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PRELIMINARY REPORT ON THE

DUTY OF WATER

Approved by the Station Council.

ALSTON ELLIS, President.

FORT COLLINS, COLORADO.

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Preliminary Report on the Duty of Water.

BY L. G. CARPENTER.

In the course of investigations relative to questions relating to irrigation begun by this section of the Experiment Station, the determination of the duty of water as under the conditions of Colorado practice, seemed one of the first questions to be undertaken. Since with us in Colorado—as indeed throughout all of the arid West—the land far exceeds the water supply, the ultimate extent of our irrigated area, and therefore of our profitable agriculture, depends upon the use we make of our water. If lavishly used, our productive area is correspondingly limited; if wisely and economically used, the greater will be the area capable of supporting a population, and consequently the greater will be our public wealth. It is, therefore, a matter of public importance to determine our limitations, either of practice or of necessity. The question is of great financial importance to the public. The current value of water rights indicates the value of the water in the consideration of the community. In most cases the water rights are subject to the uncertainties of the streams, and cannot be absolutely relied upon to furnish water when most needed. Nevertheless, they are currently rated even in the new communities at from $10 to $15 per acre, and when the rights are certain to furnish the water the value is greater. All recognize that the greater part of the price of the land in farming districts is in the water. Take away the water, or the possibility of getting water, and the land in most cases would bring but little. In the older communities the market value has a constant upward tendency, and there is every reason to think this will continue. As the value of the water is in the product which it assures or produces, rather than in its absolute quantity, any increased duty, due to greater skill in application, improved methods, or from saving of losses in the canals or ditches, or on the farm, will increase the area which may be brought under cultivation with the same amount of water. At present we have something like 1,500,000 acres under cultivation in this State. A doubling of the duty would increase the public wealth of the State from this source alone by $20,000,000 at the present estimates of water rights, and an increase of 25 per cent. would mean an increase of $5,000,000 from this source alone. But as the most of the agricultural wealth of the State is possible only with water, the increase of homes and of

the public wealth from production would be only faintly indicated by the above figures.

There are many complex factors involved in the use of water in irrigation and the amount of water that may be necessary. Some water is required for the needs of the plant and is removed with the crop; a greater amount is evaporated from the foliage during the growing season; some is evaporated from the ground, and a certain proportion sinks into the ground and passes away as ground water. In general, there are also losses, so far as the individual is concerned, in the excess water which runs over the surface. But in careful irrigation and under the pressure of necessity this becomes less and less. In a ditch system there are also the losses of carriage from evaporation and from seepage. So far as the plant is concerned some of these losses are unnecessary, but are incident and perhaps necessary to our ways of supplying it to the plant. Could we know the amount of water required in each of these ways, we should know in which direction there would be the greatest chance for improvement. A full investigation of the question would involve a determination of the losses in each of these directions, but the determination is one of great difficulty, and the results are not definite enough to report at present.

The observations and measurements which are here reported are some of those made during the past three years in the Cache-a-la-Poudre Valley, one of the first valleys in the State to be developed. The results are principally from the records of self-recording instruments. These were placed so as to record all the water which passed through weirs, which were so placed as to measure all the water applied to various crops. Instruments have been placed so as to measure the water applied to crops of potatoes, of alfalfa, of clover, of native hay, of wheat, of oats. The depths as used by some of our best farmers are given in the following tables and diagrams. We have the record of three seasons of the amount of water used by the Cache-a-la-Poudre Canal Co. No. 2, one of the original Greeley Colony canals. From the skill of the farmers drawing water from it, and from the fact that it is one of the original Greeley Colony canals, it perhaps best represents what would be the practice of skillful farmers in the valley when water is supplied to them as they desire it. One season's record of the New Mercer could not be definitely reduced, owing to the fact that most of farmers use water from a neighboring canal, and the waters could not be separated.

The experience gained in these measures has shown the difficulties to be encountered, and will enable us to make the determinations of the future more satisfactory. But though confessedly incomplete, the importance of a more general knowledge of the subject makes it desirable to publish such results as we have. It is hoped that it may lead many individual farmers to undertake more careful observations on the amount of water which they use, and measure it with more care. The observations undertaken by this section

have required the use of the self-recording instruments at considerable distances, and the visiting them in one single season has required more than thirteen hundred miles travel with horse and buggy. The work of reduction has been far greater.

WHAT IS THE DUTY OF WATER.

By duty of water is meant the irrigation performed by a given amount of water; and this may be expressed in various ways. Ordinarily by stating the number of acres which is irrigated by the constant flow of a given quantity of water, as a cubic foot per second. Sometimes the water is expressed in "inches," but as the "inch" varies between wide limits it has none of the characteristics of a unit, and should be avoided.

The duty may also be expressed in terms of the depth of the water which has been applied.

The first method is that commonly used where the water is taken from streams, and as the basis of water rights and water contracts between the canal company and the purchaser. It is in the unit most convenient for their purpose, for in this form the amount which should be delivered to the irrigator when the supply to the ditch is sufficient, is at once found. But as this estimate varies with the assumed length of the irrigation season, it is not convenient as a basis for determining the actual depth of water which has been applied, or for estimating the number of acres which may be irrigated from a reservoir. The duty as expressed in one way may be expressed in the other unit by remembering that there are 86,400 seconds in a day of 24 hours, and since there are 43,560 square feet in one acre, the flow of one cubic foot per second will cover very nearly two acres one foot deep in one day, and in 100 days will cover 200 acres one foot deep, or will furnish, as it is sometimes expressed, 200 acre-feet. The reverse reduction may be applied by remembering that two acre-feet is equivalent to the flow of one second-foot for 24 hours. Thus if the depth on a crop of 100 acres is one foot, it would require the constant flow of one cubic foot per second for 50 days, or one-half of a second-foot for an irrigation season of a hundred days.

The expression of duty in the two ways may thus be equivalent ways of expressing the same amount of water. In terms of acres per second feet, the stream is supposed to be running constantly. The needs vary from one part of the season to another. No one wants his water for irrigation in as great quantities in May as in the latter part of June, or the same amount in August and September. When the flow of the cubic foot per second is assumed constant throughout this whole period, the duty found is much greater than if the month of June was taken as the basis. But under the conditions of distribution from our streams, the quantity of water received by a ditch fluctuates according to the fluctuations of the streams, and the demands are such that there is rarely any surplus water. A farmer who is economical in one month cannot draw his saving in another

month. Consequently, the basis of his purchase of water must be a duty which will cover his needs in the month of greatest use. Thus it is, that in the same valley one method of determining the duty will give nearly 200 acres per cubic foot per second, while the basis for the sale of water rights is 55 acres per second foot, or 1.44 second-feet per 80 acres. It is because of not considering this feature of Colorado distribution that many in, as well as out, of the State have not understood the discrepancy.

The variations of duty reported from different communities or different countries may thus be due to different ways of estimating it, as well as from the difference according to the place where water is measured.

The duty will be different according as we consider the individual farmer, the canal company, or a whole valley. The methods of irrigation and of distribution are such that almost of necessity the individual draws more water than his land needs, in order to secure quick irrigation, and thus there is a surplus which runs away. To the individual this is waste.

The canal company is interested in knowing what the duty of the water is as measured at the headgate of the canal. The water is measured to the canal by the Water Commissioner, and the duty as based upon the water measured at the headgate would be less than the average duty of the individual by the losses of evaporation and seepage in the transit, and increased by the gain there may be in the average of a number of farmers. Where the canal is of some size, so that there are several users from one lateral, the water lost by one may be utilized by another, so that the canal gains in duty over the individual.

To the people of a whole valley the duty may be still different. The valley has a stream of water of certain size, and to the public it is desirable to know how much this water will serve. Besides the losses in carriage in the canals, this is subject to the additional losses of transportation in the stream. On the other hand, many losses to the individual are not such to the community. The water which sinks into the soil from seepage from the canals and the laterals, and from the sinking from the irrigation, may reappear again in the stream or in the depressions feeding the stream, and be used again by the canals in the community. In the case of the Cache-a-la-Poudre River this total return is nearly one-third of all the water which comes from the canon. Besides, the water wasted by the individual may be caught by another ditch and used again. The result is that the duty of a whole community ought to average higher than that of the individual, and measurement bears out the anticipation.

