	....	....	....
....	Inflow opposite Jones'	......	(1.35)	......	....	....	....
....	Inflow near Fletcher ditch	......	(0.75)	......	....	....	....
....	Greeley canal No 3	0	....	......	....	....	....
....	Inflow	......	(0.90)	......	....	....	....
	Sum	......	1.15	......	....	....	....
....	River near Pump house		....	132.75	29.06	12.0	2.42
....	Ogilvy ditch	1.00	....	......	....	....	....
....	River below Ogilvy ditch	......	....	141.49	9.74	2.50	3.89
	Totals	......	....	......	96.11	34.85	2.76

MEASUREMENT No 6—Made by R. E. Trimble and J. D. Stannard, October 5-8, 1892.

Time.	Place of Measurement.	Out-take.	In-flow.	River.	Gain.	No. of Miles.	Gain per Mile.
	OCTOBER 5.						
1 p. m.	River at Gaging Station	......	....	62.92	....	....	....
....	Canon ditch	.03	....	......	....	....	....
....	Jackson ditch	4.51	....	......	....	....	....
....	Little Cache la Poudre ditch	.18	....	......	....	....	....
....	Taylor and Gill ditch (est.)	6.25	....	......	....	....	....
....	Larimer County ditch	0	....	......	....	....	....
....	New Mercer canal	.35	....	......	....	....	....
....	Fort Collins Water Works	.28	....	......	....	....	....
....	Larimer County No. 2 canal	.36	....	......	....	....	....
	Sum	11.96	....	......	....	....	....
5:30	River 100 yards above L. & W. canal	......	....	66.33	15.37	7.25	2.12
....	Larimer & Weld canal	58.86	....	......	....	....	....

GAGINGS OF THE CACHE A LA POUDRE RIVER.

(In cubic feet per second.)

MEASUREMENT No. 6 –(Continued).

Time.	Place of Measurement.	Out-take.	In-flow.	River.	Gain.	No. of Miles.	Gain per Mile.
....	River below L. & W. canal..........	......	....	5.95	....	....	....
	OCTOBER 6.						
....	Pioneer ditch, near Inverness farm	.01	....	......	....	....	....
....	Josh Ames ditch..............	.89	....	......	....	....	....
....	The Lake canal....................	2.00	....	......	....	....	....
....	Coy ditch..........................	(.74)	....	......	....	....	....
	Sum	2.90	....	......	....	....	....
Noon.	River, below Lindell Mills.........	......	....	52.56	*.60	3.00	....
....	Dry ditch.........................	......	(.95)	......	....	....	....
....	Ames slough....................	......	(2.56)	......	....	....	....
....	Cooper slough...................	......	(2.63)	......	....	....	....
....	Box Elder creek................	......	(2.90)	......	....	....	....
....	Spring creek.....................	......	(1.25)	......	....	....	....
....	Box Elder ditch..................	2.14	....	......	....	....	....
	Sum	2.14	....	......	....	....	....
3 p. m.	River, below Strauss bridge........	......	....	53.93	3.51	4.75	0.74
	OCTOBER 7.						
11 a. m.	River below Strauss bridge.........	......	....	21.03	....	....	....
....	Inflow below Strauss bridge......	......	(.02)	......	....	....	....
....	Cache la Poudre No. 2 canal......	1.93	....	......	....	....	....
	Sum	1.93	....	......	....	....	....
Noon.	River, below No. 2 canal..........	......	....	21.65	2.52	2.40	1.05
....	Fossil creek......................	......	(1.33)	......	....	....	....
....	Whitney ditch....................	2.72	....	......	....	....	....
2 p. m.	River, below Eaton ditch	......	....	24.90	5.97	3 00	1.99
....	Jones ditch.......................	.15	....	......	....	....	....
....	Greeley No. 3.....................	32.20	....	......	....	....	....
	Sum	32.35	....	......	....	....	....
	OCTOBER 8.						
9 a. m.	River, near Greeley Pump house....	......	....	14.36	21.81	12.00	1.82
....	Ogilvy ditch......................	29.14	....	......	....	....	....
....	River, below Ogilvy dam..........	......	....	2.53	17.31	2.50	6.92
3 p. m	River at mouth....................	......	....	31.69	29.16	3.75	7.78
	Totals......	......	....	......	101.65	38.65	2.47

* Estimated.

MEASUREMENT No. 7—Made by R. E. Trimble and R. Q. Tenney, November 9-11, 1893.

	NOVEMBER 9.						
....	River at Gaging Station...........	......	....	52.47	....	....	....
....	Canon ditch......................	0.48	....	......	....	....	....
....	Pleasant Valley canal.............	4.69	....	......	....	....	....
....	Larimer County ditch.............	0	....	......	....	....	....
....	Jackson ditch....................	4.83	....	......	....	....	....
....	Little Cache la Poudre ditch......	0.23	....	......	....	....	....
....	Taylor and Gill ditch............	1.41	....	......	....	....	....
....	New Mercer ditch................	0	....	......	....	....	....
....	Fort Collins Water Works (est.)..	.60	....	......	....	....	....
....	Larimer County No. 2 canal......	1.87	....	......	....	....	....
....	Arthur Irrigating canal..........	0	....	......	....	....	....
	NOVEMBER 10.						
....	Larimer & Weld canal.........	(0.54)	....	......	....	....	....
....	River below L. & W. canal..........	......	....	69.61	31.25	7.25	4.31
....	Pioneer ditch.....................	0.45	....	......	....	....	....
....	Josh Ames ditch....	1.39	....	......	....	....	....
....	Lake canal	0	....	......	....	....	....
....	Coy ditch.........................	2.00	....	......	....	....	....

GAGINGS OF THE CACHE A LA POUDRE RIVER.

(In cubic feet per second.)

MEASUREMENT No. 7—(Continued).

Time.	Place of Measurement.	Out-take.	In-flow.	River.	Gain.	No. of Miles.	Gain per Mile.
....	River below Hottel Mill	......	....	72.48	6.71	3.25	2.61
....	No. 2 Feeder	6.80	....	......	....	....	....
....	Spring creek	......	(0.68)	......	....	....	....
....	Ames slough	......	(5.00)	......	....	....	....
....	Cooper slough	......	(1.50)	......	....	....	....
....	Box Elder creek	......	(3.70)	......	....	....	....
....	Box Elder ditch	1.04	....	......	....	....	....
....	Cache la Poudre Irr'g Canal No. 2	60.03	....	......	....	....	....
	NOVEMBER 11.						
....	River below No. 2	......	....	9.84	5.23	6.90	0.76
....	Fossil creek	......	(1.35)	......	....	....	....
....	Whitney ditch	0.08	....	......	....	....	....
....	Eaton ditch	0.	....	......	....	....	....
....	River below Eaton ditch	......	....	4.95	—4.81	3.00	—1.60
....	Jones ditch	0.19	....	......	....	....	....
....	Greeley No. 3 canal	0	....	......	....	....	....
....	Boyd and Freeman ditch	3.65	....	......	....	....	....
....	River north of Pump house	......	....	20.32	19.21	12 00	1.60
....	Ogilvy ditch	0.65	....	......	....	....	....
....	River below Ogilvy dam	......	....	43.26	23.59	2.50	9.44
....	River at the mouth	......	....	60.76	17.50	3.25	5.38
	Totals	......	....	......	98.68	38.15	2.59

MEASUREMENT No. 8—Made by R. E. Trimble and R. Q. Tenney, March 13–15, 1894.

Time.	Place of Measurement.	Out-take.	In-flow.	River.	Gain.	No. of Miles.	Gain per Mile.
	MARCH 13.						
....	River at Gaging Station	......	....	99.21	....	0	....
....	Canon ditch	0.03	....	......	....	....	....
....	Pleasant Valley & Lake canal	(4.70) 12.60	....	......	....	....	....
....	Larimer County canal	0.25	....	......	....	....	....
....	Jackson ditch	6.17	....	......	....	....	....
....	New Mercer canal	0	....	......	....	....	....
....	Fort Collins Water Works	0.60	....	......	....	....	....
....	Little Cache la Poudre canal	0.53	....	......	....	....	....
....	Taylor and Gill ditch	5.22	....	......	....	....	....
....	Chamberlain ditch	(2.00)	....	......	....	....	....
....	Larimer County No. 2 canal	0.57	....	......	....	....	....
....	Arthur Irrigating canal	0	....	......	....	....	....
....	Larimer and Weld canal	25.30	....	......	....	....	....
....	Riddle ditch	0.33	....	......	....	....	....
....	River below L & W. canal	......	....	49.18	1.57	7.25	0.22
	MARCH 14.						
....	Pioneer ditch	......	....	......	....	....	....
....	Ames ditch	1.28	....	......	....	....	....
....	Lake canal	0.16	....	......	....	....	....
....	Coy ditch	0	....	......	....	....	....
....	No. 2 Feeder	49.70	....	......	....	....	....
....	River below No 2 Feeder	......	....	1.49	3.45	4.45	0.78
....	Spring creek	......	(2.78)	......	....	....	....
....	Ames slough	......	(0.22)	......	....	....	....
....	Cooper slough	......	(1.21)	......	....	....	....
....	Box Elder ditch	0.11	....	......	....	....	....
....	Box Elder creek	......	(0.24)	......	....	....	....
....	No. 2 Feeder, north of Timnath	(23.90)	....	......	....	....	....
	MARCH 15.						
....	Cache la Poudre No. 2 canal	1.43	....	......	....	....	....
....	River below No. 2	......	....	27.17	27.22	5.65	4.82
....	Fossil creek	......	(0.19)	......	....	....	....
....	Eaton ditch	.08	....	......	....	....	....
....	River below Eaton ditch	......	....	20.44	—6.65	3.00	—2.22
....	Jones ditch	0	....	......	....	....	....
....	Greeley No. 3 canal	0.12	....	......	....	....	....
....	Boyd and Freeman ditch	0.12	....	......	....	....	....

GAGINGS OF THE CACHE A LA POUDRE RIVER.

(In cubic feet per second.)

MEASUREMENT No. 8—(Continued).

Time.	Place of Measurement.	Out-take.	In-flow.	River.	Gain.	No. of Miles.	Gain per Mile.
....	River near Pump house...	......	....	46.46	26.26	12.00	2.19
....	Greeley drain sewer..............	(1.47)	....	......	....	....	....
....	Ogilvy ditch......................	0	....	......	....	....	....
....	River below Ogilvy dam...........	......	....	56.51	10.05	2.50	4.02
....	River at mouth, ½ mile above.......	......	....	76.93	20.42	3.25	6.28
....	Totals......	......	....	......	82.32	38.10	....

MEASUREMENT No. 9—Made by R. E. Trimble and John D. Bloomfield, August 20-23, 1894.

Time.	Place of Measurement.	Out-take.	In-flow.	River.	Gain.	No. of Miles.	Gain per Mile.
	AUGUST 20.						
12:35	River at Gaging Station............	......	....	268.07	....	....	....
2:45	Canon ditch.......................	0.80	....	......	....	....	....
11:30	Pleasant Valley & Lake canal..	23.63	....	......	....	....	....
3:15	Larimer County ditch............	31.39	....	......	....	....	....
4:15	Jackson ditch....................	11.17	....	......	....	....	....
10:40	New Mercer canal..	3.42	....	......	....	....	....
....	Fort Collins Water Works........	0.60	....	......	....	....	....
4:40	Little Cache la Poudre canal....	7.87	....	......	....	....	....
4:50	Taylor and Gill ditch............	4.46	....	......	....	....	....
....	Chamberlain ditch...............	4.53	....	......	....	....	....
....	Larimer County No. 2 canal......	0	....	......	....	....	....
....	Arthur Irrigating canal...........	0	....	......	....	....	....
5:40	Larimer & Weld canal..........	27.80	....	......	....	....	....
6:15	River below L. & W. canal......	......	....	153.17	0.77	7.25	0.11
	AUGUST 21.						
9:20	Pioneer ditch.....................	0.16	....	......	....	....	....
9:50	Ames ditch.......................	2.56	....	......	....	....	....
10:10	Lake canal.......................	0.13	....	......	....	....	....
10:20	Coy ditch..................	16.30	....	......	....	....	....
11:10	River at Coy's farm..............	......	....	(151.61)	17.59	3.50	5.26
11:55	Coy ditch waste	......	0.82	......	....	....	....
12:00	Coy slough	......	(1.70)	......	....	....	....
2:45	Horner supply	6.39	....	......	....	....	....
3:15	Chaffee ditch	2.77	....	......	....	....	....
3:40	Pioneer waste .... Horner supply waste.............	......	9.51	......	....	....	....
9:15	Spring creek (Aug. 22)........ ...	......	(5.56)	......	....	....	....
4:00	Ames slough........	......	(0.90)	......	....	....	....
4:30	Emigh drain ditch	(3.00)	....	......	....	....	....
9:50	Cuthbertson (Aug. 22)...........	......	(0.51)	......	....	....	....
....	Cooper slough (into Emigh drain)	......	(0.50)	......	....	....	....
4:45	Box Elder creek.................	......	(2.52)	......	....	....	....
10:15	Box Elder ditch (Aug. 22)	7.93	....	......	....	....	....
5:40	River at Strauss bridge...........	......	....	141.52	—3.33	4.20	—0.79
	AUGUST 22.						
11:05	River at Strauss bridge.............	......	....	139.61	....	....	....
12:35	Cache la Poudre No. 2 canal......	74.27	....	......	....	....	....
1:35	River below No. 2.......	......	....	68.46	3.12	2.40	1.30
2:45	Fossil creek......................	......	(4.58)	......	....	....	....
3:30	Whitney ditch	19.98	....	......	....	....	....
3:35	Eaton ditch......................	10.90	....	......	....	....	....
4:00	River below Eaton ditch...........	......	....	49.44	11.86	3.00	3.95
6:40	Jones ditch............	5.28	....	......	....	....	....
	AUGUST 23.						
10:50	Greeley No. 3 canal....	56.55	....	......	....	....	....
10:25	River below No. 3..............	......	....	0.29	12.68	9.00	1.41
12:10	Boyd and Freeman ditch..........	3.30	....	......	....	....	....
2:30	River near Pump house............	......	....	18.13	21.14	3.00	7.05
3:15	Greeley drain sewer	(3.51)	....	......	....	....	....
3:50	Ogilvy ditch.....................	38.39	....	......	....	....	....
4:15	Camp Bros river supply........	1.17	....	..... .	....	....	....
4:45	Camp Bros. Slough supply......	(2.16)	....	......	....	....	....
4:25	River below C. Bros, river supply	......	....	4.93	26.36	3.00	8.79
6:00	River ½ mile above mouth.........	......	....	32.90	27.97	2.75	10.17
	Totals	......	....	......	118.16	38.10	3.10

GAGINGS OF THE CACHE A LA POUDRE RIVER.