Where the wastes and losses of the individual farmer may be saved by others and used over again, we may then be led to the conclusion that the excessive use of water by the individual is not necessarily in conflict with a high duty in the community as a

whole. It is disadvantageous, for the loss in the large number of channels and in being spread in shallow depths is greater than when kept in more compact masses. Besides, after water has once been used, it can afterward be applied only to a more restricted area; to the land which is lower down the valley. Its reappearance, if it disappears, is only after the lapse of some time, so that it cannot be applied at will.

GENERAL CONSIDERATIONS AFFECTING DUTY.

The amount of water actually needed, as every irrigator knows, varies according to many conditions. The method of irrigation, the slope of the ground, character of the soil, kind and character of subsoil, the crop, amount of rainfall, the use of water in large or small heads, preparation of ground, the skill and knowledge of the irrigator, thorough cultivation.

In general, the more rain the less irrigation needed. This is true for crops of the same character and in the same community It is not neeessarily true of different communities widely separated, nor of different crops where irrigation is carried on not from necessity of drouth, but as a means of furnishing nutriment to the plant. The amount used may be very excessive, as in the hay lands of the Vosges in France, which use over 200 feet in depth per year.

Certain methods will be best adapted to certain slopes and crops. With a given method there is a slope of the ground at which a given amount of water will do the most work. The object being to reach the roots of the plants, unnecessary slowness in the water permits increased evaporation, and perhaps unnecessary absorption. Much more water is needed for a thorough irrigation than one unaccustomed to irrigation would think necessary, but the experience of all countries finds it practically impossible to make an irrigation with a depth of less than three inches of water on sod ground, and from four to six on cultivated crops.

Different crops require different amounts of water and at different periods. Grasses being grown for forage, an increase of water usually means an increase in product. With the cereals, as well as with grasses when grown for seed, there is a limit beyond which irrigation may be detrimental. Different cereals, as well as different vegetables, have different powers of withstanding excessive moisure on the one hand or drouth on the other. Hence irrigation is applied with greater care, and perhaps more frequently in case of scarcity, to the one crop than to the other, and the duties obtained under the conditions of ordinary practice will vary in consequence.

A soil retentive of moisture will need fewer irrigations than a sandy soil, and if the irrigations in the two cases can be made with the same depths of water, will furnish a higher duty.

It is a common observation throughout the irrigated valleys that land requires less water after it has been irrigated a series of years. Though we have no definite measures on this point, the fact

is one of such common observation that there is no reason to question it. Many times land may cease to need water at all, and may require drainage. The cause of the lessened need is connected with the change in the level of the ground water, which is universally observed. After irrigation the soil gradually becomes saturated with water, and the level of water in the wells rises in the course of a few years sometimes forty feet. After the level has approached the surface, the water which the soil will permit is only that needed by the crops and evaporation, and enough to supply the loss of the ground water by lateral or downward percolation. In the earlier years enough has to be supplied to fill up the sub-soil, and as ordinary soil holds a large percentage of its volume of water, the duty of later years is materially increased.

It is evident that a permeable or impermeable sub-soil, and its distance from the surface of the ground, will affect the duty. If impermeable and close to the surface, there will be little soil to fill, there will be a higher duty, and more care will be necessary on the part of the irrigator, or he will drown out his crop. A very porous sub-soil, as is found in many cases in our river bottoms, and near mountain streams, requires frequent and abundant irrigations in general, as the water passes through it like a sieve. It is because the sub-soil is of this character that the duty in Northern Italy is so small. Lands which naturally sub-irrigate, as in the San Luis Valley in this State, and the San Joaquin Valley in California, are those where the impermeable sub-soil is close to the surface, and lateral percolation may readily take place, because of the character of the surface soil.

The character of the flow of the supplying stream also affects the duty of the water derived from it under the conditions of Colorado and most of the Western States. The streams being fed by the melting snows are high in May or June, and low in late summer. In consequence, while there may be an excess of water in the former month, there may be a deficiency in August and September. In many, if not in most cases, there is not sufficient water in late summer, and the crops do not receive what they should, or what their owners would apply if it were to be had. In consequence, it does not follow that an increase in water in late summer would give an increased acreage, but that the area cropped would give better returns and the duty would be less. The cereals which mature early, frequently receive all that would be given them. But alfalfa and other forage crops would receive in most cases one or more irrigations in addition to the two which are now generally given them. In consequence of this it does not always follow that the duties obtained by dividing the acreage cropped by the water supplied to a canal gives a measure of the relative needs of different communities.

It is partially, if not entirely, due to this that the newest canals will generally give a high duty, for their water supply may be small in proportion to the area underneath, and the early canals with

early water rights may appear to use large quantities of water and thus have small duties. But they will all the more likely represent the practice where there is water accessible whenever needed.

The water applied to the individual fields was measured over a weir of the trapezoidal pattern, due to Cippoletti of Milan, as described in Bulletin No. 13. This form of weir was adopted because of the greater ease in reducing the measures. The maps of the various fields show the location of the weirs which were arranged to fulfill the conditions as described in the bulletin mentioned. In one, that of Mr. McClelland, the crest which was originally 30 inches, was found to be too small for the convenience of the irrigator, and was lengthened to three feet, without, however, widening the box in which it was placed. This would have the effect of slightly lessening the lateral contraction and thus increasing the discharge, but as the error due to this is small, it has not been taken into account in the reduction, as necessary errors do not warrant this degree of refinement.

The instrument for recording the depth of water on the weir was of a pattern made by Richards Bros., of Paris. At one side of the box and above the weir a well for the float to move in was made and connected with still water above the weir. This float rose and fell with the water in the ditch, and was connected with a pen which recorded on a cylinder moved by clockwork the change in the height of water. A copper wire served as the connecting cord between the float and the pen. The first clockworks sent by the manufacturers revolved daily, but as this was inconvenient for our purposes weekly movements were afterwards substituted. When the papers were changed, as they were weekly, the height of water was measured and recorded as a check upon the instrument. Only once or twice was there any reason to suspect a slipping of the wire over the pulley connecting with the clockwork.

In the case of the river and the canals it was impracticable to measure the water over weirs, but each canal is provided with a rating flume some distance below the headgate, which is officially rated by the State Engineer, and is the basis for the distribution of water to the ditch. The instruments were so placed as to record the depths in these flumes. In the case of the river, the water district has provided a gauging station where all ratings are made, and sufficient have been made during the past years at different stages of water to give the quantity of water flowing at any given depth with a fair degree of accuracy.

From the sheets from the recording instrument the depths acre found, reduced to cubic feet per second, and multiplied by the number of seconds during which the height could be considered constant. When the height was varying, this time was short. Each day was added separately.

The reductions themselves have been made almost entirely by Mr. R. E. Trimble, assistant in this section of the Experiment Station.

The field of J. H. McClelland, three miles south of the College, and the same distance from the foothills, was given for a test of the measurement of water applied. The field is shown in Fig. 1, the slope as shown by the contour lines being to the north and east at the rate of about 50 feet per mile. The water is supplied from the

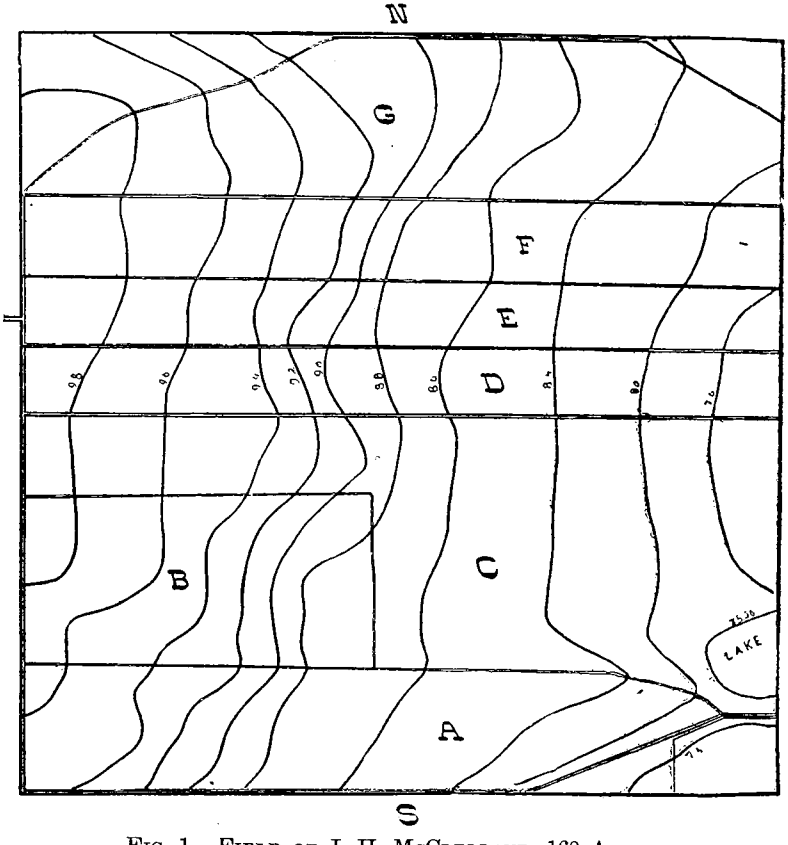

FIG. 1.—FIELD OF J. H. MCCLELLAND, 160 ACRES.

Pleasant Valley and Lake Canal to the west of the tract, the box for measurement being placed in the supplying ditch a few rods to the west of the boundary. The soil is of the same general type as that of much of the Poudre Valley, sand and clay mixed with more or less humus, responding readily to the application of water. There is more or less gravel, varying from the smallest particles to boulders. The field was owned by Hon. J. S. McClelland, and under the immediate charge of J. H. McClelland, formerly a student of the College, who took great interest in the measurement.

The field was divided into several crops, alfalfa, clover, wheat and oats, besides garden and orchard at the southeast corner. The time of turning on and off the water to each plat was furnished by Mr. McClelland. The measurement gives only the gross amount

of water taken into the field. The waste could only be estimated. There was at times considerable which passed on through the field to the east.

The measurement was begun in 1891, but the instrument then used not proving reliable, the reductions have not been used.

The areas of the different plats and the crops in 1892 and preceding years, were as follows.

A—15.75 acres, alfalfa, 1891-2 ; wheat, 1890.
B—20.2 acres, alfalfa, 1892 ; wheat, 1891 ; corn, 1890.
C—38.5 acres wheat, 1892 ; clover, 1891.
D—14.3 acres, clover, 1892 ; clover, 1891, preceded by wheat.
E—13.5 acres, alfalfa, 1891-2.
F—17.4 acres, oats, 1892 ; alfalfa, 1890-1.
G—34.0 acres, wheat, 1892 ; preceded by alfalfa for about 7 years.

The amounts of water used varies according to the height of water in the main canal. That used for garden purposes was not counted in the summation, nor when there was a small amount of water running in the ditch, but too small for irrigation purposes.

Fig. 2 shows the quantity of water entering the field by days, as measured at the weir. The black portion is the water applied

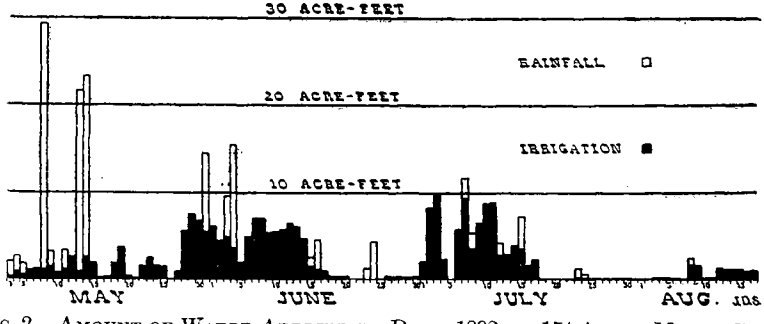

FIG. 2.—AMOUNT OF WATER APPLIED BY DAYS, 1892, TO 154 ACRES, MIXED CROPS.

artifically, the light portion represent the number of acre-feet equivalent to the rainfall over the whole 154 acres on the corresponding days. The rain gauge was at the house of Mr. McClelland, in the southeast corner of the field.

As the water was turned on or off each separate piece the sheet was marked by Mr. McClelland. From the records the following table shows the amount of water applied to each crop and the depths. Frequently the irrigation was suspended temporarily, either from lack of water or to supply the needs of another piece.

FORAGE.

NORTH ALFALFA—13.5 Acres. Plat E.

Date.	No. of Hours.	Acre ft.	Depth ft.	Remarks.
May 19	10	3.71	.47	First irrigation.
" 28	12	2.60		
July 6	10	4.78	.36	.....
	32	.....	.83	.....
Rain.....	.....	.....	.84	From April 1st.
Total.....	.....	.....	1.67	.....

SOUTH ALFALFA—36 Acres. Plats A. B.

Date	No. of Hours.	Acre ft.	Depth ft.	Remarks.
May 27-28..	12	2.74	.51	.....
" 29-31..	56½	15.45		.....
July 11-17 .	120	18.11	.50	.....
	188½	.....	1.01	.....
Rain	.....	.....	.84	From April 1st.
Total	.....	.....	1.85	.....

CLOVER—14.8 Acres. Plat D.

Date	No. of Hours.	Acre ft.	Depth ft.	Remarks.
May 28-29..	12	2.93	.54	First irrigation; in night, perhaps one half waste.
May 31, J. 1	16	4.82		
July 1-2 ...	14	4.38	.60	Second irrigation.
" 3-4 ...	13	4.14		
" 9-10 ...	17	4.34	.30	.....
	72	.....	1.44	.....
Rain	.....	.....	.84	.....
Total	.....	.....	2.28	.....

CEREALS.

NORTH WHEAT—34 Acres. Plat G.

Date.	No. of Hours.	Acre ft.	Depth ft.	Remarks.
June 1-4...	72	19.10	.96	
" 6-8...	33	7.15		First irrigation.
" 10-11..	23	5.53		
" 13	3	.73	.....	Cut about Aug. 16.
July 6-9...	49	13.96	.41	.....
Sum.....	220	.....	1.37	.....
Rain.....	.....	.....	.83	.....
Total.....	.....	.....	2.20	.....

SOUTH WHEAT—38.5 Acres. Plat C.

Date	No. of Hours.	Acre ft.	Depth ft.	Remarks.
June 6-8...	72	21.24	.55	First irrigation.
July 10-11 .	28	13.05	.34	2nd, incomplete.
	100	.....	.89	.....
Rain.....	.....	.....	.83	April 1 to Sept. 1.
Total	.....	.....	1.72	.....

OATS—17.4 Acres. Plat F.

Date	No. of Hours.	Acre ft.	Depth ft.	Remarks.
June 11-14.	66	17.83	1.02	.....
July 2-3....	36	9.75	.56	.....
" 17	12	2.10	.12	Incomplete watering.
	114	.....	1.70	.....
Rain	.....	.....	.83	.....
Total	.....	.....	2.53	.....

The first column gives the date on which water was applied to the crop, and the second the number of hours during which the watering lasted. The alfalfa and clover is generally watered once for each cutting. The north wheat was cut about August 16, the first cutting of alfalfa and clover the last week of June, the second cutting a month later, and the third cutting was begun September 23. The rainfall during the growing season was: In April, 1.60 inches; May, 5.22; June, 2.02; July, 1.04; August, .19; September, .07, which reduced to feet is added to the depth artificially applied. The duties as obtained for a constant flow of cubic foot per second then varies according to the assumed length of the season, and whether the rainfall is or is not considered, varying from 12 to 400 acres per second-foot.

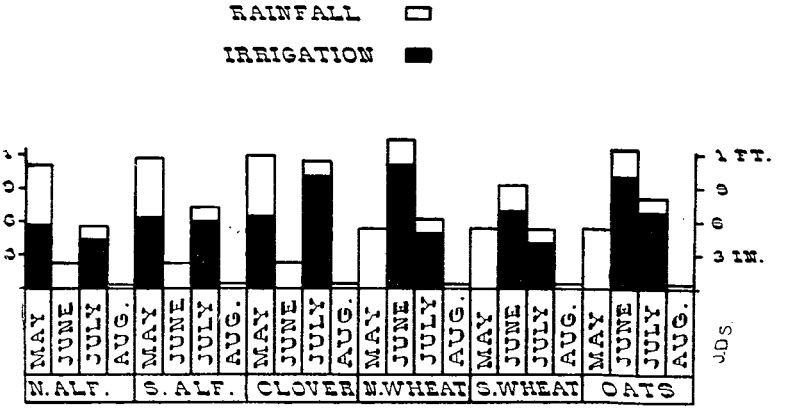

Fig. 3.—Depths of Water Applied by Months, 1892, by J. H. McClelland.