(In cubic feet per second.)

MEASUREMENT No. 10—Made October 9-14, 1895.

Time.	Place of Measurement.	Out-take.	In-flow.	River.	Gain.	No. of Miles.	Gain per Mile.
	NOVEMBER 9.						
....	River at Gaging Station............	......	....	66.47	....	....	....
....	Canon canal......................	.10	....	......	....	....	....
....	Pleasant Valley & Lake canal..	21.23	....	......	....	....	....
....	Inflow from Canon canal.........	......	.13	......	....	....	....
....	Larimer County canal....	0	....	......	....	....	....
....	Jackson ditch.....................	0	....	......	....	....	....
....	River 150 yards above Mercer ditch	......	....	63.53	18.75	5.50	3.41
....	New Mercer ditch................	0	....	......	....	....	....
....	Little Cache la Poudre ditch.....	6.67	....	......	....	....	....
....	Taylor and Gill ditch.............	4.55	....	......	....	....	....
....	Chamberlin ditch..................	......	....	......	....	....	....
....	Larimer County No. 2 canal......	.50	....	......	....	....	....
....	Fort Collins Water Works (est.).	.75	....	......	....	....	....
....	Inflow waste from T. & Gill ditch	......	3.63	......	....	....	....
....	Inflow waste from T. & Gill ditch	......	.93	......	....	....	....
....	Arthur ditch.....................	2.88	....	......	....	....	....
....	River above Larimer & Weld.....	......	....	54.10	1.46	1.75	.81
	OCTOBER 10.						
....	River below Larimer & Weld....	......	....	0.55	....	....	....
....	Pioneer ditch....................	0.28	....	......	....	....	....
....	Seepage ditch	.....	(0.50)	......	....	....	....
....	Ames ditch...................... .	0.21	....	......	....	....	....
....	Lake canal.......................	3.06	....	......	....	....	....
....	City sewer.......................	......	....	......	....	....	....
....	College sewer....................	......	....	......	....	....	....
....	Coy ditch........................	.01	....	......	....	....	....
....	No 2 Res. supply canal...........	.18	....	......	....	....	....
....	River below No. 2 Res. Supply canal	......	....	26.44	26.63	4.4	6.05
....	Dry creek........................	......	(1.71)	......	....	....	....
....	Ames slough......................	......	(0.96)	......	....	....	....
....	Emigh drain......................	......	((3.68))	......	....	....	....
....	Cooper slough..............	......	((0.53))	......	....	....	....
....	Box Elder creek.......	......	(3.76)	......	....	....	....
....	Spring creek.....................	......	(6.12)	......	....	....	....
....	Box Elder ditch..................	0	....	......	....	....	....
....	Seepage ditch from Spring creek.	......	((0.63))	......	....	....	....
....	Side Hill ditch from Spring creek	......	((2.53))	......	....	....	....
....	Ditch from Cooper slough........	......	((1.15))	......	....	....	....
....	River at Strauss bridge...........	......	....	32.53	6.09	4.2	1.45
	OCTOBER 14.						
....	River at Strauss bridge.	......	....	26.24	....	....	....
....	Cache la Poudre No. 2 canal......	.02	....	......	....	....	....
....	River below Cache la P. No. 2 canal	......	....	33.73	7.51	2.4	3.13
....	Fossil creek......................	......	(7.63)	......	....	....	....
....	Whitney ditch...............	5.72	....	......	....	....	....
....	Eaton canal......................	8.09	....	......	....	....	....
....	River below Eaton canal...........	......	....	26.91	6.99	3.0	2.33
....	Seepage ditch...........	......	(1.34)	......	....	....	....
....	Jones ditch......................	1.39	....	......	....	....	....
....	Greeley No. 3 ditch (Oct. 15)......	13.10	....	......	....	....	....
....	River below Greeley No. 3 ditch....	......	....	19.77	7.35	9.0	.82
	OCTOBER 15.						
....	Greeley No. 3....................	.61	....	......	....	....	....
....	River below Greeley No. 3 ditch....	......	....	32.26	....	....	....
....	Waste into No. 3..................	......	((1.86))	......	....	....	....
....	Waste into No. 3....	......	((0.56))	......	....	....	....
....	Boyd and Freeman ditch..........	2.77	....	......	....	....	....
....	River at Pump house..............	......	....	62.73	33.85	3.0	11.28
....	Mill Power canal.................	(4.05)	(5.40)	......	....	....	....
....	Ogilvy ditch.....................	0	....	......	....	....	....
....	River below Ogilvy dam...........	......	....	70.47	7.74	2.5	3.10
....	Camp ditch......................	0	....	......	....	....	....
....	River ½ mile above mouth..	......	....	116.84	46.37	3.25	5.05

TABLE III.

SUMMARY OF THE PRECEDING TABLES, SHOWING GAIN IN SEEPAGE OF CACHE A LA POUDRE RIVER.

(In cubic feet per second.)

	1885.	1889.	1890.	1891.	Mar. 1892.	Oct. 1892.	1893.	Mar. 1894.	Aug. 1894.	1895.
Canon to Larimer & Weld canal..	11.9	11.3	25.8	18.3	......	15.4	31.3	1.6	0.8	19.61
Larimer & Weld to No. 2 canal...	25.5	36.8	13.7	8.7	......	12.0	11.9	30.67	17.4	13.6
No. 2 canal to Ogilvy ditch.......	49.5	44.5	38.1	38.3	......	45.1	38.0	29.8	72.0	55.9
Ogilvy ditch to Mouth of Poudre.	......	6.4	23.2	19.4	......	29.2	17.5	20.4	28.0	46.4
Total Gain	86.9	99.0	100.8	84.6	96.1	101.6	98.7	82.3	118.2	164.4

DESCRIPTION OF THE PLATTE.

§ 16. The portion of the Platte river which was subjected to measurement consisted of that portion below the junction of the Poudre river with the Platte, to the State line between Colorado and Nebraska, at the point where the Platte enters the western extension of Nebraska. The country traversed by the Platte has still the main characteristics of that nearer the mountains. From the junction with the Cache a la Poudre, the Platte leaves the general northerly course which it has traveled since leaving the foothills above Denver, bends abruptly eastward and crosses the ridges which run approximately parallel to the mountains. The effect of these ridges in guiding the drainage of the plains is shown by the long lateral channels. On the south these extend nearly parallel to the Platte for 90 miles, extending to the divide between the Platte and Arkansas rivers, east of Colorado Springs. For a portion of the distance, the Box Elder is within a short distance of the Platte, but, confined by these ridges, it does not meet the Platte until the latter cuts through these ridges. These are drainage channels rather than tributaries, for, except in times of freshets or storms, they do not contain water. Near the heads they are living streams. The last drainage channel from the south of any consequence enters the Platte east of Fort Morgan; for the rest of the distance the drainage of the country on the south side is collected by branches of the Republican river.

§ 17. On the north the Platte takes the drainage of the country as far north as Wyoming. The three principal lines of drainage—Lone Tree, Crow, and Lodge Pole creeks—each head near Cheyenne, the first two entering the Platte near Greeley, the last passing nearly eastward for 150 miles, forming the line followed by the main line of the Union Pacific Railway between Julesburg and Cheyenne, and enters the Platte 150 miles farther east, just above Julesburg.

None of these, nor any of the other channels to which the name creek is applied, can be spoken of as tributaries. It is rare

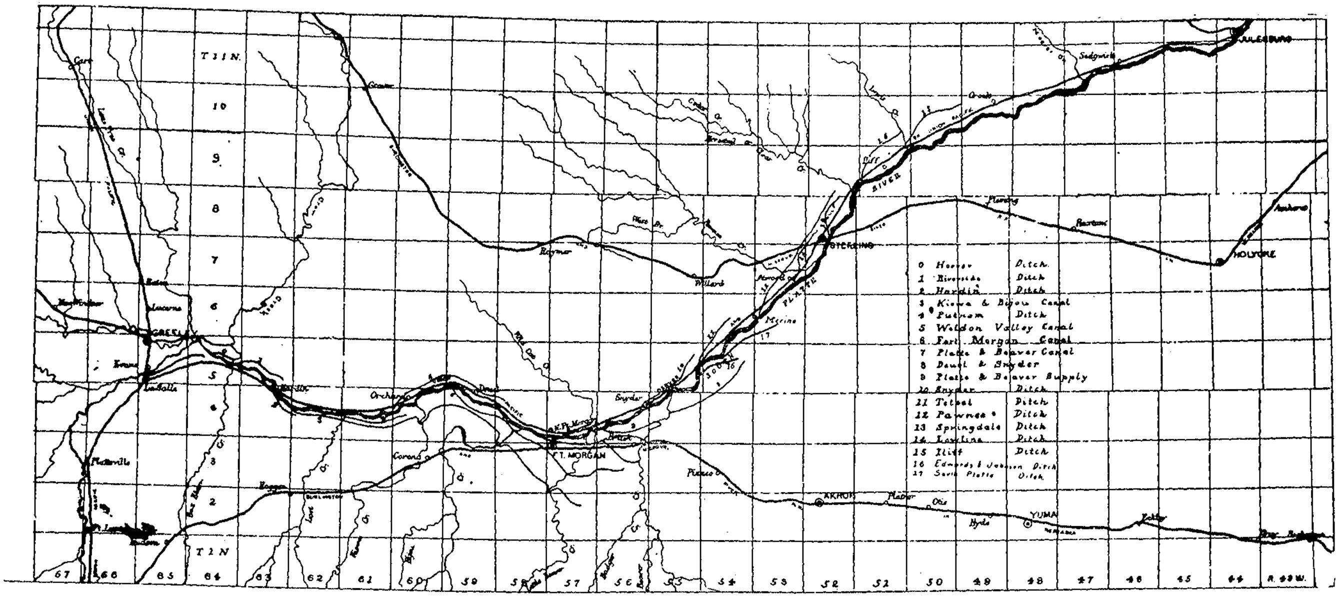


FIG. 3--Map of the South Platte Valley.

that any water reaches the Platte through their channels, the only times being after heavy rains or sudden and violent storms on the higher grounds on either side. In these cases, the plains shed water as a roof, and the channels bring down violent floods, dangerous, it may be, to travelers. The area drained by these channels is great. As in most cases, the channels are confined by ridges of rock, it was thought that there might be some indication of underground increase from these streams, even if no visible surface inflow. Accordingly in 1894 it was tested by measuring the river above and below the points where the creeks debouch into the bottoms, with results given later.

For a portion of the lower course of the stream, it is lined on one or both sides by a strip of sand hills and dunes, molded and blown by the wind, back of which is a country free from sand.

§ 18. The bed of the stream is a bed of sand, of varying fineness—in some places and at some times quicksand—and shifting with the current, which changes from one side to the other. For some miles below the mouth of the Poudre, the stream is in one channel. It is then gradually broken up by sandbars and by small islands into smaller channels, increasing in number. At the State line there were sixteen channels where we measured in 1895. These channels are constantly shifting by bars forming or washing away in the rapid current, so that they change their importance and frequently their position. The general location of the bed seems to be fairly stable. The river requires bridges some 600 to 1,000 feet in length. The slope of the bed of the river averages about eight feet per mile between the mouth of the river and Julesburg, being greater at the upper portion and less at the lower end. When there is much water this fall is sufficient to give the current great velocity, constantly carrying along the sand, depositing, removing and shifting it.

§ 19. The principal ditches along the course of the river are shown on the map (Fig. 3). It will be noted that the area limited by the outermost ditch under irrigation does not cover a wide strip. Many of the ditches are small, some used to irrigate only the bottom lands. Others, like the Fort Morgan, the Weldon Valley, the Platte and Beaver, and Pawnee Canal systems, irrigate considerable areas of excellent land and are almost the only ones passing out of the bottoms.

If the water reaches the river from the land irrigated, it may be expected to drain into the river following the lines of surface drainage, though remaining unseen. It cannot cross the ridges between the channels. As a rule, wherever the facts are known, the ridges are of rock which is higher than the bottoms of the channels. With the system of ditches, there is then some possibility of separating the drainage of extensive areas of irrigated land from land which receives little or no irrigation.

COMPLICATING CONDITIONS.

§ 20. The bed is almost invariably of sand of unknown depth. In a few places the rock of the ridges cut through by the river shows at the surface. If there is any flow in the sand, it may be expected to be forced to the surface at such places and increase the volume of the stream. Such a place is just above the Bijou creek, above Fort Morgan. And again below the Hardin ditch and above the Corona ditch the bluffs on the south side of the river are prominent, and show evidence of rock outcropping across the river. The sand is porous and has the capacity to hold much water. The results which may be met with in the natural inflow are masked by the effects due to the varying distance to the rock. These may sometimes be more than sufficient to counterbalance the increase from the inflow. This may explain the unusual gains noticed in several places and the losses which are found in certain stretches, even where an area of irrigated land is tributary to that section. The most marked case is at the mouth of Bijou creek. In the measurement of 1894, which was made above and below the Bijou, a gain was looked for in the few miles between the two measurements. The Bijou drains some 1,400 square miles. Besides, there was some water evident on the south side seeping into the river. Nevertheless, a loss was found in 1894, and in 1895 on making another test the gain was so slight that it may be called a loss. In both cases the Platte & Beaver canal was measured several miles from its head, and the loss for the few miles if considered may make a slight gain. But with all allowance possible for this, the gain is slight, or an actual loss which the measurements show. Moreover, at the last point of measurement, there are practically no bottom lands.

§ 21. The methods of irrigation on the lower Platte are somewhat different from those on the Cache a la Poudre, and this may account for the difference in the relative magnitude of the result. The Poudre being a mountain stream, fed almost solely by melting snow, is low in the autumn and late summer. On the Platte the summer flow is small, being reduced both by the usage above and by the avidity of the sands and atmosphere. In the fall, however, the seepage from all the streams nearer the mountains—Clear creek, Boulder creek, St. Vrain, Big Thompson, and Cache a la Poudre—pour the seepage from these channels and the greater part of the flow received from the mountains into the Platte. As a consequence the Platte is higher in the fall and winter. This gives the settlers along the Platte opportunity to irrigate extensively in the fall, and as late as the ditches can well carry water; they thus each year irrigate their lands. At the time of measurement they were irrigating extensively. It will be noticed in the tables, as in 1895, that the canals are running nearly, if not quite full, though late in the season. This in itself increases the rapidity of flow from the lower ends of the small tubes extending to the river, and is one reason why the increase of water is more than in the case of the Poudre in proportion to the same area irrigated. The use of water at this time when vegetation is not active, also permits the use of water in greater quantities without damage. We have no measures which determine the amount actually used, but from observation and the conditions, it seems probable that water is used in greater quantities than in the Poudre valley.