Fig. 3 represents graphically the depths of water received by each crop by months, that received from irrigation being represented by the black part of the diagram, the rainfall by the light portion.

WHEAT.

The field which was used for measuring the water supplied for irrigation was one some six miles southeast of the Station, and three miles directly east of the field of Mr. McClelland. The field belonged to Mr. Walter Campbell, of the firm of Ames & Campbell, of Fort Collins and Denver, and an able farmer. The field slopes to the north and east, toward the river, as is shown by the map, Fig. 4, is of friable sandy loam, retentive of moisture, and in a section well-known for the quality of the wheat. The farm buildings stood in the southwest corner of the tract. The main supplying lateral ran to the north along the west side of the tract, and the distributaries to the east at intervals of about 200 feet. The measuring box and the recorder were at A, in the right hand lower corner. The water for the first section of the field, consisting of 3.1 acres, was not measured through this box,

but all the water for the remainder of the field was measured. The waste, if any, from this first portion of 3 acres, would be caught by the next section of the field, but there was little, if any waste, and the result would be inappreciably affected. The area occupied by the farm buildings and barnyard was deducted from the

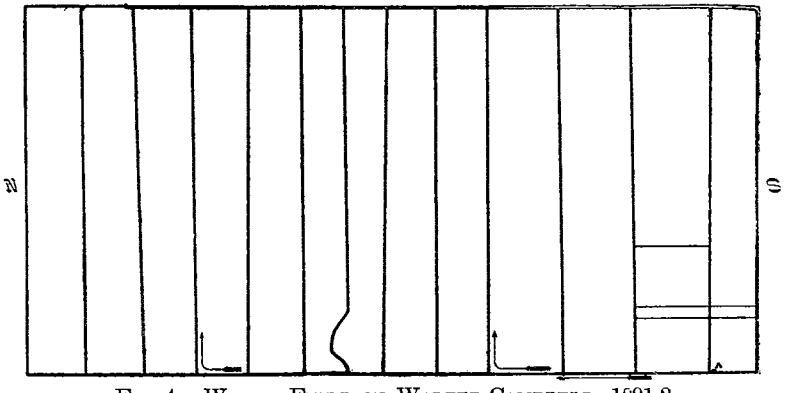

FIG. 4.—WHEAT FIELD OF WALTER CAMPBELL, 1891-2.

remaining area, leaving 71.5 acres to which the water was applied. This includes a small area of garden and fruit which is not separately taken into account. The total area of wheat thus measured is 70.5 acres. There was little, if any, waste water. None wasted to the north, and very little to the east.

The register was placed in position on its receipt in June, 1891, after the first irrigation. Owing to the scarcity of water, there was no second irrigation given, and in consequence the records are incomplete for that year. In 1892 it was in place during the whole season. The box sometimes became filled with sand, so that the entrance to the pipe supplying the well in which was the float, became filled, and the zero point of the scale was changed during the season. This has caused some doubt regarding the proper point for the record of something over one week, but the point as selected from the evidence is thought to be closely correct.

The amount as applied daily from June 1 to July 6, is shown by the diagram 5, the total quantity being 78.5 acre-feet, or a depth of 1.10 feet in two irrigations, an average of 6 inches, very closely, per irrigation. Some 3 inches of rain fell in the same time.

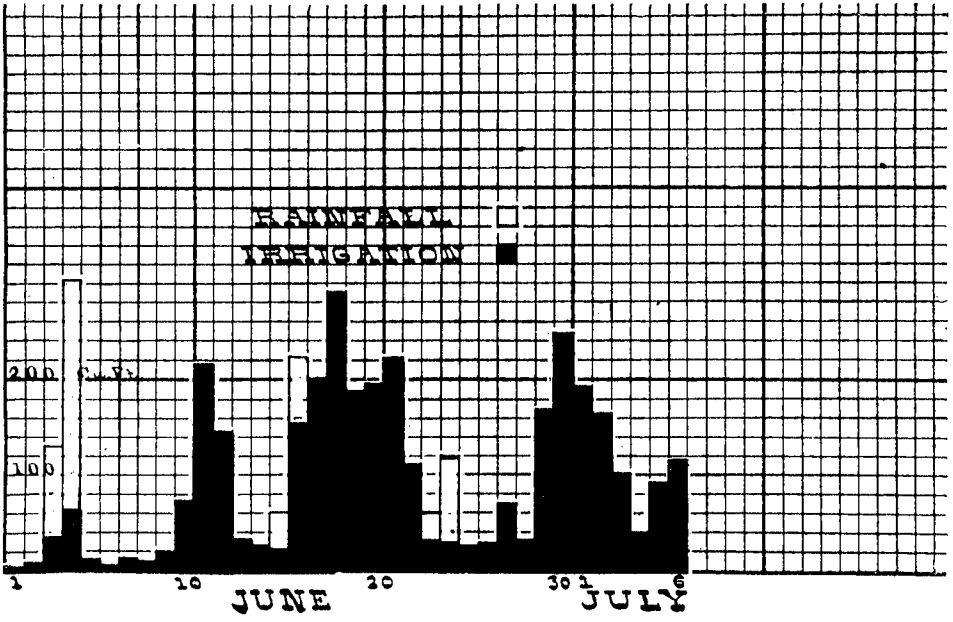

FIG. 5.

NATIVE MEADOW.

Capt. Wm. M. Post kindly allowed us to measure the water applied to a field represented in Fig. 6, devoted to native hay. The field is within the foothills, near the gauging station of the Poudre river, and contains below the position of the measuring box, some sixty acres. The portions inclosed by dotted lines were devoted to onions, corn, and an inclosure for hay corral, a total of 1.6 acres, and there

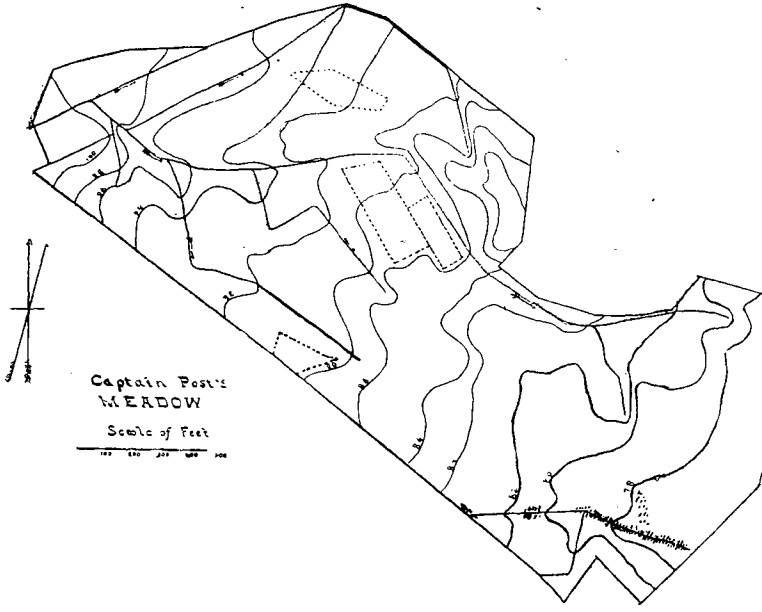

FIG. 6.

were 4.2 acres of wheat at the extreme upper part of the field. The lines of the map show the contours of the field, at two feet differences of level, the double lines representing the ditches, those at the lower part of the map being ditches to catch the seepage water. The lower part of the field is so wet that no irrigation is required, and none is given except with the waste water from the upper ground. The total area of meadow which is irrigated is 32 acres. The field is in an ancient bed of the river, so that gravel sub-soil is close to the surface. The total amount of water measured includes that given to the 32 acres of meadow, and to 4.2 acres of wheat, 1.6 acres of corn, 0.3 acres of onions, or a total of 38 acres. The instrument was put in place in 1891, and measured the water which ran in the latter part of that year, as well as during the whole of 1892. Fig. 7 shows graphically the amount applied expressed in depths over the area mentioned, the light portion representing the rainfall and the dates on which it fell. This is taken from the record furnished by Chas. Gilkison, five miles southeast of the field. The rainfall at that place is slightly smaller than in the foothills,

but not having a definite record, his is taken. The difference is not great. Some water was running nearly all the time, but in the intervals on the diagram showing none, the quantity was too small to show on this scale, and was generally the leakage from the gates and of no use for irrigation. The custom of Capt. Post in conduct-

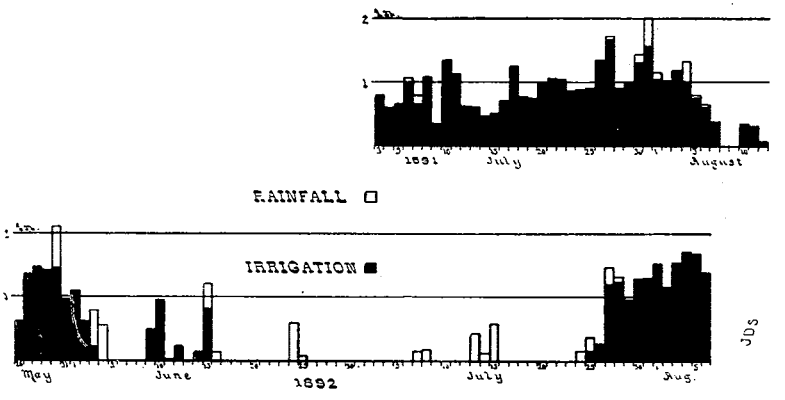

FIG. 7.

ing the irrigation, is to turn the water on a portion of the field and allow it to run for some time, his ditches and gates being so arranged that it may be done conveniently. The excess, when any, runs back to the river. Irrigation is stopped about a week before cutting, one crop being cut per year. In 1891 the total water applied from July 3 to the close of the season, was 100 acre-feet, from which we may deduct at least 6 acre-feet for the other crops, which do not require as much as the meadow, taking the other measures in the valley as the basis. This would leave 92 acre-feet applied to 32 acres of meadow, or a depth of 2.9 feet.

In 1892 the quantity used was not so great as in 1891, the total quantity from May 25 to the time of cutting being 81.4 acre-feet. Six acre-feet of this may be considered as having been applied to the six acres of other crops, leaving 75 acre-feet for the 32 acres of meadow, or a depth of 2.4 feet.

This shows a larger use of water than the cereals and alfalfa, and thus a smaller duty, as is well known, but the quantity used is much less than was anticipated. In European meadows waterings are given at short intervals, and it is expected to cover them to much greater depths. The most careful measurements on the water applied to meadows have been made by Mangon on those in Southern France and in the Vosges. Sometimes the amount applied is sufficient to cover the field to a depth of 1,400 feet (448 metres), measuring the gross amount applied, as in this case, and the net amount absorbed is equivalent to over 160 feet. (Mangon Experiences sur l'Emploi des Eaux dans Irrigation, p. 46, 153, table 12.)

In this case most of the water is applied in the winter, though some 374 feet in depth was applied from April to July, of which 88 feet were absorbed.

For meadows where summer irrigation is more the rule, or for the same meadow during a corresponding season, the amount used is still much greater than is the custom indicated above. In the meadow of Capt. Post, the depth found is, if anything, too great. On the meadow of Saint Die in the Vosges, the water applied from May 8 to August 11, a period nearly the same as on Capt. Post's meadow, was equivalent to a depth of 120 feet (36.7 metres), of which, however, 112 feet ran off (34.2 metres), leaving a depth of 8 feet absorbed by the meadow. Ordinarily, Mangon says, in drier years one or two more irrigations are given. (P. 47.)

Another meadow, that of Taillades in Vaucluse, in Southern France, between June 5 and September 13 received water to a depth of 5.25 feet (1.63 metres), of which .05 feet (.32 metre) was collected in the waste ditches, leaving 4.20 feet as the net amount of water absorbed. (Mangon, p. 26). This was given in 13 irrigations. Ordinarily 25 are given, each one requiring the same amount of water.

THE NO. 2 CANAL.

It was desirable to find the amount of water used by a whole community under one ditch, and by the kindness of the officers of this canal a self-recording instrument was placed in their measuring flume in 1891, and records continued through 1892. This canal was one of the first planned and built by the Union Colony of Greeley, being laid out by E. S. Nettleton in 1870. It has been several times enlarged, so that now its official rating calls for 585 cubic feet per second. There are three hundred water rights in the canal, each of which is considered sufficient for 80 acres. The area watered is closely 24,000 acres. The last report of the Water Commissioner makes the acreage 26,800 acres, of which 400 is watered by seepage water and 2,500 by reservoirs.

Its early construction, together with the long experience of most of the farmers underneath it, show perhaps better than any other canal easily accessible, the average of good practice in the valley when water is to be obtained at most parts of the growing season. The uncertainties in the amount of water in the river are such that farmers are constantly pressed to use water at times when they otherwise would not for fear there will be scarcity when it is needed. This compulsion of conditions affects the later canals the most, as they are the ones which are the soonest shut down in case of low water. While the pressure causes farmers with small amounts of water to study means of economizing the water to the utmost, the duty is more apt to be abnormally high, though on the other hand it might be contended that their practice would show what could be done with water better than the older ones. Even in the canal under consideration, the

duties may be raised from lack of water in the latter part of the season, as when the river falls in August, there may not be sufficient water to bring all the late crops to their best condition of yield. In such a case the comparison of the area with the amount of water which enters the canal will give a duty higher than would otherwise have been the case.

The canal is 35 miles long and passes most of the distance through sandy loam. Its grade is 2.56 feet per mile. The loss from seepage is not definitely known. Much land has been waterlogged since the canal was originally constructed, as has been the case with most canals in the State. From the lowering of the bed of the canal it has been necessary to check the canal in many places to raise the surface of the water for the lateral canals, and the seepage in many places has been lessened if not entirely stopped.

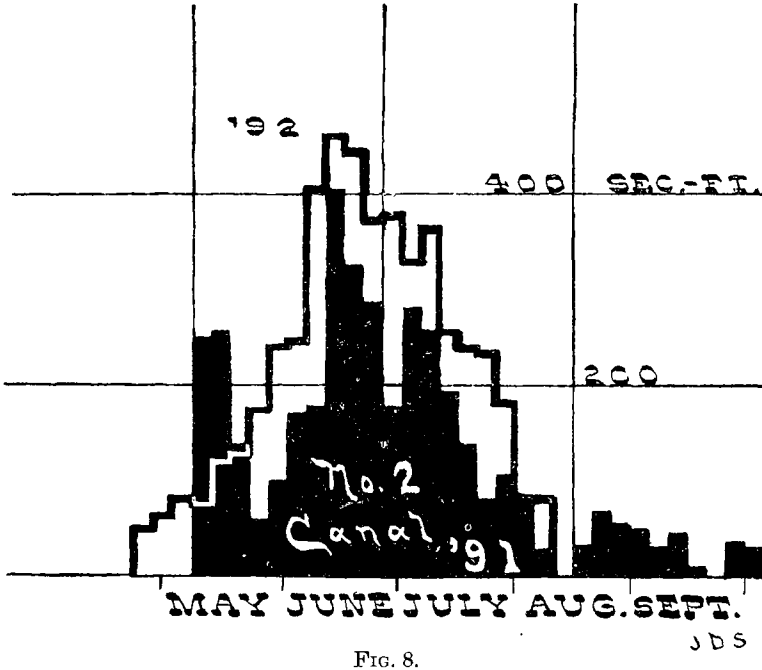

FIG. 8.

The crops raised are principally the cereals, alfalfa and potatoes, the latter of which has become important at the lower end of the canal. The acreage is approximately 7,500 acres of alfalfa, 800 of native grasses, 18,500 of the cereals and potatoes; of this total. nearly 3,000 is irrigated from seepage and water from reservoirs.

Alfalfa is grown in rotation with the other crops. The number of irrigations varies to some extent even in the same year among neighboring farmers; ordinarily two irrigations are given to each crop. Alfalfa would be given more, undoubtedly, if water were plen-

tiful in late summer. Potatoes receive two or three in late summer. The land slopes from the canal towards the stream, the fall averaging over the best of the area 20 to 25 feet per mile.

In order to make a complete study of the water under these conditions it was desired to make a complete record of the land and the crops under the ditch, with the number of irrigations each was given. Though considerable work was expended in this direction the record is too incomplete from the means available for this work.

In 1890 the intake of the canal was taken from the daily gauge heights at the headgate taken by Mr. Hendrickson. The record being printed in the Annual Report for this Station, as is also that for 1891, will only be summed in this bulletin. In 1892 the headgate was visited weekly, the clock wound and the papers changed. In addition to the record, the company has kindly furnished the gauge heights to guard against possible changes in the zero height of the instrument.