§ 22. Fig. 4 shows graphically the results of the gagings below the mouth of the Poudre. The distances between the points of measurement are in proportion to the distance between the lines. The amount of gain is indicated by the distance the line is above the base. Hence the steeper the line in any section, the faster is the gain in that section. If the line descends, as it does in some places, it indicates a loss.

§ 23. The tables show the measurements in detail, and give the results of each. The dates and the observers are also given. The distances given are different from the distances given in the report of the State Engineer, but are believed to be here correct. In some cases the distance between the same points in different years is apparently not the same, the reason being that the place of gaging was not quite the same.

In gaging the Platte, the trouble to find accommodations caused considerable interference with the best prosecution of the work. Often after the last gaging of the day a drive of some miles would be necessary, and the river would be taken up at another point the next morning. This did not allow a check on any change the river may have undergone during the night. In 1895 a tent and camp wagon was taken as far as Sterling, and the party camped where night overtook them.

The height of the river was observed both night and morning. It was proved that the change was exceedingly small, amounting, usually, to an increase of about one-fourth inch during the night and a corresponding decrease during the day. A loose block of wood placed at the edge of the water the second night out from Greeley was undisturbed a week later and still just at the edge of the water, indicating a very steady condition of the stream.

The ditches were not disturbed. Where streams are not mentioned in some of the measurements, it is because they were found to be dry.

In 1895 several small ditches near Julesburg were found to be drawing water. Their existence had never been reported to the Water Commissioner, so that they had not been looked for in 1894.

The measurement of March, 1892, was interfered with by snow, which prevented carrying the gaging beyond Fort Morgan.

In 1895 where any of the quantities are enclosed in parentheses, they are not to be taken in the summation. In the case of inflow it was known to be seepage, or in case of out-take it returned immediately to the river.

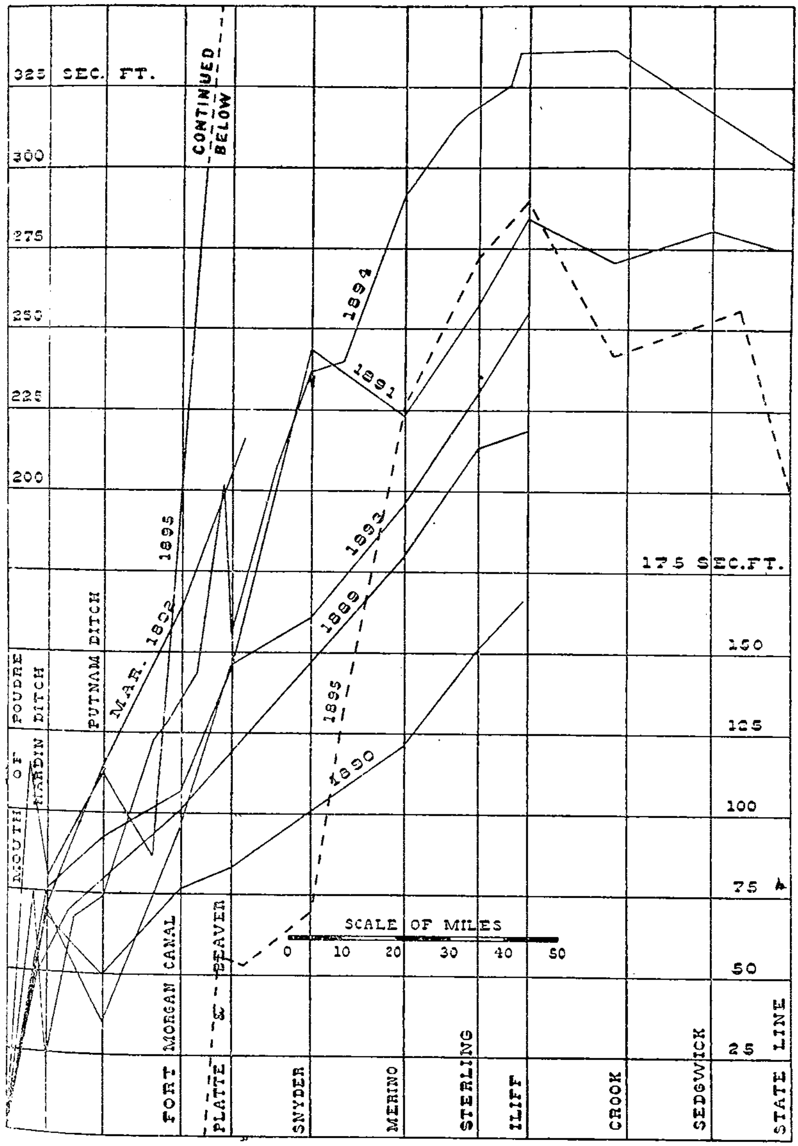


FIG. 4.—Seepage Increase of the South Platte River.

GAGINGS OF THE SOUTH PLATTE RIVER.

(In cubic feet per second.)

MEASUREMENT No. 1—Made by L. R. Hope and E. C. Hawkins, October, 1889.

Place of Measurement.	Out-take.	In-flow.	River.	Gain.	No. of Miles.	Gain per Mile.
River at head of Latham ditch	......	....	45.718	....	....	....
Cache a la Poudre river	......	14.830	......	....	....	....
River at Hoover ditch	......	....	120.136	*49.000	6.30	9.46
Hardin ditch	1.005	....	......	....	....	....
River, at head of K. and B. ditch	......	....	139.641	20.51	7.20	2.85
Small ditch (no name)	2.00	....	......	....	....	....
Putnam ditch	30.905	....	......	....	....	....
River at ——	......	....	105.769	....	....	....
Fort Morgan canal	131.932	....	......	....	....	....
River below Fort Morgan canal	......	....	3.625	30.755	19.0	1.62
Bijou creek	......	3.575	......	....	....	....
River at Deuel	......	....	8.310	1.11	12.0	0.09
Deuel and Snyder ditch	3.567	....	......	....	....	....
Platte & Beaver canal	25.023	....	......	....	....	....
Lower Beaver ditch	17.487	....	......	....	....	....
Beaver creek	......	7.000	......	....	....	....
Smith ditch	8.447	....	......	....	....	....
Tetsel ditch	2.340	....	......	....	....	....
South Platte ditch	24.106	....	......	....	....	....
Pawnee ditch	4.367	....	......	....	....	....
River at Merino	......	....	8.481	78.508	30.75	2.55
Schneider ditch	12.609	....	......	....	....	....
Springdale ditch	3.583	....	......	....	....	....
Sterling ditch No. 1	10.076	....	......	....	....	....
Low-line ditch	1.796	....	......	....	....	....
Smith and Henderson ditch	6.833	....	......	....	....	....
River at Sterling	......	....	6.378	32.794	13.75	2.39
Sterling ditch No. 2	1.946	....	......	....	....	....
Arnette ditch	8.871	....	......	....	....	....
River near Iliff	......	....	......	4.439	9.25	0.48
Total	......	....	......	217.116	....	....

* Estimated portion seepage from mouth of Poudre river to Hoover ditch.

MEASUREMENT No. 2—Made by L. R. Hope and E. C. Hawkins, October, 1890.

River above Cache a la Poudre river	......	....	98.458	....	....	....
Cache la Poudre river	......	32.729	......	....	....	....
Box Elder creek	......	23.524	......	....	....	....
Hardin ditch	10.279	....	......	....	....	....
River below Hardin ditch	......	....	213.174	68.742	8.0	8.59
Bijou canal	21.424	....	......	....	....	....
Winkle ditch	2.220	....	......	....	....	....
Putnam ditch	6.581	....	......	....	....	....
River below Putnam ditch	......	....	164.881	-18.775	12.25	—1.53
Weldon Valley ditch	31.674	....	......	....	....	....
River 4 miles below Orchard	......	....	156.403	23.196	12.25	1.89
Fort Morgan canal	114.262	....	......	....	....	....
River below Fort Morgan canal	......	....	45.931	3.79	1.5	2.53
Small gulch (no name)	......	7.421	......	....	....	....
Bijou creek (waste from Ft. M. canal)	......	2.028	......	....	....	....
Platte & Beaver canal	36.674	....	......	....	....	....
River below P. & B. canal	......	....	25.215	6.509	11.0	0.59
Platte & Beaver Supply ditch	24.155	....	......	....	....	....
Smith ditch	5.199	....	......	....	....	....

GAGINGS OF THE SOUTH PLATTE RIVER.

(In cubic feet per second.)

Measurement No. 2—(Continued).

Place of Measurement.	Out-take.	In-flow.	River.	Gain.	No. of Miles.	Gain per Mile.
River at Snyder	......	....	12.950	17.089	13.75	1.24
Tetsel ditch	4.250	....	......	....	....	....
South Platte ditch	17.661	....	......	....	....	....
Pawnee ditch	3.881	....	......	....	....	....
River ¼ mile above Merino	......	....	8.444	21.286	18.0	1.18
Schneider ditch	5.063	....	......	....	....	....
Springdale ditch	18.500	....	......	....	....	....
Smith and Henderson ditch	2.640	....	......	....	....	....
River at Sterling	......	....	11.933	29.692	13.75	2.16
Sterling No. 2 ditch	3.827	....	......	....	....	....
Arnette ditch	11.448	....	......	....	....	....
Midline ditch	7.054	....	......	....	....	....
River below Midline ditch	......	....	3.647	14.043	8.0	1.76
Totals	......	....	......	165.57	98.50	....

Measurement No. 3—Made by L. R. Hope and R. E. Trimble, October, 1891.

Place of Measurement.	Out-take.	In-flow.	River.	Gain.	No. of Miles.	Gain per Mile.
River above the Cache a la Poudre river	......	....	114.60	....	....	....
Cache a la Poudre river	......	61.11	......	....	....	....
Hoover ditch	6.40	....	......	....	....	....
Hardin ditch	1.51	....	......	....	....	....
River below Hardin ditch	......	....	244.33	75.53	8.0	9.44
Kiowa & Bijou canal	38.86	....	......	....	....	....
Putnam ditch	10.39	....	......	....	....	....
River below Putnam ditch	......	....	211.69	16.61	12.25	1.36
Weldon Valley ditch	20.93	....	......	....	....	....
Fort Morgan canal	99.35	....	......	....	....	....
River below Fort Morgan canal	......	....	106.69	15.28	13.75	1.11
Deuel & Snyder ditch	7.81	....	......	....	....	....
Platte & Beaver ditch	2.33	....	......	....	....	....
River, below Platte & Beaver ditch	......	....	134.81	38.26	11.0	3.48
Platte & Beaver Supply ditch	46.21	....	......	....	....	....
River at Snyder	......	....	186.79	98.19	13.75	7.14
Smith ditch	1.36	....	......	....	....	....
Edwards ditch	18.27	....	......	....	....	....
South Platte ditch	35.51	....	......	....	....	....
Pawnee ditch	64.70	....	......	....	....	....
River, above Merino	......	....	46.68	-20.27	18.0	-1.13
Schneider ditch	3.46	....	......	....	....	....
Springdale ditch	9.85	....	......	....	....	....
River at Sterling	......	....	66.73	33.36	13.75	2.43
Smith and Henderson ditch	6.74	....	......	....	....	....
Low-line ditch	2.12	....	......	....	....	....
Iliff & Platte Valley ditch	33.22	....	......	....	....	....
River, at Iliff	......	....	52.72	28.07	9.25	3.03
River, 2 miles above Crook	......	....	39.65	-13.07	16.50	-0.79
River, below Sedgwick	......	....	47.70	8.05	21.50	0.37
River, at Julesburg	......	....	42.96	-4.74	11.50	-0.41
Totals	......	....	......	275.27	149.25	....

GAGINGS OF THE SOUTH PLATTE RIVER.

(In cubic feet per second.)

MEASUREMENT No. 4—Made by L. R. Hope, March, 1892.

Time.	Place of Measurement.	Out-take.	In-flow.	River.	Gain.	No. of Miles.	Gain per Mile.
....	River, above Cache a la Poudre river	......	....	473.09	....	....	....
....	Cache a la Poudre river..........	......	145.56	......	....	....	....
....	River, below Hardin ½ mile........	......	....	687.73	69.08	8.5	8.13
....	Kiowa & Bijou canal..............	0.50	....	......	....	....	....
....	River, 2¾ miles below Putnam ditch	......	....	732.59	45.36	14.25	3.18
....	River, below Fort Morgan canal....	......	....	762.07	29.48	11.25	2.62
....	River, opposite Fort Morgan.......	......	....	834.72	72.65	13.5	5.38
	Totals......	......	....	......	216.57	47.50	....

MEASUREMENT No. 5—Made by P. J. Preston, October 30–November 10, 1893.

Time.	Place of Measurement.	Out-take.	In-flow.	River.	Gain.	No. of Miles.	Gain per Mile.
....	River, above the Cache a la Poudre.	......	....	124.16	....	....	....
....	Cache a la Poudre river......	......	64.11	......	....	....	....
....	River, below Hardin ditch..........	......	....	257.30	69.03	8.0	8.63
....	Choat's ditch....................	4.05	....	......	....	....	....
....	River, above Putnam ditch.........	......	....	219.52	-33.73	12.25	-2.75
....	Putnam ditch....................	12.28	....	......	....	....	....
....	Weldon Valley ditch.............	30.70	....	......	....	....	....
....	Fort Morgan canal...............	132.08	....	......	....	....	....
....	River, below Fort Morgan canal....	......	....	105.29	60.83	13.75	4.42
....	Deuel & Snyder ditch............	4.11	....	......	....	....	....
....	River, below P. & B. canal..........	......	....	151.49	50.31	11.0	4.57
....	Platte & Beaver Supply canal.....	114.12	....	......	....	....	....
....	Gill ditch.......................	0.94	....	......	....	....	....
....	River at Snyder....................	......	....	51.46	15.03	13.75	1.09
....	Smith ditch......................	8.49	....	......	....	....	....
....	Edwards ditch....................	10.20	....	......	....	....	....
....	Tetsel ditch.....................	6.94	....	......	....	....	....
....	South Platte ditch...............	44.12	....	......	....	....	....
....	Pawnee ditch.....................	11.80	....	......	....	....	....
....	River, at Merino..................	......	....	4.63	34.72	17.75	1.96
....	Schneider ditch..................	16.55	....	......	....	....	....
....	Springdale ditch.................	8.51	....	......	....	....	....
....	River, at Sterling.................	......	....	13.33	33.76	14.0	2.41
....	Smith and Henderson ditch......	11.49	....	......	....	....	....
....	Low-line ditch	6.19	....	......	....	....	....
....	Iliff & Platte Valley ditch.........	14.77	....	......	....	....	....
....	River above Iliff..................	......	....	5.72	24.84	9.25	2.69
	Totals......	......	....	......	254.79	99.75	....