Fig. 8 shows the intake for the years 1891 and 1892. The scale is too small to distinctly separate the individual days, and therefore the discharges of five consecutive days have been averaged for the vertical lines. The record for 1891 is from May 9 to October 3; for 1892, from April 17 to August 11, when the water became too low to record. The quantity used after that date is relatively inconsiderable.

The following tables give the amount of water taken into the canal during the various months of the irrigation season. Some water is turned into the ditches early in the season very frequently, and it is kept running as late as water is available, but the water is used principally for purposes other than irrigation. In the aggregate the amount is not important, and would not appreciably alter the results of the tables. The second of the two tables shows the difference in the results obtained in the nominal duty according to the period considered as the season for irrigation. Even in the month of June, which, as shown by the intake, and by the preceding diagrams, is the month when water is used the most freely, the duty of a cubic foot per second from the canal has not fallen below 65 acres during the past three years.

INTAKE IN ACRE FEET.

Month.	1890.	1891.	1892.
April	*	*	741
May	3,582	7,746	7,759
June	20,850	15,050	22,216
July	12,426	10,932	17,266
August	6,372	2,848	2,099
September	1,324	1,334	175
October	*	296	*
Sums	44,554	38,206	50,250
Corresponding depths over 24,000 acres, in feet	1.86	1.59	2.09

*Intake small, principally for stock or trees.

DUTY, ACRES PER SECOND-FOOT—CACHE-A-LA-POUDRE CANAL NO. 2.

Period.	No. of Days.	Canal Alone.			Canal and Rain.		
		1890.	1891.	1892.	1890.	1891.	1892.
May 1—Sept. 1	123	132	153	112	105	108	81
April 1—Sept. 1	153	164	192	146	131	134	101
May 1—Nov. 1	184	198	232	176	153	155	124
June alone	30	72	95	65	71.5	56.5	53.5

DUTY IN THE WHOLE POUDRE VALLEY.

This valley being one of the first in the State to feel the necessity of knowledge of the amount of water available for distribution among the canals, is the one in which there is available the longest series of systematic records. The canals drawing water from the river contributed some $1,500 to construct a gauging station above the point where the canals divert water from the river, and a plank floor was put in place in 1883 under the direction of State Engineer Nettleton and Water Commissioner B. S. LaGrange. This floor remained until 1889, when having become injured by floods and frost, much of the water passed beneath, and the floor was taken away, leaving the natural bed of the stream. The stream flows through masonry sidewalls, a projecting stone being used as the reference point to measure from. Measurements of the amount of water flowing have been made at various stages of the river from depths of 0.7 foot to 4 feet, by L. R. Hope and E. C. Hawkins of the State Engineer's office, and by this section of the Experiment Station with current meters, and from these gaugings the amount of water for intermediate depths has been determined. Though for the past two years the natural bed of the stream has been exposed at the gauging station, there has been but little change in the cross section.

June 9, 1891, a mountain reservoir broke and discharged its waters through the canon, with the effect of carrying away the instrument house, and slightly altering the cross section of the river, so that more water is now carried for the same depth of water.

A self-recording instrument has been at the gauging station for most of the time, which kept record of the rise and fall of the river. Until June, 1891, the instrument was one furnished by the office of the State Engineer. After the flood already mentioned, which resulted in the destruction of the instrument there, one of the Richards instruments was put in place by this section, and from this the readings for 1892 were made until the river became too low to move the float. The method of reduction, which was done by Mr. Trimble, is shown by the table, page 31.

The general character of the stream, which is typical of the streams flowing down the eastern slope of the Rockies, is shown by Fig. 9, which shows the flow of the river during the years 1891 and 1892. With no living tributaries from the plains, these rivers are

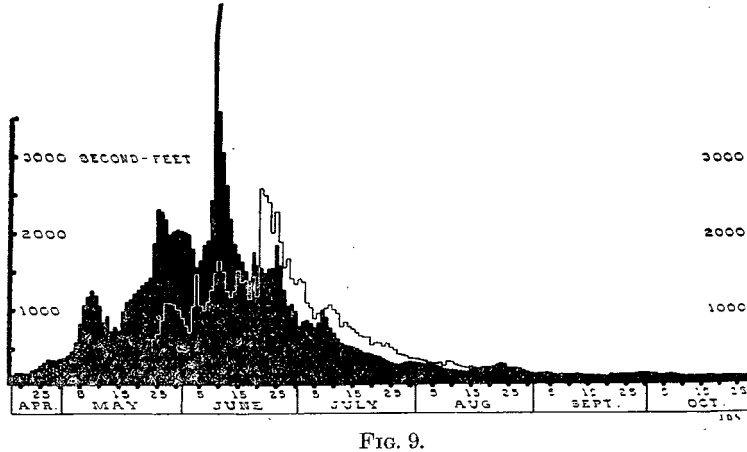

FIG. 9.

fed by the melting snows of the mountains. Low in winter and early spring, they begin to rise as the snows melt, or with the spring rains, and increase with increase of heat, or until there is a lessening in the snow fields, and then decrease until the low stage is reached in the fall and remain low until the rise in the following spring. An understanding of the character of the streams is necessary to understand some of the peculiarities of Colorado practice. The river is usually high in June, sometimes earlier, depending upon the character of the season, and whether a large part of the snow is on the lower or the higher mountains.

The character of the flow of the stream affects both the character of the crops raised and the nominal duty of the valley as a whole. With an abundance of water in June, and little in August,

those drawing water directly from the river, must in a general way grow crops whose needs for water vary somewhat as the stage of the river.

Hence there cannot be a large acreage of crops needing late water without danger of loss. As the late crops are the most profitable, there is a strong temptation to run some risk, especially as the water in early summer is usually in excess of the needs of that period.

Some of the crops do not secure all the water needed. At present it is not possible to determine how much. Some water runs to waste which is counted in the amount entering the valley. There is a rough balancing between the two, and while the results are not so accurate as desired, with these facts in view they will not be misleading and will be useful as a preliminary estimate. It is hoped by the end of another year, by placing a register at the mouth of the Poudre, to have a more definite knowledge of the amount which is not used.

Most of the valley under consideration is retentive of moisture. The crops are the cereals, alfalfa and clover, and especially toward the lower end of the valley, potatoes. The rainfall from 12 years observations at Fort Collins, which is some twelve miles from the gauging station, and about four from the foothills, is 13.80 inches per year. Observations have not been continued at other points in the valley for a period long enough to determine the rainfall, but from the record of two years it seems probable that the average is slightly greater than at Fort Collins.

Table I. gives the average rainfall for the irrigated area, as deduced from the reports of a number of observers who have kindly co-operated by taking observations of precipitation.

Table I. also gives the total amount of water which entered the valley at the gauging station, and shows the number of acres which would be covered to a depth of one foot.

TABLE I.

Month.	River Flow, Acre Feet.		Rainfall, Av. in Inches°	
	1891.	1892.	1891.	1892.
April	8,570	6,450*	1.60	2.00
May	75,090	25,500*	4.50	4.00
June	113,050	86,750	2.00	2.50
July	33,260	45,300	1.50	0.75
August	14,000	11,550	0.25	2.00
September	10,180	6,000*	1.00	1.25
October	7,350	4,650*	0.20	0.15
Totals, April 1—Sept. 1	243,970	175,550	9.85	11.25
" May 1—Sept. 1	235,400	169,100	8.25	9.25
" May 1—Nov. 1	252,930	179,750	9.45	10.65

*Part of month estimated.
°Average for whole valley.

The area supplied by the water measured at the gauging station is considered as 135,000 acres. The total acreage in the valley is slightly larger, but some is irrigated from the waters of the North Poudre, which is not measured at the gauging station. This acreage is not exact, but is believed to be within 3 per cent.

The totals at the bottom of Table I. show the number of acre-feet which entered the valley for given periods; April to September, May to September, and May to November.

Dividing these totals by the number of acres, and reducing the rainfall to feet, we have Table II. Very little irrigation is given in April, except to trees, but, as much water is run in reservoirs, it is included. The table shows that the rainfall during the periods of irrigation is equivalent to a large fraction of the water of the river.

TABLE II.

Period.	Depths in Feet over 135,000 Acres.					
	1891.			1892.		
	River.	Rain.	Total	River.	Rain.	Total.
April 1—Sept. 1	1.81	0.82	2.61	1.30	0.94	2.24
May 1—Sept. 1	1.74	0.69	2.42	1.25	0.77	2.05
May 1—Nov. 1	1.87	0.79	2.66	1.33	0.89	2.22

If all the water which passes the gauging station were applied to the 135,000 acres below that point, the land would have been covered to a depth of 1.74 feet, or 21 inches between May 1 and September 1 in 1891, and 15 inches in 1892. The rainfall during the same time would have increased this to over two feet in each case.

If the water from the river alone be considered, the duty of a cubic foot per second flowing constantly will evidently be larger than when the water furnished by the rainfall is considered.

The duty will also vary according to the length of the season assumed. Table III. gives the number of acres which would be served by the constant flow of one cubic foot per second, and covered to the depths indicated in Table II. The first section of the table considers the water furnished by the river alone, the second portion the depths furnished by the river and the rain together.

The table is taken from Table II. by the formula:

$$\text{Duty} = \frac{\text{2 times the number of days in the irrigation season.}}{\text{Depth of water required in feet.}}$$

This gives a result which is 1-121 too great.

The table, as well as the formula, shows that the duty thus found is greater as the number of days in the irrigation season, with a given depth of water needed, is greater.

TABLE III.—DUTY, ACRES PER SECOND FEET.

Period.	No. of Days.	River Alone.		River and Rain.	
		1891.	1892.	1891.	1892.
April 1—Sept. 1	153	170	233	116	136
May 1—Sept. 1	123	141	195	101	119
May 1—Nov. 1	184	195	274	137	164

This is equivalent to stating the number of acres which the constant flow of one cubic foot per second will cover to the required depth in the given period. This assumes a condition of things which is not attained as yet in Colorado. The diagrams of the water as used on the crops of wheat, and alfalfa, and hay, as well as the inflow into the canal, show that the period of need of water is much less than the legal period, which is from May 1 to November 1, and unless the water which comes when not directly needed for the crops may be stored and saved until needed, the duties as thus found are misleading.

The widely varying results obtained under the same conditions by different methods of estimating the duty of water, or different lengths of the irrigation season, show that the duty as expressed in acres per cubic feet per second may be very misleading unless the whole circumstances be understood. The better way would be to express the depth of water, or, still better, to determine the depth required for a single irrigation, and the number of irrigations then would indicate the total depth of water needed, or would serve to measure the duty of water.

From the tables given we may bring together the depths applied to single crops:

	1st Irrig.	2nd Irrig.
Wheat, Walter Campbell, 1892	6	6
Wheat, J. H. McClelland, 1892	12	5
Wheat, J. H. McClelland, 1892	6	4
Oats, J. H. McClelland, 1892	12	7
Clover, J. H. McClelland, 1892	6	7
Alfalfa, J. H. McClelland, 1892	6	4
Alfalfa, J. H. McClelland, 1892	6	6
Potatoes, S. Hopkins, 1891	4.5	
Potatoes, S. A. Bradfield	6.4	

The measurements on potatoes were made on fields of 4 and 7 acres respectively, forming parts of larger fields.

A single irrigation may require from 4 to 12 inches of water over the whole extent of the area irrigated. The number of irrigations may be lessened by the rainfall, but very skillful management as well as perfect preparation of the ground is required to uniformly water a field with less than three inches in depth of water, even if in sod. It was not long since that 12 inches was considered the uniform practice in this valley; now six would probably be a better estimate when the measures are made at the entrance to the field.

The ultimate duty reached by the individual will depend on the skill with which he can distribute the water, the small depth he can use and make a successful irrigation. As the application of water is generally followed by a temporary checking of the growth of the plant, most Colorado irrigators prefer to give thorough rather than many irrigations. The character of the soil is such as to retain moisture well. Hence the practice of Northern Italy and Southern France and adjacent countries where waterings are given two to four times per month, is rarely followed.

As compared with the duty of water in other countries, that of Colorado is better than is generally supposed. The amount of water applied is in general far greater than with us. Irrigations are given more frequently, but the land being prepared with greater care, the amount of water applied at one watering is generally less.

The duty which is commonly stated in countries using the metric system is one litre per hectare, much as many people in the West are inclined to estimate the amount of water needed as "an inch to the acre," no matter whether the inch is large or small. One litre per hectare is equivalent to 70 acres per cubic foot per second. But as in most of these cases the water is running constantly, the amount of water used is more than is commonly applied under the same nominal rates of duty. On the Cavour Canal system in Piedmont, the association to the west of Sesia uses 136 cubic metres per second from all the government canals on 80,252 hectares, or at the rate of 41 acres per cubic foot per second. Much of this land is sandy with gravelly sub-soil, and the crops irrigated are principally grasses, with some rice.

Reports of very high duties in far off countries are common, and are frequently used to show that the practice in Colorado is wasteful in the extreme, or sometimes to make glowing estimates of the possibilities of a given water supply. Most of these reports, often given on what ought to be good authority, are based on a misunderstanding of the facts. And it is worth while to examine the most persistent reports which are often given, as of a thousand acres per cubic foot per second at Elche in Spain, and of over 2,000 at Lorca.

At Elche some 30,000 acres form the huerta, or irrigated plain, which is irrigated from a small stream, the Vinalopo. But of this area the greater portion, some 23,000 acres, consists of crops like the cereals which can prosper without irrigation and rarely receive irrigation. The only portion which absolutely needs irrigation are the plantations of palms, amounting to about 300 acres. The stream carries 600 litres per second in the lowest period, or 21 cubic feet per second, and 1,000 litres per second at ordinary times. There is a reservoir, the reservoir of Puentes, so that the water used during the season generally exceeds 1,500 litres per second. If all the huerta were cultivated and irrigated, the resulting duty would be about 560 acres per second foot, but as the summer irrigation is confined to less than 7,500 acres, the duty is between 140 and 150 acres per second foot, instead of the 1,000 which is often said.

At Lorca the reports of high dutes are still greater, making it over 2,000 acres per second-foot. This is under similar circumstances to the huerta of Elche, and the basis for high duty is the same. The area of the huerta is, according to Aymard, 27,500 acres, and the flow 340 litres, or 12 cubic feet per second; whence if all is irrigated, the duty would be 2,300 acres per second-foot. But Aymard also says that the large proportion is of cereals which require but one or two irrigations per year, ordinarily, and the irrigations may be entirely omitted.

Zoppi and Torricelli, two Italians who visited Spain for the Italian government in 1886, in *Irrigazioni e Laghi Artificiali della Spagna*, give the mean winter flow of the stream as 1,000 litres, or 35 cubic feet per second, which gives a duty for the winter season of 780 acres per second-foot. Much of the huerta is devoted to winter crops, which require no more than two irrigations per year. In summer there are small crops and the stream carries 340 litres, or 12 cubic feet per second in low water. But at this time the number of acres irrigated falls short of 2,500, whence the duty is only about 200 acres per second-foot, instead of the 2,000 reported.

THE LARIMER & WELD CANAL.

The Larimer & Weld Canal is the largest of the canals drawing water from the Poudre river. The farmers drawing water from it have the reputation of using water to great advantage. Daily gauge heights are taken of this canal by the Company, under the direc-

tion of the Water Commissioner. The acreage using water from the different canals is to some extent uncertain, but during the last season, the acreage of the different crops underneath this canal was taken by Hon. A. L. Emigh and from the report of the Water Commissioner, John L. Armstrong, to the State Engineer. The acreage is given as 5,407 alfalfa, 1,540 grasses, 29,547 other crops, almost entirely cereals and potatoes. Total, 36,494 acres. An area of 6,600 acres is reported as irrigated by water from reservoirs and from seepage, which area is included in the above.

From the daily gauge heights, the amount of water entering the canal during the period from May 1 to September 1, is as follows:

	Acre-feet.
May	11,248
June	26,196
July	10,896
August	745
Total from canal	49,085

Some water entered the canal both before and after this period, but the additional amount taken from the river does not appreciably affect the average depths applied, and perhaps should not be considered, inasmuch as but little of that which does enter outside of these months is used for irrigation.