MEASUREMENT No. 6—Made by P. J. Preston and R. E. Trimble, October 16–24, 1894.

Time.	Place of Measurement.	Out-take.	In-flow.	River.	Gain.	No. of Miles.	Gain per Mile.
	OCTOBER 16.						
2 p. m.	River, below Cache a la Poudre river	......	....	308.68	....	....	....
3:15	Lone Tree creek..................	......	3.01	......	....	....	....
3:50	River, below Lone Tree creek......	......	....	323.85	12.16	1.50	8.11
	OCTOBER 17.						
8:30	River, below L. T. creek, same place	......	....	345.60	....	....	....
10:30	Sterling Seepage ditch...........	6.60	....	......	....	....	....
11:15	Hoover ditch.....................	11.84	....	......	....	....	....
12:30	River, below Hoover ditch..........	......	....	389.90	62.74	3.50	17.93
2:45	Hoover ditch (waste)............	......	0.61	......	....	....	....
2:35	Box Elder creek.................	......	10.19	......	....	....	....
4:15	River, above Hardin ditch..........	......	....	349.65	-51.05	3.00	-17.02

GAGINGS OF THE SOUTH PLATTE RIVER.

(In cubic feet per second.)

MEASUREMENT No. 6—(Continued.)

Time.	Place of Measurement.	Out-take.	In-flow.	River.	Gain.	No. of Miles.	Gain per Mile.
	OCTOBER 18.						
7:45	River, above H'r'n ditch, same place	......	....	343.29	....	....	....
9:20	Hardin ditch	5.36	....	......	....	....	....
10:30	Illinois ditch	2.58	....	......	....	....	....
11:50	River, at head of Corona ditch	......	....	378.89	43.54	7.00	6.22
3:20	River, above Putnam ditch	......	....	385.87	6.98	5.25	1.33
2:45	Putnam ditch	27.90	....	......	....	....	....
	OCTOBER 19.						
8:25	Weldon Valley ditch	36.98	....	......	....	....	....
10 a. m.	River, above Kiowa creek	......	....	369.81	48.82	8.50	5.74
12:20	River, below Kiowa creek	......	....	375.07	5.26	1.75	3.01
2:15	Fort Morgan canal	170.30	....	......	....	....	....
2:55	River 3½ miles below Fort M. canal	......	....	219.00	14.23	7.0	2.03
	OCTOBER 20.						
9:15	River, above Bijou creek	......	....	278.45	59.45	5.75	10.34
11:55	Deuel & Snyder ditch	3.65	....	......	....	....	....
2:35	Platte & Beaver canal	77.28	....	......	....	....	....
12:05	River, below Bijou creek	......	....	152.09	-45.43	1.75	-25.96
3:50	Platte & Beaver Supply canal	71.90	....	......	....	....	....
4:05	River, below P. & B. Supply canal	......	....	131.54	51.35	8.00	6.42
	OCTOBER 21.						
9:10	Parson ditch	4.95	....	......	....	....	....
10:05	Smith ditch	9.06	....	......	....	....	....
10:15	River, at Snyder	......	....	142.37	24.84	5.75	4.32
1:30	River, below Big Beaver creek	......	....	149.63	7.26	5.75	1.26
5 p. m.	South Platte ditch	60.01	....	......	....	....	....
	OCTOBER 22.						
8:25	Pawnee ditch	99.55	....	......	....	....	....
9:20	River, at Merino	......	....	41.48	51.41	12.25	4.20
10:50	Schneider ditch	20.33	....	......	....	....	....
11:40	Springdale ditch	22.66	....	......	....	....	....
1:20	River, above Pawnee creek	......	....	20.80	22.31	9.00	2.48
3 p. m.	River, below Pawnee creek	......	....	24.32	3.52	1.75	2.01
4:20	Henderson and Smith ditch	2.08	....	......	....	....	....
	OCTOBER 23.						
9:45	River, above Cedar creek	......	....	30.36	8.12	10.00	0.81
11:30	Iliff & Platte Valley ditch	4.14	....	......		....	....
10:35	River, below Cedar creek	......	....	35.93	9.71	1.50	6.47
3:50	River, 2½ miles above Crook	......	....	36.07	0.14	17.25	0.01
	OCTOBER 24.						
8:20	River, at State line	......	....	1.90	-34.17	36.00	-0.95
	Totals	......	....	......	301.19	152.25	....

MEASUREMENT No. 7—Made by L. G. Carpenter and P. J. Preston to Sterling, and by P. J. Preston and R. E. Trimble from Sterling to Julesburg, October, 1895.

Place of Measurement.	Out-take.	In-flow.	River.	Gain.	No. of Miles.	Gain per Mile.
OCTOBER 21.						
Cache a la Poudre river	......	123.02	......	....	....	....
River below the Poudre	......	....	826.55	....	....	....
Lone Tree creek	......	5.24	.....	....	....	....
OCTOBER 22.						
Hoover ditch	6.07	....	......	....	....	....
River below Hoover ditch	......	....	939.95	114.23	3.50	33.0
Hoover ditch	......	4.47	......	....	....	....
Sterling Seepage ditch	......	(3.86)	......	....	....	....
Box Elder	......	0	......	....	....	....
Illinois ditch	0	....	......	....	....	....
River above Hardin ditch	......	....	909.15	-35.27	4.50	-8
Hardin ditch	6.74	....	......	....	....	....
OCTOBER 23.						
Corona ditch	10.00	....	......	....	....	....

GAGINGS OF THE SOUTH PLATTE RIVER.

(In cubic feet per second.)

MEASUREMENT No. 7—(Continued).

Place of Measurement.	Out-take.	In-flow.	River.	Gain.	No. of Miles.	Gain per Mile.
River above Putnam ditch	......	....	935.36	42.95	12.25	3.5
Lost creek	......	0	......	....	....	....
Putnam ditch	14.38	....	......	....	....	....
Kiowa creek	......	0	......	....	....	....
Weldon Valley ditch	86.85	....	......	....	....	....
OCTOBER 24.						
River at Orchard	......	....	940.73	106.60	8.25	12.92
Seepage ditch	......	(4.10)	......	....	....	....
Fort Morgan canal	208.28	....	......	....	....	....
River, at Shaffer's ford	......	....	778.37	45.92	9	5.10
OCTOBER 25.						
River, above the Bijou	......	....	861.85	83.48	5.75	14.50
Bijou creek	......	(4.84)	......	....	....	....
OCTOBER 26.						
Platte & Beaver canal	100.39	....	......	....	.....	....
Deuel & Snyder ditch	14.70	....	......	....	....	....
River, at Fort Morgan	......	....	745.21	—3.97	4.25	—0.93
Pyott ditch	15.58	....	......	....	....	....
Platte & Beaver supply	55.72	....	......	....	....	....
Smith ditch	2.88	....	......	....	....	....
River, at Snyder	......	....	685.85	14.82	11	1.35
OCTOBER 27.						
River, 5 miles below Snyder	......	....	751.23	65.38	5	13.08
Tetsel ditch	.90	....	......	....	....	....
Johnson and Edwards ditch	18.06	....	......	....	....	....
South Platte ditch	4.80	....	......	....	....	....
Pawnee ditch	129.00	....	......	....	....	....
OCTOBER 28.						
River, at Merino	......	....	691.63	93.16	13	7.17
Schnieder ditch	14.60	....	......	....	....	....
Springdale ditch	38.59	....	......	....	....	...
Sterling No 1 ditch	10.63	....	......	....	....	....
Smith and Henderson ditch	2.97	....	......	....	....	....
OCTOBER 29.						
River, at Sterling bridge	......	....	671.64	46.80	13.75	3.40
Iliff ditch	0	....	......	....	....	....
River, at Iliff	......	....	688.63	16.99	9.25	1.84
OCTOBER 30.						
Powell and Dillon ditch	3.04	....	......	....	....	....
McPhee and Mullins ditch	10.42	....	......	....	....	....
River, at Crook	......	....	626.12	-48.05	19.00	—2.53
NOVEMBER 1.						
Henry Fuller ditch	3.07	....	......	....	....	....
South Side Res. Co. ditch	2.37	....	......	....	....	....
Tom Little ditch	(2.19)	....	......	....	....	....
River, at Pole creek	......	....	633.23	14.75	24	.61
OCTOBER 31.						
River, at State line	......	....	585.60	-47.63	9.50	—5.01
Total	......	....	......	....	152.25	....

TABLE IV.

SUMMARY OF PRECEDING TABLES, SHOWING GAIN IN SEEPAGE OF SOUTH PLATTE RIVER.

(In cubic feet per second.)

	No. of Miles.	Oct. 1889.	Oct. 1890.	Oct. 1891.	Mar. 1892.	Oct. 1893.	Oct. 1894.	Oct. 1895.	Ave.
Mouth of Poudre to Hardin ditch	8	49.0	68.7	75.5	69.1	69.0	23.9	79.0	62.0
Hardin ditch to Putnam ditch	12	....	-18.8	16.6	45.4	-33.7	50.5	43.0	17.2
Putnam ditch to Fort Morgan canal	14	51.3	27.0	15.3	29.5	°60.8	°68.3	°152.5	57.8
Fort Morgan canal to P. & B. canal	11	....	6.5	38.3	*72.7	50.3	65.4	....	46.6
P. & B. canal to Snyder	14	....	17.1	98.2	....	15.0	24.8	94.3	49.9
Snyder to Merino	18	79.6	21.3	-20.3	....	34.7	58.7	158.5	55.4
Merino to Sterling	14	32.8	29.7	33.4	...	33.8	†25.8	46.8	33.7
Sterling to Iliff	9	4.4	14.0	28.1	....	24.8	17.8	17.0	17.7
Iliff to Crook	17	....	....	-13.1	....	....	0.1	-48.1	-20.3
Crook to State line	36	....	....	3.3	....	....	-34.2	-32.9	-21.3
Totals	151	217.1	165.5	275.3	216.7	254.7	301.1	510.1	298.7
Average per mile	..	2.2	1.7	1.8	1.6	2.6	2.0	3.4	2.0

*Opposite Fort Morgan. °Schaefer's Ford. † Below Pawnee.

§ 24. We also include the results of the measurements on the Upper Platte, from the canon, 22 miles above Denver, to the mouth of the Cache a la Poudre, a total distance of 74 miles. The measurements were usually made continuous with those of the Lower Platte, though here given separate. In 1895 they were made after the Lower Platte was completed. These measurements were made under direction of the various State Engineers, with the exception of the first, which was made under direction of Col. E. S. Nettleton in connection with the U. S. Irrigation Survey.

TABLE V.

SEEPAGE INCREASE OF THE UPPER SOUTH PLATTE FROM CANON.

(In cubic feet per second.)

	Distance in Miles from Canon.	Oct. 18, 1889.	Oct. 14, 1890.	Oct. 23, 1891.	Mar. 7, 1892.	Oct. 30-Nov. 1893.	Oct. 29-Nov. 4, 1894.	Nov. 1895.	Average.
To head of City ditch	6	....	8.95	27.6	26.0	18.4	49.2	19.4	24.9
" Littleton	12	59.30	18.9	83.2	73.9	50.1	84.6	80.4	64.3
" Denver	22	64.1	70.8	105.0	137.4	94.9	221.6	198.2	127.4
" Fulton ditch	28½	....	110.4	146.5	149.4	138.8	256.0	179.0	163.3
" Brighton	35½	91.6	115.8	181.8	124.5	164.6	306.0	214.1	171.6
" Elwood and Wheeler ditch	44½	133.6	191.3	228.3	145.7	220.4	342.6	272.0	219.1
" Platteville	51½	147.9	....	236.5	189.9	230.6	371.0	336.8	252.1
" above St. Vrain	56½	....	172.7	242.9	....	....	....	....	(207.8)
" Union ditch	60½	161.4	....	....	....	264.5	426.6	357.5	302.5
" Latham	68	211.5	192.8	308.8	202.7	291.7	478.4	381.1	295.3
" Cache a la Poudre river	74	260.*	232.1	335.7	226.0	329.9	501.8	438.3	332.0

*Interpolated.

The sums given in this table will be found to differ from those given in the reports of the State Engineer. In many cases the seepage collects in side channels, and runs to the river. Where there is good reason to know that it is seepage, it seems better to include this as a part of the seepage inflow of the river. The examination of numerous channels has shown that in almost all cases they are dry above the lines of the ditches. In some cases waste from irrigation and from ditches, not seepage, also reaches these channels. As a rule, along the line of the Platte, there is little wasted, especially at the time of this measurement. To eliminate the waste, the inflow from the same channel was compared in the various years, and in cases where unusually large, the excess is counted as waste. The inclusion of these lateral inflows causes an increase of the amount by about twenty feet on the average to the mouth of the Poudre.

RELATION TO AREA IRRIGATED.

§ 25. If the water returned comes from the water applied in irrigation there should be a relation between the amount of water applied and the amount returning to the river as seepage. There should also be a relation between the area irrigated and the amount of return. There are so many interfering conditions, that we cannot expect to find the relation a very close one, even had we the means to know the total area, or the total amount of water applied, with accuracy. A portion of the water applied raises the water table or the height of the water in the soil. The land newly irrigated gives no material return for several years, as most of the excess of water applied fills the subsoil. If the land is some distance from the river the element of time also enters. In the case of the Poudre river, there have been many seepage ditches constructed for the purpose of taking the seepage water before it reaches the river, and again applying it to the land. In the aggregate they use a considerable number of second-feet. The increase as shown in the tables should be increased by the amount thus used. The relation between the seepage and the area irrigated will be obscured by these and other causes. The return for any one year is not from the water applied in that or in any other one year. It is rather the result of the applications of several different years at different distances. Hence, while the amount varies from year to year, the variation from one year to another is less necessary to take into account as the strip irrigated becomes of greater width. In the case of the Poudre valley and also in the Platte, the area under irrigation has steadily increased since the first measures were made. The total amount irrigated in the Poudre valley may be considered as between 120,000 and 135,000 acres. The latter sum was used in bulletin No. 22, on the "Duty of Water."

Table VI. gives the data regarding the principal ditches in the valley, and is given in full to show the character of the land devoted to agriculture. In this table, column 3 includes the total amount of land supplied with water rights under the canals. The waste and pasture land includes much that is not irrigated, and some that is. Hence the difference, given in column 11, is really less than the area irrigated, if the figures are otherwise correct. The area shown by this table as irrigated in 1894, exceeded 116,000 acres. In the previous year it was less. The increase amounted to several thousand acres per annum, principally under the outer ditches, and at the lower end of these canals. The drainage from a portion of this area does not enter the Poudre, but instead it enters the Platte directly, and through the Lone Tree and Crow creek valleys. This seepage has amounted to probably not less than from twelve to twenty second-feet during the past few years, but is included in the seepage of the Platte and cannot be separated. But, considering that all this area is tributary to the Poudre, we have from 116,000 acres a return of 104½ cubic feet per second on the average, or one cubic foot per second from each 1,100 acres irrigated. The seepage known to be caught and stored in reservoirs is more than enough to make the return one cubic foot per second for less than 1,000 acres. In 1895 it amounted to one cubic foot per second to every 700 acres. In the case of the Platte, one cubic foot per second returns from still fewer acres.

TABLE VI.

Reference Number.	Name of Canal.	Total Acres.	Pasture and Waste Land.	Acres Alfalfa.	Grass.	Other Crops.	Wheat, Oats and Barley. No. of Bushels.	Corn, No. of Bushels.	Potatoes, No. Sacks.	Total Acres, Less Waste and Pastures.	Amount of Water Applied, 1894. Acre-feet.
(1)	(Col. 2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1	N. Poudre canal	9.074	7.081	843	795	2.430	63,626	3,775	5,687	1.993	18,306
2	Box Elder canal	1,280	1,000	50	....	100	1,200	25	200	280	.....
3	Canon	497	197	160	5	90	427	300	500	300	.....
4	Larimer Co.	27,844	11,131	4,010	....	12,847	120,838	4,075	113,795	16,713	27,830
5	Jackson ditch	3,160	991	1,131	223	453	5,246	....	350	2,169	7,984
6	Small ditches, n. side	2,054	453	786	145	886	4,542	100	2,770	2.101	....
7	Larimer & Weld.....	59,507	15,123	7.428	878	32.184	390,601	6.702	554,303	44,384	77,225
8	Pleasant Valley & L.	8,221	3,110	1,750	470	2,234	19,746	1,972	3,655	5,111	17,387
9	New Mercer	4,256	1,867	1,664	174	1,020	48,015	2,032	13,448	2,389	11,110
10	Larimer Co. No. 2..	8,623	985	2,751	61	2,680	56,191	280	10,389	7,638	18,545
11	Fort Collins.........	1,179	374	492	45	387	1,944	65	860	805	.....
12	Box Elder	1.735	1,028	270	144	351	3,178	95	3,184	707	.....
13	Watrous, W. and S..	120	75	20	....	25	......	....	600	45	.....
14	Ames, P. and C. d's.	1,468	1,303	409	295	646	17,036	1,755	11,070	165	.....
15	Lake	6,242	2,076	1,007	156	1,762	36,698	3,855	23,280	4,166	11,262
16	Cache a la P. No.2..	33,173	11,128	5,032	704	15,065	236,689	3,670	602,485	22,045	70,610
17	Whitney	2,080	683	358	55	652	10,461	100	17,500	1,397	.....
18	Eaton and Jones....	360	149	75	119	135	1.900	250	2,240	211	.....
19	No. 3	1,275	480	147	103	517	3,015	....	14,652	795	.....
20	Boyd and Freeman..	900	158	90	350	300	3,150	300	7.000	742	.....
21	Ogilvy	3,800	1,728	720	....	1,357	20,755	....	29,660	2,072	.....
	Totals	176,848	61,120	29,193	4,722	76,119	1,045,258	29,351	1,417.628	116,228	260,259

§ 26. The foregoing table shows the distribution of the irrigated land, and of the water applied in the valley, according to the canals. The record is taken from the figures obtained by Water Commissioner Tenney in 1894, and include the first complete data for the entire valley. The data gives nearly the relative quantities, and is far better than other records available. Some of the figures will be referred to later.

§ 27. On the Lower Platte the extent of the irrigated area is not so well known as on the Poudre. This portion of the valley includes two districts—Water District No. 1, from the mouth of the Poudre to the east line of Morgan county, just below the head of the Tetsel ditch, and No. 64, from that point to the State line. In the report of the Commissioner for district No. 1, for 1890, the total amount irrigated is given as less than 11,000 acress. In 1892 it is given as 43,730 acres. This latter is probably excessive. The amount is reported in 1895 as practically the same, distributed among the ditches as follows:

	Acres.
The Hardin ditch	525
The Hoover and Illinois ditches	720
The Putnam ditch	1,875
The Weldon Valley	6,250
The Fort Morgan	12,600
The Platte & Beaver	14,080
The Platte & Beaver Supply	9,500
Deuel & Snyder	1,000

In district 64, through the courtesy of Mr. Patterson, the Water Commissioner for that district, we are given the following approximations:

	Acres.
South Platte ditch	3,500
The Pawnee	4,700
Schneider	2,600
Sterling Irrigation Co.	4,400
Henderson and Smith	1,275
Sterling No. 2	1,800
Low Line	1,900
Springdale	3,200
Powell and Dillon	930
Iliff & Platte Valley	5,000
Small ditches	6,000
Or a total of	35,000

This makes a total acreage for the valley of about 75,000 to 80,000 acres. With an average inflow of 340 cubic feet per second from the mouth of the Poudre river to Iliff, this is an inflow of one cubic foot per second from 220 to 240 acres irrigated. This is far more than in the case of the Cache a la Poudre. It is to be noticed that in the case of the Platte, a relatively large proportion of the irrigation is given to the bottom lands, which are used for hay. The principal exceptions are in the vicinity of Fort Morgan and Sterling. The river overflows the bottoms many years, and did so in 1893, 1894 and 1895, and soaks them with water sometimes for a considerable period. More water is applied in the bottom irrigation than in the uplands. The practice of fall irrigation is very extensively followed. The river then having sufficient water, all the lands with few exceptions are soaked. We do not have measurements to show how much water is thus applied, but from what I observed, and from the conditions, the watering seems to be relatively a very profuse one. This land receives more water than an equal area on the Poudre, and is, as a whole, much closer to the river. These conditions tend to give a more profuse and a speedier return to the Platte.

On the Upper Platte, the conditions have not been under observation, and the areas are not well known. The seepage of fully half a million acres drains into this portion of the Platte and the tributaries which flow into it. In the cases of the latter, the construction of numerous seepage ditches have interfered with the natural flow of the water, so that the amount which reaches the river is much less than the total amount of seepage. A portion of the land irrigated from these lateral streams drains directly into the Platte. This is especially the case with Clear creek. According to the reports of the Superintendent of Irrigation of this division to the State Engineer, there have been, using round numbers, 58,000 acres irrigated in district No. 2, including the Platte from Denver to the mouth of the Poudre; 39,500 in district 8, which includes the Platte from Denver to the canon. This is a total of 98,000 acres irrigated directly from the Platte. In addition to this there are about 45,400 acres draining into the Platte which are irrigated from Bear creek, Clear creek, St. Vrain and Big Thompson, making a total of 143,000 acres lying along the Platte and tributary thereto. This sum is rather above than below the truth. Comparing with the total inflow, we have an average return of 332 cubic feet per second from 143,000 acres, or one cubic foot per second from 430 acres.

During the first four measurements the average return was 264 second-feet, and during the last three, 423 second-feet. The latter is at the rate of one second-foot for each 238 acres. It is certain that many acres of the land in this valley returns but little water to the stream. Whether the rate of increase noted in the table from year to year will continue, further measurements are necessary to determine.

RELATION BETWEEN SEEPAGE AND AMOUNT OF WATER APPLIED.

§ 29. An attempt was made to determine the amount of land the drainage of which enters each of the lateral channels and enters the river between the points of measurement, thinking that this might explain some of the exceptional gains. But still better is the amount of water which is applied, if it can be known. A manuscript map was prepared, showing the location of the water rights in the principal canals. A water right usually includes the right to the water for 80 acres. From this map a table was prepared, showing the number of rights draining into the river between the different points of measurement. From the amount of water used by the different ditches during the year, as shown in Table VI., this could be expressed in acre-feet of water, or in the number of acres which would be covered by the water one foot in depth. The inflow can not be expected to be very closely proportional to the area irrigated or the amount of water applied between these points, or not until after a series of years. The return is slow, and there is reason to think that the seepage from some of the outer ditches has not yet reached the river. The construction of seepage ditches, to drain the seepage water from the water-logged land, or to catch the seepage water, also interferes with the normal distribution. They collect and carry the water sometimes a number of miles from where it appears. The effect of the seepage ditches is to increase the apparent return near the lower end of the stream. The amount of water lost from the canals is much more than from an equal area of irrigated land. An area of one acre forming part of a canal channel loses as much water as 200 to 400 acres of land under ordinary irrigation. The losses near the heads of the canals, especially those near the mountains, is greater than the average. An estimate of the number of acres of canals would be desirable before the study can be completely satisfactory.

From Table VI., we find 260,000 acre-feet of water is applied to 106,000 acres. This includes loss and waste from the canals, and is equivalent to a depth of 2.45 feet over the entire area irrigated. If this depth were applied by the smaller canals too, we have 284,000 acre-feet applied in the whole valley.

As a rule, the smaller canals have earlier appropriations from the river, and therefore use water more freely; hence it is safe to assume that at least 284,000 acre-feet of water have been applied to the irrigated area. The amount of water which is applied is affected by the stage of water in the river. When the river is high the canals are full, water is unstinted. If low, the amount used is decreased. In this case the ditches of later construction are the first to suffer. The development of storage reservoirs has increased the amount applied late in the season, especially since 1892. At present the reservoirs already in use in the valley of the Cache a la Poudre have a storage capacity of about 48,000 acre-feet. Of the 284,000 acre-feet applied to the whole valley, about 35,000 acre-feet is applied so that it drains into the channels running into the Platte. Deducting this, as it does not affect the inflow into the Poudre, we then have an inflow reaching the Poudre of 104 cubic feet per second, from an application of 250,000 acre-feet, or a constant flow of one cubic foot per second from each 2,400 acre-feet applied. The amount is actually greater than 104 second-feet, because of the amount, at present unknown, which is caught by the seepage ditches. As one cubic foot per second corresponds to 724 acre-feet in the course of a year, there is a seepage return of 724 acre-feet from 2,400 acre-feet of water taken from the river. If the seepage from the outer canals has not yet reached the river, then an actual application of much less than the 2,400 acre-feet gives the observed return. What the exact proportion is cannot be determined in this valley for some years to come, after all the land irrigated furnishes its portion of the seepage to the stream.

§ 30. Bringing together the amount of increase in different parts of the Cache a la Poudre and the area of irrigated land which drains into the same section, we have Table VII. In the third column is given the amount of water applied to that portion of the valley whose natural drainage is into the river between the points indicated in the first column In the fourth column is given the per cent. of the total amount applied to the whole valley. In the column headed "Computed inflow" is given the amount of inflow there would be if the inflow were in exact proportion to the amount of water applied. How much land will furnish underflow to a given part of the river cannot be very closely told, even with detailed knowledge of the topography and the location of the farms where water is applied. The course of the underground drainage can be told in most cases, until the river bottom is reached. Thence the channels often end in sloughs, and sometimes follow old river channels, or the water is collected in seepage ditches, which carry it sometimes for considerable distances. From our present maps the limit of the drainage areas cannot be told with sufficient accuracy to make the areas and the amount of water applied, given in the third column, anything but an approximation. The table shows, however, that the relation is close enough to be more than accidental, and in future years, when the influence of the outer area begins to be felt, may be expected to be closer.

It shows that there is a reason for the large amount of increase observed in the last few miles of the Poudre, before it empties into the Platte.

In the case of the increase from the No. 2 canal to the Pump house, and from the Pump house to the Ogilvy ditch, it may be stated that a portion of the drainage above the Pump house enters the bottoms above that place, and does not enter the river until below that point. While the water applied is counted in the section above the Pump house, the seepage is included in the section below. It has not been possible to estimate this, and it is therefore noted as a disturbing condition. Likewise, some of the seepage which should enter the next section between the Pump house and the Ogilvy ditch, enters the river lower down.

TABLE VII.

	Distance in Miles.	Water Applied.		Average Inflow from Seepage.			
		Acre-feet.	Per Cent. of Total.	No. Years Observation.	Observed.	Computed.	Observed gain per Mile.
Canon to L. & W. canal	7.25	18,400	7	9	15	8	2
L. & W. to No. 2 canal	10.10	51,800	21	9	21	21.6	2
No. 2 to Eaton canal	3.0	37,000	15	..	....	....	....
Eaton to No. 3	9.0	30,300	12	..	....	....	....
No. 3 to Pump house, Greeley	3.0	46,700	18	..	....	....	....
No. 2 to Pump house, Greeley	15.0	114,000	45	7	28.6	48	2
Pump house to Ogilvy ditch	2.5	23,100	9	8	19.2	10	8
No. 2 to Ogilvy ditch	17.5	137,100	55	9	45.2	57	2.5
Ogilvy to mouth of Poudre	4.0	42,700	17	8	23.8	18	6
Beyond mouth of Poudre	....	38,000	..	..	....	....	....

THE EFFECT OF TEMPERATURE ON THE INFLOW.

§ 31. The effect which temperature might have upon the amount of inflow was not considered of any importance until the unexplained differences caused a consideration to be given to its possible effect. It is known that low temperatures increase the viscosity of water. The effect is especially noticeable in the flow through small tubes, so much so that five times as much water will pass through a capillary tube at 200° as at 32° F. The effect has been noticed on the amount collected by drains, and in varying the discharge in cases like those of the gathering pipes of the Denver Water Co., in the bed of Cherry creek. A comparison between the soil temperatures at the Colorado Agricultural College and the inflow into these gathering galleries has been made in bulletin 38 of the Utah Experiment Station. As our measurements of the seepage were nearly all taken in the same month, it was not thought that the difference of temperature would be sufficient to affect the quantity of flow. But it may have a much greater effect than was at first thought probable. The water-carrying stratum lies at different depths, and is of different thicknesses. Its temperature therefore varies. Besides, the descending water carries down the temperature of the surface to some extent. Still, the indications of the soil thermometers may be taken to show the variations in the temperature of the seepage water at the time of gaging, and hence give the means of estimating the effect of temperature.

The readings of the soil thermometers will not be far from the temperatures of the soil at the corresponding depths throughout the Cache a la Poudre and the Platte valleys. There are three sets of thermometers: One in well-drained irrigated soil; one in low, undrained irrigated soil, the water standing within six feet of the surface; and one in well-drained unirrigated soil. At a depth of six feet the variation during the year is from 20° to 24°, being least in the low ground. At three feet in depth the range is 32°. At six feet the highest temperature of the year is reached early in September, the lowest early in March. Its temperature thus lags six or eight weeks behind the temperature of the surface. At three inches depth the annual range is about 70°. With the range of temperature at the depth of six feet, other conditions remaining the same, one-third more water would flow in August than in March, and at a depth of three feet, nearly one-half more.

But as the gagings of the different years were made at almost the same time, the difference in temperature is comparatively small, and the effect in different years for the same month will be less marked. Nevertheless it is not insignificant.

The table shows the average temperature at three and six feet depth during the time of the gagings of the Poudre river, and the amount of inflow found is shown in the fourth column.

Had the temperature been uniformly 60° instead of that observed, the amount of seepage would have been that given in the last column. This is under the supposition that the temperatures at three and six feet in depth from the surface will be the most influential. The correction is obtained by determining graphically the co-efficients of viscosity from the co-efficients, at 32°, 50°, 68°, etc.†

TABLE VIII.

TEMPERATURE OF SOIL AT 3 AND 6 FEET BELOW SURFACE, AND ITS EFFECT ON SEEPAGE.

YEAR.	Thermometers. Set A.	Thermometers. Set B.	Am't of Seepage in Poudre River.	Am't Corrected for Temperature of 60°.	
Oct., 1889	57.8	59.4	99.0	101	Set A in dry, well-drained irrigated soil.
Oct., 1890.....	58.7	56.2	100.8	104.8	Set B in low ground," water standing within six feet of the surface.
Oct., 1891.....	55.7	54.9	84.6	90.4	
Mar., 1892.....	38.9	40.0	*96.	122.0	
Oct., 1892.....	60.4	59.9	101.6	101.4	
Nov., 1893.....	51.5	53.4	98.7	108.6	
Mar., 1894.....	36.2	37.9	82.3	107.2	
Aug., 1894.....	64.3	62.5	118.2	113.5	
Oct., 1895.....	52.2	52.3	164.4	187.4	

* To Ogilvy ditch.

The amount of return throughout the year is sensibly the same, the principal disagreement being the one for March, 1892, when the gain in less than the full distance would have been 122 second-

† Daniell's Physics, p. 306.

feet, and in 1895, when the gain was much greater than in previous years. The large gain corresponding to March, 1892, is probably due to the fact that this measurement was taken immediately following a storm, which had covered the ground with snow, and, slowly thawing, had filled the surface of the soil. Such a case as has been shown by King, makes its influence felt at once on the underground water, even though the intermediate space be dry. The return for 1891 is less than the average amount. There is a doubt concerning that gaging. The measurements of the lower part of the stream from the Pump house, at Greeley, to the mouth of the Poudre, were made by Messrs Hope and Trimble, who continued down the Platte, while the upper ones were made by other parties. The results of the lower party were taken and compared with those of the upper. It is possible that the interval of one day, or the use of different meters, may have had some effect.

There is a sensible increase after allowing for the effects of temperature.

RAPIDITY OF FLOW OF SEEPAGE OR UNDERFLOW WATER.

§ 32. Inquiries for information regarding the movement of underground waters is so frequent, that though it was not intended to say anything on the subject in this bulletin, it is desirable to give a brief statement of the facts as they appear to be.

Direct evidence of the speed with which water passes through any considerable distance underground is almost entirely wanting. Attention has been awake to evidence bearing upon the question, but in the course of extensive travels over much country for some years almost none has been encountered. Cases where lands have been seeped subsequent to the construction of a ditch have been sought, but most cases have been complicated by other conditions, which make the answer anything but conclusive. Subsequent experience has also led to the conclusion that the appearance of seepage may give very unreliable testimony. For example, on the grounds of the Colorado Agricultural College a well was sunk about 200 feet from a canal and about ten feet lower. In the course of some measurements on the well, it was found that whenever water was turned in the ditch the water began to rise in the well within twelve hours. There is every reason to doubt that water passed that distance in that time. The case is similar to that where water is turned in a hose. If the hose is already full of water, water immediately begins to run from the lower end. If the hose is empty, some time will be required to fill the hose before the water begins to run. If already full, the pressure is transmitted in very short time, and the increase which is seen very often in the flow of seepage when water appears in a neighboring canal may be due to the transmitted pressure, rather than to the direct passage of water.

Where there is a periodical change in the head supplying the water, as in the case of the canals, there may be a series of underground waves affecting the height of the ground water. The rise and fall of such a wave, which started years before, may be mistaken for the rise and fall due to the periodical rise in the canal.

Thus the case of the Natron ponds, which rise in March, and are located thirty-five miles from the Nile, and which Storer (*Agriculture,* 1:56) attributes to the rise of the Nile of the previous September, is probably such a case.

§ 33. The best case met with was near Montrose. A deep gulch starts in the mesa below the Montrose canal. Passing across this depression the glistening in the moonlight of the alkaline deposit on the shale at the bottom attracted my attention, and on inquiry it was learned that this began to show slightly two years after the canal was used, and in considerable quantity in three years. The distance from the canal is three miles. This would make the speed about one mile per year.

§ 34. Direct experiment on the rapidity under field conditions have been unsatisfactory or inconclusive. Col. E. S. Nettleton, as Chief Engineer of the U. S. Irrigation Investigation for the Department of Agriculture, aided by W. W. Follett, attempted to determine the rapidity in the sands of Cherry creek, and on the Rio Grande, but with inconclusive results, except to come to the conclusion that the velocity was very slow. *

In the sands of the Fountaine qui Bouille, Mr. D. C. Henny concluded that the water had a velocity of about seven feet per hour. † The method of arriving at this determination is not given. From other evidence it would seem to be excessive.

Water Commissioner J. T. Hurley, of Orchard, reports that under the Weldon Valley canal the seepage has progressed one and one-half miles in five years. In one case under the Larimer County canal, according to Mr. N. C. Alford, it was five years before seepage showed at a distance of forty rods from the canal, though the slope was considerable. In one case near Greeley, according to Mr. S. A. Bradfield, it seems to have taken about ten years to go two and one-half miles.

§ 35. The rate is certainly slow, and observers throughout the State whose attention has been called to it now agree upon its small progress. A few years ago most of them believed in a rapid flow, as still do most of the adherents in the belief that there is a great "underflow" under the plains.

Comparison with familiar facts would lead one to expect slow progress. The water in passing through sand and gravel must

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* Final report Artesian and Underflow Investigation ; Pt. 2, p. 34.

† Quoted by J. D. Schuyler, report as consulting engineer to the Pueblo Gravity Water Co.

pass through small openings, which form a series of minute, tortuous and long tubes. It is a fact of common observation that the pressure of water is much reduced by attaching a short length of hose or pipe. In the case of flow through sands, the openings are many times smaller, and the length may be very great, hence no matter how great the fall, the effect of the pressure is throttled by the friction.

§ 36. In the lack of direct field evidence, we need to resort to laboratory experiments. An accomplished French engineer in investigating the water supply for the city of Dijon, experimented upon the flow through sand. He used a cast iron tube twelve feet long and twelve inches in diameter filled with sand, measuring the amount of water which passed through under different heads, and determined the relation between the pressure and the velocity. *

§ 37. From the experiments of Darcy developed by Dupuit †, it is found in minute channels the velocity varies directly as the head, and may be expressed by the equation,

$$v = k\,i$$

in which v represents the velocity, i the inclination (being the head or fall in a given distance divided by the distance), and k a factor which varies with the kind of soil, size of interstices, etc. This factor varies widely in different soils. It can be determined by experiment in specific soils, and the results there obtained applied to others of similar character.

Table IX. is an attempt to put into tabular form, which will be practically useful, the value of the factor k for different cases. The table gives the factor by which the rate of inclination or grade (expressed by the fall in feet divided by the distance in feet) is to be multiplied to give the velocity in feet for the unit of time given in the corresponding column. The table is made from data obtained from the filters of London, Paris and Berlin, through Professor Nazzini, of Rome. ||

§ 38. Since water is more viscous at low temperature than at high, the formula given in § 37 should evidently include a factor depending upon the temperature. From the experiments of Poiseulle ‡ this factor would be $1 + .00187\,(t - 32°) + .00007\,(t - 32°)$ for any other temperature than freezing.

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* Darcy, Les eaux publiques de la ville de Dijon.

† Traite de la conduite et de la distribution des eaux. Darcy and Dupuit I have not had the opportunity to consult at first hand.

|| Idraulica pratica, 1:608.

‡ Recherches experimentales sur le mouvement des liquides dans les tubes de tres petite diametre. Quoted, Jamin et Bouty, Physique, tome 1, pt. 2, p. 100 ; also see Daniell's Physics, p. 308.

TABLE IX.

TABLE FOR VELOCITY OF FLOW THROUGH PERMEABLE SOILS.

Values of k in formula, $v=k\,i$, for different units of time: v is velocity in feet; i is the inclination or fall in feet per foot.

Kind of Material.	Size Grains, in Inches.	Voids, Proportion of.	Velocity.			
			Per Second.	Per Hour.	Per Day.	Per Year.
Minute Gravel	.08	0.41	.024	86.47	2075	757520
Coarse Sand	....	0.38	.0026	9.33	224	81730
Fine Sand	.008	0.35	.00047	1.69	40.5	14777
Sandy Soil	....	0.30	.00022	.79	18.9	6897
Sandy Clay	....	0.25	.00012	.42	10.2	3725
Clay	....	0.20	.00003	.12	2.8	1035
	....	....	.00008	.295	7.1	2587

EXAMPLE.—What distance will water pass through coarse sand in a year, inclination about 1 in 100?

Here $i=1\text{-}100$. If the sand averages 1-10 inch diameter, without finer particles, it would approach what is here designated as minute gravel. In one year the distance would be the number 757,520 multiplied by the inclination, 1-100, giving a distance of 7,575 feet, or about one mile and a half. If in coarse sand, as here termed, a distance of about 800 feet.

If the movement is downward, then i is 1. If there is a head in addition, then i may be greater than 1.

§ 39. An opportunity to measure the loss by seepage from a canal, and, indirectly, the rapidity of passage of water through the soil, occurred at the time of making the seepage measurements. The Fort Morgan canal is of considerable size. It was measured about three miles below the headgate. Another measurement was made at a point 7.4 miles from the first, at the head of the old flume across Bijou creek. Two small laterals between were withdrawing water. This was measured and taken into account. For much of the distance the canal skirts the bluffs between the bottoms and the up-lands. For part of the way the soil is very sandy. At the first point of measurement the canal was carrying 208.28 second-feet; at the second point, 183.83 second-feet. The intermediate laterals withdrew 4.37 second-feet. Hence the loss, including seepage and evaporation, amounted to 20.08 second-feet. The evaporation from the surface, averaging forty-five feet wide, under the conditions of temperature of water and air cannot exceed one-fourth of one cubic foot per second, by use of formula in annual report of 1891.*

Practically, therefore, the whole loss is seepage. This stretch of the canal has not been cleaned for some years, except that in

* Annual report, Section Meteorology and Irrigation Engineering, Report Colorado Experiment Station, 1891, p. 51.

1895 some material was taken from the bed of the canal to strengthen the banks.

§ 40. A new section had been built on the same canal to avoid a long flume on the old line. Water had been running in the new portion for three weeks at the time it was visited. The total length of the new portion is 10,100 feet, including 400 feet of flume. A measurement was made of the water of this section, both at the upper and lower ends. Some water was running through the old flume. The amount decreased from 109.15 second-feet, to 97.67 second-feet, in passing through the new channel, or there was a loss of 11.48 second-feet. The new flume was so nearly water tight that its leakage may be neglected.

§ 41. In these two cases we may estimate the rapidity of the flow of water through the soil. In the first case, the loss of twenty feet took place in a distance of 7.4 miles. The average width of the channel was 45 feet, hence the area of the canal in this distance was nearly forty-one acres. The loss corresponds to a layer of water of 11.7 inches deep in twenty-four hours. As the water occupies a space of about one-third of the sand, its velocity through the sand is three feet per day. It is unquestionably true that the loss takes place at unequal rates in different portions of this stretch, so that this rate, as in those which follow, is an average one for the section considered.

In the second case, the loss was 11.48 second-feet in a distance of 9,700 feet of channel. The average width was forty feet, giving an area of nine acres covered by the water. This corresponds to the loss of a layer of water 2.53 feet deep over the whole area of the canal. For half of this distance the canal extends along the sand bluffs which line the west side of Bijou creek, and is from thirty to ten feet above the channel of the creek. It is in a compact material, some of which needed to be blasted in constructing the channel. On the east side of the creek, it passes through a loose sandy soil, which slopes about one per cent. toward the creek. From evidence since obtained from the canal superintendent, Mr. Dingman, it seems probable that the loss from the west side is small or is insensible. A hole bored under the channel, and within a few inches of the water, was perfectly dry. If the loss is from the east side only, the rate must by twice as great as if from both sides, or would correspond to a layer five feet in depth per day over this portion of the canal. This would correspond to a velocity through the sand of about fifteen feet per day.

§ 42. On the Hoover ditch, running at the base of sandy bluffs, but with the bottom of the ditch covered with a fine silt, the loss in a distance of 1,500 feet was at the rate of 1.2 feet in depth for twenty-four hours, or a velocity of 3.6 feet per day through the sand.

§ 43. On the Muzza canal, in Italy, the loss is equivalent to a layer 1.7 feet deep per 24 hours. The canal runs through an exceedingly pervious soil, and has a great fall.

The Naviglio Grande, of Italy, loses a layer of water ten inches deep. The Canale Martesana, a layer 1.5 feet deep daily. The three canals above mentioned have been built for some 700 years.

The Centreville and Kingsburg canal, in California, from data given by C. E. Grunsky, of San Francisco, loses an average of five feet in depth, for six miles, in twenty-four hours. In one particular mile, where the loss is excessive, because of porous soil as well as from the location of the canal, near the edge of a bluff, the daily loss amounts to a layer fifteen feet in depth. This is an extreme case.* Another case of a great loss occurred in the Cavour canal, of Italy, at the crossing of the Dora river. This was by an artificial embankment. At first the loss amounted to a layer nearly twenty feet in depth. This was afterward very much reduced by using muddy water and allowing the silt to settle, and fill and cover the surface.

If we consider that in each of these cases the water occupies one-third of the volume of the sand, the distance it flows in twenty-four hours would be three times the thickness of the layers noted above, or from 2.5 feet on the Naviglio Grande to 60 feet in the Cavour instance.

It may be said, in passing, that the amount of loss from the canals may be much reduced by the settlement of fine clay or sediment. In one case, in the Cache a la Poudre Canal No. 2, where the seepage had made a considerable area so wet as to be impassable with teams, a check built for other purposes, by causing the deposition of silt, was sufficient in a few years to lessen the seepage so that the land became passable.

Another instance, illustrating the same effect, was shown in a canal near Greeley. When first built, considerable damage was done from the raising of the ground water and flooding cellars in some parts of town. After a few years the cause of complaint disappeared, silt sealing the bottom of the canal. In 1895 sand was obtained from the bottom of the ditch, where the ditch crossed a ravine, and where there was a good deposit of sand suitable for building purposes. The top layers of the sand were partially cemented. Within a few months after water was turned in complaint arose regarding the influx of water into the cellars. Ten days after the water was turned out of the canal, the water began to

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*Since the above was in type, additional data, obtained through the courtesy of Mr. Grunsky, indicate losses of depths of 1.5, 1.7, and .6 feet, from stretches of the Kings River and Fresno canal; of 2.8, .25, and .4 from portions of the Fresno canal, and 1.2, 1.9, 3, 7 and 6.4 feet from certain laterals, the velocity through the soil being about three times as great.

go down in the cellars, falling about six inches in three weeks, and eighteen inches in a little over two months. A measurement of the amount of water in the ditch was made October 16, at the time of gaging the river, both above and below the point where the great loss was suspected. The quantity in the canal decreased from 25.86 cubic feet per second above the place, to 20.80 a little distance below, or a loss of 5.06 cubic feet per second. The total distance between the two measurements was forty-six rods. The total area of water surface was not noted, but with the increased breadth of the canal at the ravine crossing it is about one-half an acre. This would be equivalent to a depth of twenty feet, over the area wetted by the canal, in twenty-four hours.

SOURCE OF THE INCREASE.

§ 44. Whether the water forming this increase to the streams comes from the rainfall or from the waters applied in irrigation, is important to determine if possible. From the nature of the case, it is not possible to indentify the water, but a comparison of the increase between different regions of greater or less irrigation gives some basis for a conclusion. If the increase is partially or wholly from irrigation, it follows that the inflow will increase from year to year, as the amount of irrigation increases; that the lower reaches of streams will have a more regular supply; that the increase will show itself farther down stream, making it possible to gradually bring more land under cultivation; that many of the dry streams will become living ones; and that the damage which riparian owners in this and other States have claimed to be done by irrigation on the upper portions of the rivers will become less as time proceeds. If the inflow comes from and is due to the rainfall, then we cannot look for benefits of this kind, and those on the lower reaches cannot hope for a future lessening of the damages.

§ 45. Such gradual increase of the streams is common in countries with considerable rainfall, but the size of the streams and the invisibility of the small sources serve to mask it. The lack of measurements prevents the fact from being noticed. The rainfall in Colorado averages less than fourteen inches per annum. With this amount of rainfall, or with the rainfall of exceptional years, would there be any return to the stream without irrigation?

§ 46. There was no observation of the phenomenon before irrigation was practiced. But neither was there settlement. Irrigation was practiced for some years on the bottom lands before the use of water was sufficient to dry the stream bed, and thus make it possible to notice a small inflow, either by its effect on the volume of the stream, or by exposing the points of inflow. If there was any such inflow, it certainly was not sufficient to prevent the Platte from going dry in 1863 and other years. At the time of the first measurement of the Poudre by Col. Nettleton, in 1887, the increase amounted to eighty-seven cubic feet per second.

§ 47. Where there is abundant rainfall, there is no question but that it furnishes a supply to the streams through underground passages, with effects similar to those noticed in the measurements of these streams. The amount which thus percolates through the ground is the portion of rainfall remaining after the run-off and the evaporation have been supplied. We have no direct observations under our conditions to determine positively how much, if any, of the rainfall remains to supply the underground water of the soil. Lawes & Gilbert, of Rothamstead, have maintained a series of drainage gages for a number of years. In the twenty-two years, from 1871 to 1892, fifteen to sixteen inches of the rainfall passed through forty to sixty inches of soil, and joined the subsoil water. This would be available for springs, and doubtless largely increased the volume of the streams draining the country. This was out of a total rainfall averaging 29.95 inches. Hence it follows that some thirteen inches in the humid atmosphere of England was required for evaporation from the surface of the soil, which was left uncropped and free from vegetation.

§ 48. With a smaller rainfall, it is not probable that the evaporation would be less. The greater dryness of our climate, the greater amount and intensity of the sunshine, which heats the surface of the soil intensely, are conditions which favor evaporation. The uniform dry condition of the soil shows that there is none too much for the evaporation alone. Our average rainfall is but little more than the amount which was evaporated from the soil in England, and some of this runs directly to the streams. It does not seem probable that there can be any left for percolation into the subsoil, except under unusual circumstances. In 1895, when eighteen inches of rain fell, not much more than usual was available for evaporation and percolation, since with the heavier showers a larger proportion runs off.

That the inflow comes almost entirely from irrigation is shown indirectly by the well-known effect of irrigation upon the height of water in the ground. Before irrigation, the distance to water is generally great, and the quantity frequently scanty. The application of water in large quantities to the surface, as in irrigation, fills the subsoil when porous, and raises the level of the ground water as much as forty to sixty feet in some cases. This establishes a steeper grade to the surface of the water in the soil, and gives the conditions which causes the water to pass through the ground with greater rapidity, and also with larger cross-section, thus increasing the amount of flow from both causes. The great distance to the ground water before irrigation, the scanty supply, the low grade of its surface, would in itself show that the amount received from the natural rainfall is small, and if this furnishes any inflow at all to the streams, it must be but a small proportion of the amount at present furnished under the conditions introduced by irrigation.

§ 49. From the mountain water-shed of the Poudre river our observations show that from four to six inches of water runs off from the whole area during the course of the year.* From the plains included in the measurements reliable observations are lacking. From the curve shown, by F. H. Newell, in the report of the U. S. Geological Survey for 1892-3, the amount of run-off may be estimated as from two to four inches. The amount varies with the soil, the slope of the ground, and the character of the rainfall.

When the precipitation is in slight showers, nearly all the rainfall evaporates within a short time, without penetrating more than the surface of the soil. It requires a heavy rain to saturate more than the surface, and furnish some water for percolation. In the ordinary condition, a rainfall of two inches will penetrate not over ten or twelve inches. Heavier rainfalls within a short time are needed before there can be any percolation from the rain. On beds of pure sand most of the water immediately soaks in, and very little is lost either by evaporation or by run-off, hence it is that water is generally found at moderate distances from the surface in the sand hills. There have been but twenty-two months in eleven years of observation at Fort Collins in which the total rainfall in one month has exceeded two inches, and in only eleven cases has as much as this fallen in one week. If the rain falls rapidly a larger proportion runs off than when there is time to soak into the ground. The case most favorable to percolation which our records show is in 1895, when two rainfalls, each of 2.5 inches, followed each other with only a few days interval. The first one nearly all soaked into the ground. The second fell on a ground already saturated and nearly all ran off, causing unusually high water in the streams in consequence. There are only one or two other cases in which as much as three inches fell within a few days. But even here, the most favorable of the cases, if the ground is dry, which is its ordinary condition, there cannot be much percolation, and it is very doubtful if there is any.

If, however, the ground is already wet, as may be the case with the lands which have been irrigated, and the surface is loose and porous so as to absorb the rain as it falls, as is the case with cultivated lands, there is reason to expect that the rain will cause an increase in the underground flow. The rainfall alone, without the irrigation, would not cause it, and it is a consequence of the artificial conditions introduced by irrigation, and may properly be considered as due to irrigation. A portion of the unusual increase

*Annual reports, 1890, 1891, etc.

found in 1895 is probably due to this cause. The inflow for 1895 was sixty second-feet more than the average. The rainfall was over four inches more than the average. Yet the extra sixty feet throughout the year would be given by a depth of one inch over 40,000 acres. If this comes from the rainfall, we must conclude that but very little of the extra rainfall was effective. As irrigation water is applied more freely because the supply in the river is greater, it seems more probable that the larger amount is due rather to the more water used than directly to the greater rainfall, though at present the effects cannot be entirely separated.

§ 50. Direct evidence bearing on the question was sought in the Platte measurement of 1894, but with negative results. If there be any substantial increase from such source, then the channels which conduct the drainage from a large area should show some indications of it. There are a number of such channels leading into the Platte, each of which drains over 1,000 square miles. This is more than the mountain water-shed of the Poudre river above its exit from the mountains. As the surface of the rock or impermeable surface has the same undulations as the surface of the ground, the underground drainage must follow essentially the same lines of drainage as the surface. This is shown plainly in the excellent sections taken at various points across the plains by Col. Nettleton and Mr. Follett.* One of these sections was across the valley of the Platte at Sterling.

The streams following these drainage lines, while permanent near their upper ends, are almost never flowing near their outlets into the Platte. It has generally been believed that these streams furnish much water to the Platte through the sand of their beds, and it has been a favorite article of belief among the adherents in the underflow idea. If this be the case, it ought to be shown by taking a measurement of the river above the mouth of the stream and below, far enough apart to include the bed of sand forming the channel. Even if the increase is not noticeably great, the rate of increase might well be expected to be greater than for the average of the stream.

§ 51. In order to test the question, I instructed the observers, in 1894, to measure the river above the important drainage channels, and also below. This was done by Messrs. Trimble and Preston, with the results shown in the detailed tables, and brought together in Table X. In most cases the channel spreads out into the bottoms of the Platte, so that it is sometimes necessary to make the measurements several miles apart, in order to include the expected inflow.

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* Reports Artesian and Underflow Investigation, 1890-1, 1892, U. S. Department Agriculture.

At the time an estimate based on the flow through the sands and the amount which might be expected, had not been made, and the results were so much less than had been expected—in some cases, in fact, showing an actual loss—that it seemed advisable to secure the measurements of another year, to confirm or disprove the results, before reporting them. In 1894 the volume of the river was so small that the errors in the measurement should be small. In 1895 the volume of the river was so great that plans had to be changed, and the number of measurements reduced. Enough, however, were taken to confirm the essential accuracy of those of 1894, and a personal inspection of the channels, with this in mind, indicates that at the best the increase from such sources must be small.

§ 52. The number of cases in which there is a loss instead of a gain is striking; and even granting that there is no increase from these streams, a loss was not expected. It may be said that the second measurement has been taken too near the outlet to catch the underground flow. In most cases this is not the case. The topographical features—the narrowing of the bluffs or some other feature—usually guided the choice of the second point. The map and the detailed tables of the 1894 and 1895 measurements will give a fair chance to make an independent comparison. In the case of the Bijou, the second gaging in 1894 was taken near the head of the Platte & Beaver canal but a short ways below the Bijou. In 1895 it was taken over a mile lower down the stream, and where the bottoms were narrow. A third point of measurement was taken in 1894 at the head of the Platte & Beaver supply ditch. Comparing the gain between the point above the Bijou and this place, we find a slight gain, but it is still less than the average of the river. There is very little irrigated area draining into this section, and it is especially little between the first and second points of measurement. There is some loss for the whole distance from evaporation, but during the time of these measurements it is difficult to account for a loss of more than one cubic foot per second per mile from this cause. It has been suggested that these loses are due to the varying depths of the bed of sand under the Platte, and the nearness of the bed rock in places. There is evidence that the thickness of the layer of sand varies, but definite data is lacking. If this be the cause of the loss, it would suggest that the bed of the Platte is washed out below the entrances of most of the streams, or else is filled with a coarser and more porous sand. The gain due to the nearness of the rock in some places should correspond to the loss at other places. At the measurement above the Bijou creek, there is a reef of rock. It shows for most of the width of the stream, and, at any rate, leaves only a small channel of sand. The gain, however, while more than in many other places, has not been marked enough to give great weight to this cause.

The question needs to be left open for future information. But the result, however, shows that the gain from the natural underground drainage cannot be much at best, and is probably nothing, at least too small to be measured.

The rainfall given in Table X. as the average for the given water-shed is derived from observations taken at stations on or close to the water-shed. It may be considered as a fair average of the amount falling upon the area draining into the channel. As the stations are few in number and the records not complete, the amounts are approximations of varying degree of reliability.

The drainage areas have been determined with a planimeter by measuring the area tributary to each stream from a map published by the Post-Office Department. They show the extent of the area tributary through these dry streams. Were the run-off in the course of a year equivalent to a depth of only 1.4 inches over the water-shed, each 1,000 square miles would give an average flow of 100 cubic feet per second; or, a run-off of a depth of one inch in a year, from the basin of the Bijou, would give a constant discharge of 100 cubic feet per second.

A calculation by aid of Table IX. shows that the amount derived from the inflow from these streams must be small. The breadth and depth of the beds of sand are unknown. If we assume a bed 80 rods wide and 1 thick, or an area in cross-section of one-half acre, and a fall of thirty feet per mile, then from Table IX. the velocity may be expected to be from 2 to 8 feet in 24 hours. As this is the flow through the interstices of the soil, which are one-third only of the section of the sand layer, the whole amount corresponds to from 1 to 4 acre-feet in 24 hours, or to a constant flow of less than 2 cubic feet per second.

It is not surprising that the measurements do not show any decided gain from such sources.

TABLE X.

INCREASE OF RIVER AT MOUTHS OF STREAMS.

(The negative sign indicates a loss.)

	Drainage Area. Square Miles.	Average Rainfall. Inches.	Gain of Platte, 1894. Second-feet.	No. of Miles Between Measurements.	Gain per Mile, 1894.	Gain of Platte, 1895.	No. of Miles Between Measurements.	Gain per Mile 1895.
Box Elder creek	627	12.7	—51.05	3	—17.02	—35.27	4.5	—8
Crow "	1,443	11.5	....	....	....	....	....	....
Lone Tree "	536	11.5	12.16	1.5	8.11	114.2	3.5	33
Lost "	390	....	....	....	....	....	....	....
Kiowa "	470	16.3	5.26	3.	1.72	—34.16	9	—3.8
Bijou " .... }	1,425	14.5	—45.43	2.8	—16.2	—3.97	4	—1.00
	....	....	5.92	9.8	0.60	...	....	....
Pawnee "	600	....	3.52	1.75	2.01	....	....	....
Cedar "	514	....	9.71	1.5	6.5	....	....	....
Lodge Pole "	2,500	13.4	....	....	....	—47.6	9.5	—5.01

§ 53. The fact that, as a whole, the gain is small is a striking one, and even more so that there is in so many places an actual loss.

It, then, seems true that the amount of inflow brought down by these sands is much less than has been believed.

It seems difficult to account for as great losses at such points as is shown by some of the measurements, although the loss can be but little.

§ 54. We have not been able to secure enough detailed information of the location of the irrigated lands along the Platte, to be able to make a comparison in detail of the inflow and the irrigated area. The areas irrigated stretch along the Platte, usually near the river. The area watered near Fort Morgan is, perhaps, the most extensive, and farther from the river than the others. The number of acres which are tributary to each portion is not known closely enough to state in acres. But, making a general comparison, we have the following table. The most that can be said from it is, that the amount of increase bears a relation, in a general way, to the extent irrigated.

§ 54. Comparing the distribution of the inflow on the South Platte river with the irrigated lands, taking the average inflow as given in Table V., the average inflow to the State line is 2 feet per mile.

TABLE XI.

	No. of Miles.	Average Increase.	REMARKS.
From mouth of Poudre to Hardin ditch	8	62.0	Receives seepage from about 10,000 or 12,000 acres watered from Poudre, also from Upper Platte.
From Hardin ditch to Putnam ditch	11	17.2	Little irrigation — Hardin, Illinois and Corona ditches.
From Putnam ditch to Fort Morgan canal	14	57.8	Putnum ditch ; large part of Weldon Valley canal.
From Fort Morgan canal to Platte & Beaver canal	11	46.6	Most of Fort Morgan canal, remainder of Weldon Valley, Deuel & Snyder, and Pyott.
From Platte & Beaver canal to Snyder	14	49.9	Part of Fort Morgan canal, Platte & Beaver canal, most of Platte & Beaver supply.
From Snyder to Merino	18	55.4	Some of P. & B. supply ditch, P. & B., and Fort Morgan canal; most of South Platte ditch, all of Edwards and Johnson, Snyder, and Tetsel ditches.
From Merino to Sterling	14	33.7	Large part of Pawnee, Springdale ditches, and other Sterling ditches.
From Sterling to Iliff	9	17.7	Remainder of the Sterling group.
From Iliff to Crook	17	20.3	The Iliff ditch.
From Crook to State line	36	21.3	Almost no irrigation.
Total gain	149	298.7	

EFFECT OF IRRIGATION ON THE UPPER PORTIONS OF THE STREAM.

§ 55. A question which arises in connection with the application of water and which has been warmly disputed, is as to the effect on the lower stream of irrigation on the upper portions of a stream. In the way in which land has been brought under cultivation, it has happened in most cases that lands along the lower portions of the stream have been settled, while lands above have later been brought under cultivation. It follows then that these latter lands will often see the water go by to supply those others which were first improved. In some places it has been contended that the application of water to the upper lands is an actual benefit to the lower lands, and in some cases the contention has been partially granted.

It is evident that the water which returns to the stream returns slowly. It returns sooner when the distance is short and the gravel is coarse. The volume of the stream fluctuates between wide limits, while the effect of passing through the ground is to even the flow, and hold the water until later in the season. Usually the streams are high early in the season, and in June have more water than can be used; they are low in August. If this retention by the upper lands is such as to diminish the height in June and increase the amount in August, the result is evidently a benefit. As the effect of the subtraction of the water from the stream is immediate, while the return is slow, the abstraction of water in low stages will be felt more than the return from the seepage. Hence, for a portion of the time at least, it seems that the use of water on the gravelly plains of the upper parts of our streams will be a benefit to the lower portions, irrespective of the date of their respective rights. Just when the effect of the direct diversion is greater than that of the return could be told by investigation in the particular cases, but would manifestly vary according to the circumstances.

There has been a tacit acknowledgment of benefit of irrigation on the upper portions of the stream in some of the water districts of this State in the fact that the upper ditches have been permitted to withdraw water without interference from the Commissioners or from the ditches with earlier rights. This has doubtless been partly due to the fact that the amount used by them is small. But some weight has been given to the claim that irrigation on the upper grounds stored water which entered the river in other parts of the year, when it was more useful to the lower ditches. The question will doubtless arise in specific cases in this State and others. The length of time during the season when such irrigation will not be injurious to the later rights, can be told by special gagings carried on throughout the year, on the plan followed by Vigan.

WILL THIS INVESTIGATION APPLY TO OTHER VALLEYS?

§ 56. In the valleys here measured irrigation has been practiced for thirty-five years; to a small extent on the bottoms for twenty or twenty-five years, and extensively for fifteen years. In the case of the Poudre, the lands are some of them twelve or fifteen miles from the stream. On the Platte, they occupy a much narrower strip. The conditions of the subsoil, the amount of water applied, the dip of the impermeable stratum of clay or rocks, the coarseness of the gravel, all affect the time and amount of the return. But given time enough, it seems probable that these results will apply closely to other valleys as well. A certain amount of water is required by the crops for the purposes of growth. In round numbers, 300 to 350 pounds of water is used for every single pound of dry matter produced. On some soils it is possible by skillful irrigation to apply but little more than is required by the crop and evaporated from the soil. Under such economy, there is little water which can pass away by percolation. To the economical irrigation induced by scanty and high-priced water is due the little or no return water noticed in Southern California. This is also influenced by the relatively small acreage. The narrow strip of the lower Platte and the more copious irrigation explain partially, if not entirely, the larger amount returned to the stream per acre, while the remote places of application on the lands of the tributaries of the Upper Platte shows a reason why the inflow there is relatively less. These may not completely explain the difference. Time, and added observations, will be needed to determine.

The same or similar phenomena have been observed to some extent elsewhere.

"When the Ganges canal was constructed, the whole available "cold season supply was taken from the river, yet at a distance of "only a few miles the discharge in the river was found to be very "considerable, and further on it increased to such an extent that the "supply taken by the canal was found to be little missed." *

§ 57. In Italy the effect of irrigation does not seem to have been noticed in the rivers, but principally in the large number of springs to which irrigation seems to give rise, and which are developed by digging in Lombardy and other provinces, and which the geological conditions do not seem to be sufficient to account for. ||

The losses from canals is well known, and the damages caused to neighboring lands by the seepage is a fruitful source of suits at law. In the contract of the Cavour canal with the Sesia Associa-

*H. G. McKinney, Irrigation in Upper India, paper before the Royal Society, New South Wales, 1883.

|| Cagnassi, Irrigazione nella Provincia di Novara.

tion, for instance, the association becomes responsible for all damages from this cause.

§ 58. "I am inclined to think that the seepage is much "greater and of more importance in Colorado than anywhere in "California, for, while I know that such percolation does exist in "various places in the irrigated districts, I cannot recall a single "place where it takes place in any such volume as in your country. "The Santa Ana river is affected by seepage from Riverside and "San Bernardino valley, so that the volume of supply for the "Anaheim and Orange canals below is rather increasing than "diminishing, but the extent of this return is conjectural." †

"Some years ago the people owning water rights along the "lower parts of our mountain streams imagined that the use of the "water by parties located some distance above them would seriously "interfere with their water rights and prove very injurious to the "land below. Experience has proved that this fear was groundless "to a large extent. Indeed, it is now found that a large use of water "in the early summer on the upper lands insures a more plentiful "supply in late summer for the lower lands." ‡

Hon. Geo. P. Marsh, for a long time our minister to Italy, in *The Earth as Modified by Human Action*, in commenting on the results of Vigan (§ 59) states that it is generally estimated that from one-third to one-half of the water applied to the fields is absorbed by the earth, and this, with deduction of the amount evaporated, absorbed by vegetation, and entering into new organic compounds, returns to the streams or descends to greater depths. In Colorado a much smaller proportion of the water applied runs off and a much larger proportion is absorbed, as the system of wet meadows, or *marcite* and rice irrigation, does not prevail in Colorado. The measurements on the Poudre indicate that at least 30 per cent. of the water taken from the river returns through the seepage. If water is applied as freely until the seepage from the outer lands reaches the river, the amount of return waters will be greater than this amount.

OTHER INVESTIGATIONS.

§ 59. The phenomenon of return waters has been apparently but little noticed and less written upon. It was the subject of an investigation by the government engineers of France some thirty years ago in the valley of the Tet,* in southeastern France, where the question became important, as it is in some places in Colorado, in the dispute between water users of the lower valleys and those of

† Manuscript letter from J. D. Schuyler, Consulting Engineer, Los Angeles, California.

‡ Extract from manuscript letter from President Geo. Q. Cannon, of Utah.

* Vigan, Annales des Ponts et Chaussees, 1867.

the upper portions of the stream. The earlier canals, some built by the Moors before 1000, A D., were taken out from the lower portions of the stream, the later ditches near the head.

The lower canals desired to close the upper ones. The latter claimed that the water that was applied by them in irrigation returned to the river to a great extent, and thus had the effect of making the stream more constant in its flow, and, therefore, was as a whole advantageous for the lower users. During several years a system of measurements was carried on at different places on the stream and included all the water that came into the stream through the smaller tributaries. Measurements were made daily by the local officers. The valley is one the total length of which is something like fifty or sixty miles, and the total area irrigated is 32,000 acres. The cultivation consists largely of wheat, beans, alfalfa, meadows, and gardens, with small quantities of potatoes and flax. A biennial rotation is practiced which dates from the Moors. Grain is usually watered three times, once at the time of sowing, in November. Irrigation is practiced throughout the whole season. In the upper valley wheat is not watered. Beans are watered from the middle of July to the middle of September. From the data obtained, M. Vigan reached the following conclusions: The return waters are derived from all irrigated lands of the valley, varying according to the crops, amount of water used in each season, thickness of the soil, its composition, and the slope of the impermeable layer. He concludes that, in the bottom lands, which form a bed about a mile wide along the stream, and are abundantly watered, from the first of March, that the return waters from this source are sufficient to compensate for the losses caused by irrigation during the greatest part of the low water. He also concludes that, in the area forming a strip two or three miles wide, with a very deep layer of permeable soil, the return waters come to the surface only in some places; that the greatest part of the springs which are caused flow unused in the subsoil and return frequently to the sea. On these lands irrigation occasions considerable loss; hence he concludes that, in case of an application for water right in the stream for canals, or ditches, which are to be newly constructed, the concession should be refused, except conditionally. In case water is lacking in the other canals, then the new ones should be closed. In general, under the conditions existing in that valley of the Tet, irrigation at the upper portions of the stream with water taken at periods of high water, is beneficial to the lower portions of the stream. The water thus applied gradually returns to the stream in such quantity that the stream is not so low as if the irrigation had not been practiced.

Some of the measurements of the Poudre river have been given in the Colorado Agricultural Experiment Station Report, 1891, p. 45-50.

Also see reports of the State Engineer of Colorado, 1885-6, p. 205-208; 1889-90, p. 559-570; 1891-92, p. 51-65; 1893-4, p. 176-192.

In bulletin No. 38, of Utah Experiment Station, Prof. Fortier has given some measurements for one year, showing the amount on some Utah streams, and leading to essentially the same conclusions as Vigan. Prof. Fortier's study is a valuable contribution to the subject.

A discussion by Senator David Boyd of the applicability to the Arkansas valley of conclusions from the Platte measurements, occupies part of a report of a special committee on the State Canal No. 1, Tenth General Assembly, p. 40-49.

In the Annales des Ponts et Chaussees, 1883, p. 34-60, M. Bazaine has a study on *L'Influence des Irrigations sur l'Altitude d'une nappe souterraine* occasioned by the observations of the effect of irrigation from the sewage of Paris on the ground water of the sewage farms of Gennevilliers. It has little application to the present discussion, except as it deduces the equation of the surface of the underground water, which is parabolic.

CONCLUSIONS.

We may draw the following conclusions from the observations and considerations shown. The facts are presented in sufficient detail to show the bases of these conclusions, or to enable independent conclusions to be reached, if the reader so desires:

1. There is a real increase in the volume of the streams as they pass through the irrigated sections.

2. There is no such increase in the streams as they pass through the unirrigated sections. On the contrary, there is an actual loss, even when the drainage of a large area enters.

3. The increase is more as the irrigated area is greater.

4. The increase is approximately proportional to the irrigated area, and it seems probable that with more intimate knowledge of the amount of water applied and the features of the drainage, the proportions would be found to be close.

5. The amount of the increase depends very slightly, if at all, upon the rainfall, and, so far as it does, it is influenced principally by the rainfall on the irrigated lands. Only where the lands are already saturated, is the rainfall sufficient to cause seepage.

6. There is no perceptible underflow from the side channels, even where they drain several thousand square miles.

7. The inflow is practically the same throughout the year. It is more in summer, less in winter, principally because of the effect of the temperature of the soil.

8. The passage of the seepage water through the soil is very slow, so that it may take years for the seepage from the outlying lands to reach the river.

9. The amount of seepage is slowly, but constantly, increasing.

10. It may be expected to increase for some years to come.

11. An increased amount of land may be bought under cultivation, with time, more especially on the lower portions of the streams.

12. The seepage being nearly constant throughout the year, while the needs are greatest in summer, the use of storage will best utilize the water from inflow.

13. The seepage from one thousand acres of irrigated land on the Poudre river gives one cubic foot per second constant flow; on the Upper Platte, one foot to about 430 acres; on the Lower Platte, one foot to 250 acres. The difference is due mostly to the greater distance for the seepage to reach the main stream, and to the time and amount of water applied.

14. One cubic foot per second of inflow is obtained on the Poudre river for each 2,400 acre-feet applied, or the inflow is about one-third as much as the water applied.

15. On the Poudre river about 30 per cent. of the water applied in irrigation returned to the river.

16. The use of water on the upper portions of a stream, when water is not immediately needed by prior appropriators, will increase the flow of the stream late in summer and prevent such low stages as it would have without this regulating action.

17. The seepage water is already an important factor in the water supply for the agriculture of the State. The capital value of the water thus received in the valley of the Cache a la Poudre alone is not less than $300,000, and perhaps $500,000, and for the Platte is from $2,000,000 to $3,000,000. It is large for the other streams, but of unknown amount.

18. An actual loss is incurred in carrying a stream like the Platte through sandy beds.

19. Ultimately, the returns from seepage will make the lower portions of such valleys as the Platte more certain of water, and probably enable a larger acreage to be grown.

20. The results here shown may be expected to apply with limitations to other valleys similarly situated, where irrigation is

as copious, crops the same in character, subsoil and rock strata of much the same inclination. Where the soil is less pervious, a greater time must elapse for these results to hold good.

21. Measurements are greatly needed in the Arkansas and Rio Grande valleys, for the determination of facts which will soon become of importance. In the Rio Grande, especially, because of the claims made by Mexico that irrigation in Colorado is proving an injury to her people and infringing privileges guaranteed them by treaty. If the results of this investigation apply to the Rio Grande, then any injury must be largely compensated by the return, and the greater regularity in the flow produced in the river.

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The diagrams have been drawn by Mr. J. D. Stannard, who has also aided the laborious work of reduction of the observations; Mr. Trimble has also aided extensively in the same work, and in the field work, as noted in the detailed observations, and also in preparing and checking the tables.

Through oversight, credit was not given, on page 32, in a part of the edition, to Mr. P. J. Preston, for Measurement No. 5, made under direction of the State Engineer.

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