There is, however, a reservoir belonging to a company of farmers drawing their water from this canal. The reservoir being filled from other sources of supply than the canal, increases the depth of water applied correspondingly. The Terry Lake reservoir furnished some 5,500 acre-feet of water during the past season, thus making the total amount applied to the land 55,585 acre-feet approximately. The water from the reservoir was all used for late crops, principally potatoes, in late August. The corresponding duties, if water be considered to flow constantly during the periods as in the preceding tables, would furnish duties in acres per cubic foot per second, as in the following summary:

Period.	No. of Days.	Irrigation.	Irrigation and Rainfall
May 1—Sept. 1	123	165	109
April 1—Sept. 1	153	205	126
May 1—Nov. 1	184	246	155
June alone	30	81	64

THE ULTIMATE DUTY OF WATER.

A large amount of water is needed for carrying on the vegetable processes, and this must fix the ultimate duty to be expected from water even under the most economical methods. Ordinarily it may be estimated that for each pound of dry matter produced, three hun-

dred times as much water has been evaporated from the leaves. Some variation is to be expected in different kinds of plants, and in the same kind under different conditions; but as a whole, the variation is less than might be supposed. The subject has been experimented upon by many. According to the experiments of Hellreigel, quoted by Storer (Agriculture, 1:14), the cereals require more than the leguminous crops, weight for weight; and of the cereals, oats more than wheat, the amount varying from 376 pounds for oats to 273 for peas, for each pound of dry matter produced. If the ratio be considered as three hundred to one for alfalfa, then to produce three cuttings of 3,000 to 4,000 pounds each per acre during the season, a depth of from 12 to 16 inches must have been available for transpiration from the leaves for the growth of the crop. There is, in addition, some growth of the roots in the soil which would require an additional amount of water. If this growth be considered as confined to five months, say 153 days, as used in some of the preceding tables, the net duty of a cubic foot per second could not exceed 225 acres, even if there was no waste. Such water as the plant secures from other sources than irrigation, as rainfall, from ground water, etc., would lessen proportionately the amount which it would be necessary to supply by irrigation, but when it is considered that this does not allow for any of the losses by evaporation or seepage from the ditches, evaporation from the surface of the soil, or losses by downward filtration, which in the aggregate are large, we may consider such a duty as exhibiting good, if not the best practice.

Bringing these results together for comparison, there results the following table, showing the depths which, on the average, have been applied to the lands under the two canals under consideration, and to the valley as a whole. The second part of the table gives the corresponding duties. There is some water applied once to the lands which returns to the river. In the average it seems to equal to the flow of ninety cubic feet per second between the measuring flume in the canon and the last canal taken from the river, as based on a series of measurements taken in the fall, by the State Engineer's department, and by this section of the Experiment Station, and by one determination in the spring by this section. There are reasons to think it is approximately constant. This water is again taken from the river by the various canals, and should be counted with the water which is applied to the land of the whole valley, for unless this inflow could be utilized, it is evident that a correspondingly greater amount of water would be needed to enter the canon, or else the acreage in crops would be correspondingly less. Counting the return as ninety cubic feet per second for the time covered by the table, the duties of a cubic foot per second as measured at the heads of the canals, is given by the numbers in the line where seepage is included.

For the valley there is given the average duty. When seepage is considered it may be noted that the duties for the whole valley are nearly the same as those of the Larimer & Weld Canal.

DEPTHS IN FEET.

	May 1 to Sept 1 123 days.		Apr. 1 to Sept. 1 153 days.		Apr. 1 to Nov. 1 184 days.		June 30 days.	
	Depth from Irrigation.	Irrigation and Rain.	Depth from Irrigation.	Irrigation and Rain.	Depth from Irrigation.	Irrigation and Rain.	Depth from Irrigation.	Irrigation and Rain.
No. 2 Canal	2.09	2.86	(2.09)	3.03	(2.09)	2.96	.925	1.12
Larimer & Weld Canal	1.49	2.26	1.49	2.43	1.49	2.36	.73	.93
Valley	1.25	2.02	1.30	2.24	1.33	2.22	.64	.84
Valley, seepage included	1.41	2.18	1.50	2.44	1.57	2.46	.68	.88
CORRESPONDING DUTY PER SECOND-FOOT, IN ACRES.								
No. 2 Canal	112	81	146	101	176	124	65	53½
Larimer & Weld Canal	165	109	205	126	246	155	81	64
Valley	195	122	233	136	274	168	94	71¼
Valley, seepage included	174	113	204	125	244	151	88	68

The bulletin, intended only as a step towards determining the present practice in Colorado, holds true of other valleys so far as the conditions of the Cache-a-la-Poudre valley are typical.

The duty, as estimated in acres per cubic foot of water per second, may vary between wide limits, according to the method of estimation, and on the same farm and the same depth of water applied. Unless these conditions are taken into account, it is better to estimate the depth of water needed and the time through which it is necessary. There is less difference between different canals and different users than is generally considered true.

The amount of water given at one irrigation depends more upon the preparation of the ground or its conditions than upon the crop. Under Colorado conditions, irrigations of less than six inches in depth are rarely given.

The difference between the nominal rates of duty in Colorado and those in other countries, has been partly because those of Colorado are based upon the use in June, the month of greatest need, while those of others take the whole season or year through. When reduced to the same basis, the practice in Colorado agrees favorably with that of other countries. It would seem as probable from the measures that the average duty of one cubic foot per second flowing constantly, as measured at the head of the canal, is 60 to 65 acres in June, to 175 to 300 for the whole season. The last represents the conditions when a reservoir is available in which water may be stored.

Amount of Water Taken into the Cache-a-la-Poudre Canal No. 2.

DATE. 1892.	Uncorrected Reading of Register.	Corresponding Depth in Rating Flume. Feet.	Number of Time Divisions.	Cubic Feet per Second Passing Rating Flume. Cor. to Height in 3.	Number of Time Divisions times Height, Cor. to Height in 3.	Cubic Feet per Day, being Numbers in 6 times 3½ Number of Seconds in One Time Division.
May 9, 5:25 p. m.	16.8	1.30	11	59.0	649.0	
"	17.8	1.40	52½	68.0	3,570.0	
"	18.0	1.42	5½	69.8	383.9	5,078,003.8
May 10	18.0	1.42	18	69.8	1,256.4	
"	18.2	1.44	16	71.6	1,145.6	
"	18.4	1.46	89	73.4	6,622.6	
"	18.2	1.44	50	71.6	3,580.0	
"	19.0	1.52	62	79.0	4,898.0	
"	19.1	1.53	12	80.0	960.0	6,461,910.0
May 11	19.1	1.53	58	80.0	4,640.0	
"	19.3	1.55	176	82.0	14,432.0	
"	19.6	1.58	13	85.0	1,105.0	7,061,950.0
May 12	19.6	1.58	84½	85.0	7,182.5	
"	19.6	1.58	86	85.0	7,310.0	
"	19.5	1.57	59	84.0	4,756.0	
"	19.9	1.61	17½	88.0	1,540.0	7,275,975.0
May 13	19.9	1.61	90	88.0	7,920.0	
"	20.4	1.66	38	93.0	3,534.0	
"	20.2	1.64	18½	91.0	1,683.5	
"	20.4	1.66	3	93.0	279.0	
"	20.8	1.70	35	97.0	3,395.0	
"	21.7	1.79	44	106.0	4,664.0	
"	22.9	1.81	19	108.1	2,053.9	8,234,290.0
May 14	22.9	1.81	28	108.1	3,026.8	
"	22.6	1.88	5	115.8	579.0	
"	24.5	2.07	106½	139.8	14,888.7	
"	23.5	1.97	85½	126.4	10,807.2	
"	23.4	1.96	22	125.2	2,754.4	11,219,635.0
May 15	23.4	1.96	158	125.2	19,781.6	
"	23.2	1.94	46	122.8	5,644.8	
"	22.9	1.91	20	119.2	2,384.0	
"	22.4	1.86	23	113.6	2,612.8	10,648,120.0
May 16	22.4	1.86	2	113.6	227.2	
"	22.5	1.87	15	114.7	1,720.5	

DIAGRAM.

Knowing the depths which may be necessary during the season and the number of days in which it must be applied, the diagram shows the number of acres which one cubic foot per second flowing constantly during that time will serve, or the duty. Thus if one foot is needed for wheat in forty days, look at the right for the depth required. At the top find the vertical line corresponding to the number of days as forty in which the amount of water is needed, say one foot for wheat. At the intersection of the two lines is the diagonal line showing eighty acres as the corresponding duty: