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Losses from Canals from Filtration or Seepage.

Approved by the Station Council,

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FORT COLLINS, COLORADO.

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THE AGRICULTURAL EXPERIMENT STATION,

FORT COLLINS, COLORADO.

ON THE LOSSES FROM CANALS FROM FILTRATION OR SEEPAGE.

By L. G. CARPENTER.

The present bulletin is one of a series bearing on irrigation questions, and while suggested by the conditions in Colorado, it is not limited in its application to that State. The author has kept steadily in view the fact that Colorado has a limited supply of water and that the success of her individual farmer, as well as her agricultural extent, depends upon a clear understanding of the means of using water properly, of saving useless losses, and of the prevention of waste. While the author has believed that there are questions which might be more immediately useful to the individual farmer, he is fully convinced from a study of the development of other irrigated countries, that in the formative period of our development a more lasting benefit will accrue to the agriculture of the State by considering certain fundamental questions not so immediately applicable to individuals.

The present bulletin, however, has its immediate individual application. It is to some extent complementary to bulletin 33, on seepage or return waters from irrigation. While the earlier bulletin discussed the seepage or return waters entering streams, the present bulletin considers the losses from canals which, there is reason to think, is the principal source of the gain in the streams. If the connection between the canals and the streams is an intimate one, we may finally expect to find an approximate equality between the losses from the canals and the gains in the streams.

But more suggestive, the measurements here reported give an idea of the extensive losses involved in the carriage of water. The amount has been believed to be large, but when it is found that the leakage may become as much as 20 or even 30 feet in depth per day, it suggests the importance of taking steps to lessen the amount.

By stating the loss in the depths lost per day, a better idea can be obtained even by those familiar with the terms of water computation.

The loss of water from canals and distributaries seems to be greater than the loss from irrigation into the soil. Many cases of leakage can be lessened with profit, thus saving considerable water, and much more water can be saved when its value is enough to warrant the expense.

While the author's conclusions are necessarily influenced by the cumulative effect of numerous observations difficult to fully summarise, the measurements throwing light on the subject under discussion, are presented with sufficient fullness to enable the reader to disagree with the writer if the facts do not warrant his conclusions.

The loss from canals is known to be large, and often produces a serious problem in their management. This loss is often the cause of unnecessary scarcity in the water supply, especially at the lower end of the canal during the season when water is low. It has sometimes been enough to cause canals or laterals to be abandoned. It has many times led to failure of crops and has always made a material decrease in the water supply. The serious nature of the loss has been understood by the farming community, and associations have sometimes discussed methods by which it might be lessened. But I am unaware of any serious attempt to locate the loss or to determine the amount.

While we have made occasional measurements on the losses from canals, the past year (1897), has been the first when systematic measurements could be made. Without attempting to develop the general law of the loss, the measurements on a number of canals under different conditions are given with such conclusions as the data seem to warrant. A knowledge of the facts is the first step toward finding the remedy, or even to decide whether a remedy need be sought.

It is hardly necessary to observe that the cases here given are specific ones, and the losses found in these cases, may or may not be the same on other canals. The similarity of conditions, especially the similarity of the canal bottom, gives a basis for judgment. In many cases the loss is undoubtedly less, in others more. Hence the need of caution in hastily assuming that these measurements apply to all cases. So far as the canals chosen represent average conditions, the measurements may be considered as averages. From these and from a larger number of cases we may hope to determine the probable losses and from more extensive investigations obtain principles which may be applicable under new conditions.

The canals measured include stretches of canals in the Platte Valley and Cache a la Poudre valley near Fort Collins, and several in the San Luis valley, and one canal on which automatic records were kept for two years. The method of measurement was essentially the same in all cases, namely, to measure the amount flowing in the canal at different points, and then to compare the increase or decrease in the amount of water in the canal after allowing for the water taken out by laterals between the points of measurement. The measurements show that many of the canals, especially those deep in the ground, serve as drains during a portion of the year or for a portion of their course. This is often true where there are other canals on higher ground whose seepage drains into the lower canal. Some canals lose water in places and gain water in other places. We have thus found some stretches where the results differ from those anticipated. In some cases the loss from the canals was found to be very large.

The results suggest that it is desirable for many of the larger canals to determine their loss from seepage throughout their length and thus determine whether unreasonable losses take place in any portion. It is true that some sections are much more subject to loss than others, in fact that much of the loss is apt to be in a comparatively short distance. When such is the case it may be profitable for the company to take steps to lessen the amount of loss.

The loss of water from canals has been considered an incident necessary to the carriage of water. To a limited extent this is true, but where the loss is more than moderate, it may be considered as due to defective conditions, and generally can be lessened. The loss from the canals is a pure evil. It lessens the amount of water available for use and in so much lessens the productive power of the land under the canal. In some cases it may be sufficient to cause the damage or loss of crops. More than that, the seepage is undesirable to the lands below the canal. In most cases it is a positive injury, leading to the water-logging of tracts of land, and frequently results in troublesome claims for damage against the canal company.

METHOD OF EXPRESSING THE LOSS.

For the present I prefer to express the loss as the depth over the surface of the canal, lost in one day, rather than in per cent. of the water in the canal. The losses from different canals are then more easily compared, and cases of unreasonable loss sooner recognized. In ditch management the tendency is to express the loss in per cent. in which case the loss suggests nothing as to the economy of water. To say, without other information, that a canal loses 25 per cent., gives no indication whether the carriage is economical or not. In a long canal the managers could congratulate themselves that it is no more; in a short canal it might be excessive and should set the officers to determining the location of the losses and to seek a remedy.

For those unaccustomed to this form of calculation, it is convenient to remember that the amount of water given by one cubic foot per second in 24 hours is enough to cover two acres one foot in depth (correct within less than 1 per cent.), and hence a daily loss of two feet over an acre would require the constant flow of one cubic foot per second to make good. The deeper the water in the canal the more rapid is the leakage, but with our ignorance of the exact relation we neglect the depth and consider only the surface of the canal. In the table full data is given and if the connection is subsequently determined, the data should be sufficient for the later investigations. It would doubtless be better to consider the wetted area of the canal rather than the width as a factor. As the canals are shallow and broad it matters little whether the surface area of the canal or the wetted area is used.

EVAPORATION RELATIVELY SMALL.

In considering the losses from canals, it is common to consider the loss from seepage and evaporation together. In most cases the evaporation is small in comparison with the loss from seepage. In ten years record of an evaporation tank freely exposed to the sun and wind, at the State Agricultural College, Fort Collins, Colorado, the annual evaporation has averaged but 41 inches.*

The temperature of the water surface in the tank is, however, lower than in many of the canals. As evaporation increases with the temperature of the water, the evaporation from some canals would be correspondingly

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*Annual reports Colo. Agricultural Experiment Station, 1889 and 1890. Monthly evaporation given in full, table 4, p 18, bulletin 45, on Losses from Reservoirs.

greater. Nevertheless, only on specially favorable days can the evaporation from a canal surface amount to as much as one-half inch for the twenty-four hours. But the loss from seepage is rarely less than one foot and more often twice that in the same time, hence the evaporation is relatively small and may be left out of consideration in this connection without affecting our conclusions.

CANAL SEEPAGE IN THE CACHE A LA POUDRE VALLEY.

The Pleasant Valley and Lake Canal is an old canal taking water from the south side of the Cache a la Poudre river near the canon. It was originally built to supply lands in Pleasant valley, a glade of several hundred acres formed by the faulting and erosion of the rocks, principally the red sandstone, between the Dakota sandstones and the primitive rocks. The general course of the river is to the southeast; the canal sweeps to the south in a long curve, mounting the first and second benches and skirting at places the bluffs which form the edge of these benches. The ridge of Dakota sandstone confining the river between cliffs on either side, forces the canal back to the river, and its course almost overhangs the bed of the river. Through this ridge the canal is through and over the rock on a steep grade with some tunnels. The bank is often rockwork, with some soil. After passing this ridge the canal bends abruptly south, leaving the river at a large angle, and skirts the foot of the hog-backs formed of the ridge of resisting Dakota sandstone. It is thus the highest ditch on the south side of the river and like such ditches, is known locally as the "Highline." There is no irrigation of any extent above the canal. In several places a few acres are watered from reservoirs filled from small mountain streams. There can be no seepage into the canal except as furnished by the natural rains. The drainage of about 35 square miles is cut by the canal, but except in or after storms there are no surface streams. There are several small streams above the line of the ditch, but all disappear before reaching the line of the canal. Plum thickets show that spring waters appear near the surface in many places. The observers passed on foot along the bank of the ditch and thus could not miss any of the lateral headgates.

The conditions were favorable for loss by seepage. Much of the soil is of coarse gravel and sand, and the canal skirts the edge of the benches, across sandstone ridges with the strata exposed and with a decided dip offering an easy course for descending waters.

The measurement showed a loss in 7 miles of over 15 cu. ft. per second; or, starting from the river with 22.09 cu. ft. a little over 2 cubic feet being withdrawn by lateral ditches, there were left but 4.54 cu. ft. or there was a loss of a little over 15 cu. ft. per second.

In the portion outside of the foothills occasional gains were found. In most cases the gains were found to be associated with drainage areas of some extent. The soil is largely disintegrated granite, coarse and porous, and absorbs rain very readily.

TABLE I a.

PLEASANT VALLEY AND LAKE CANAL.

Measurements made by R. E. Trimble and J. C. Mulder.

No. of Measurement.	Date and Hour.	Place of Measurement.	Amount.	Outtake.	Gain or Loss.	Dist. in Miles.	Notes.
	1897—						
1	Oct. 23, 9:20-[illegible]:50 a. m.	Canal near headgate	22.09				
	" 10:20 a. m.	Lateral		0.16			
2	"	Canal (near Capt. Post's upper place)	17.23		-4.70	1.30	Gravelly and sandy; near river.
	" — 11:40 a. m.	4 Laterals		.69			
3	" 11:50-12 m.	Canal (point of bluff below school house)	10.64		-5.90	1.31	" " "
	"	6 Laterals		.02			
4	" 1:20-1:55 p. m.	Canal at road crossing	7.85		-2.77	2.39	West of Bellevue, clayey sand.
		10 Laterals		1.51			
5	" 3:10 p. m.	Canal (near C, E. Pennock's)	7.17		+0.83	1.45	Crosses several lines of drainage.
		Lateral		0			
6	" 3:55-4:00 p. m.	Canal (50 ft. below 1st tunnel)	6.29		-0.88	.82	Stratified slope; rocks inclining.
		Lateral		0			
7	" 4:30-4:35 p. m.	Canal (200 yds. above 2nd tunnel)	5.65		-0.64	.72	" " "
8	" 4:55-5:00 p. m.	Canal (at end of rock work on Bingham hill)	6.41		+0.76	.50	Crosses some of the glades of ridge.
		Lateral		0			
9	" 5:20-5:30 p. m.	Canal (near Claymore lake)	4.54		-1.87	.30	Along outer side ridge near junct'n of earth and rock.
9	30, 8:30-8:40 a. m.	At same place	17.98				
	"	2 Laterals		Trace			
10	" 9:20-9:30 a. m.	Canal (west of Michaud's)	19.07		+1.09	1.04	In excavation.
	" —	7 Laterals		1.19			
11	" 10:55 11:10 a.m.	Canal (west of Prendergast's)	16.53		-1.35	2.50	Crosses ridge of sandstone.
	" —	2 Laterals		1.16			
12	" 11:40-11:55 a.m.	Canal (west of cemetery)	13.57		-1.80	1.41	Along side hill, moderate slope.
	" --	2 Laterals		0.15			
13	" 1:15-1:25 p. m.	Canal (west of Loomis' farm)	13.42		0	1.94	Some seepage showing below ditch.
	" --	5 Laterals		6.19			
14	" 2:35 2:45 p. m.	Canal (west of B. B. Harris' farm)	11.73		+4.50	2.55	Some land irrigated above ditch from Dixon canon.
	" --	3 Laterals		0.16			
15	" 3:45-3:55 p. m.	Canal (west of Rugh Farm)	13.02		+1.45	1.75	Crosses some lines of drainage.
	" --	11 Laterals		2.82			
16	" 5:25-5:30 p. m.	Canal (west of Cunninghams)	9.95		-0.25	2.64	More gravelly, some irrigated land above ditch from Spring canon.

Measurements by R. E. Trimble and J. D. Stannard.

12	1898— April 23, 8:55 a. m.	Canal west of Cemetery	17.26				10:10 a. m. at starting point, no change noticed.
		2 Laterals		1.25			
	" 9:45-9:57 a. m.	Canal near west end of bend about ½ mile.	17.56		+1.55		
13	" 10:25-10:38 a. m.	Canal west of Loomis' farm	17.97		+0.41	1.94	At 2:00 p. m. the water had fallen ⅝ in.
		8 Laterals		6 62			
14	" 12:02-12:12	Canal west of B. B Harris' farm	12 67		+1.32	2.55	Water fallen ½ inch since noon.
	" 2:30-2:41 p. m.	At same place	11.69				
		6 Laterals		0.61			Water had fallen 2 inches by 4:25 p.m.
15	" 3:40-3:50 p. m.	Canal west of Rugh farm	8.53		-2.55	1.75	Water had fallen ½ inch by 6:10 p. m.
		10 Laterals		3.31			
16	" 5:38-5:45 p. m.	Canal west of Cunningham's	5.91		+0.69	2.64	

TABLE I b.

PLEASANT VALLEY AND LAKE CANAL.

Place of Measurement.	Temp, of Water.	Area of Section. Sq. Feet.	Average Depth in Feet.	Greatest Depth in Feet.	Surface Width. Feet.	Gain or Loss. Sec. Feet.	Distance in Miles.	Equivalent depth of Loss in ft.
1	42°.7	21.23	1.34	1.72	15.9	....	0	....
2	43°.9	18.74	.90	1.26	18.9	-4.70	1.30	-4.7
3	44°.5	7.20	.64	0.81	11.2	-5.90	1.31	-5.1
4	48°	7.26	.63	0.87	11.5	-2.77	2.39	-1.7
5	48°	4 89	.54	0.75	9.0	+0.60	1.45	+0.7
6	48°	3.93	.44	0 65	8.8	-0.71	.82	-1.6
7	48°	3.68	.50	0.72	7.4	-0 64	.72	-0.4
8	48°	4.90	.65	0.97	7.5	+0.76	.50	+1.7
9	47°.5	12.63	1.09	1.59	11.6	-1.87	.30	-3.2
9	39°	18.40	1 36	2.07	13.5	....	0	....
10	39°.5	13.71	.64	0 79	21.5	+1.09	1.04	+1.0
11	41°	14.40	1.00	1.27	14.3	-1.35	2.50	-0 5
12	42°	12.56	.70	1.12	16.3	-1 80	1.41	-1.4
13	44°	13.73	84	1.10	16.3	0	1.94	0
14	44°.2	12.40	.84	1.42	14.8	+4.50	2.55	+1.9
15	44°.5	11.01	.77	1.02	14.4	+1.45	1.75	+0.9
16	....	9.98	1.00	1.45	10.0	-0.25	2.64	-0.1
12	50°	15.45	1.13	1.39	13.7	0	....	....
13	51°.8	13.60	1.07	1.35	12.7	+1.55	....	....
13	53°.0	13.92	.97	1.26	14.4	+0.41	1.94	+1.3
14	55°.0	12.24	.84	1.25	14.6	+1.32	2.55	+0.6
14	55°.0	11.99	.79	1.34	15.1	....	....	....
15	55°.8	9.11	.67	0.88	13.5	-2 55	1 75	-2.7
16	55°.0	5.90	.62	1.01	9.5	+0.69	2.64	+0.4

SEEPAGE FROM CANALS IN THE SAN LUIS VALLEY.

Measurements were made to determine the loss by seepage and absorption on a number of canals and on laterals, approaching canals in size, in the San Luis valley, and the measurements are given in the following tables. These include measurements of the losses on the Empire canal, on the Blackmore or Fisk Ditch, on the Prairie Ditch, on a branch of the Rio Grande canal, known as the North Farm lateral or ditch, and on other laterals of the company known as the 1 F and 1 C laterals.

The conditions in the San Luis valley are somewhat different from those in most places of the state, but the conditions causing the loss or gain by canals are necessarily the same.

The San Luis valley is one of great extent—nearly the size of Connecticut. In Geological times it was the bed of a lake. Its surface is of very uniform and moderate slope, so that canals often pass for long distances in straight lines. The Prairie Ditch, for example extends nearly twenty-six miles on a straight line without turn or bend. The fall of the country is moderate, though large for canal purposes. It decreases from about fourteen feet per mile near the rim east and west, to half as much as the center of the valley is reached. A map of the valley showing these contour lines has been prepared and will be published in connection with a bulletin giving further results of investigations in the valley.

A large part of the valley is irrigated by sub-irrigation which consists in filling the sub-soil by water from the canals and laterals. The slope of the land is so uniform and gentle that the water does not find low places in which to appear in the form of seepage as in an undulating region.

The general process of irrigation in these regions is to run water into the laterals and allow it to soak away, and by so doing fill the sub-soil until the water is at a moderate distance from the surface, about eighteen inches being desired during the growing period of the grain crops. The soil of the valley is very deep, but is everywhere underlaid with coarse gravel which becomes finer as the distance from the mountains increases. Most of the ditches are excavated into this gravel.

The irrigated region includes most of the valley east of what is known as the "Gun-barrel road"—which extends directly north from Monte Vista—and the tract in which sub-irrigation shows, includes a portion of this region. In places irrigation extends west of the road. It may be expected that as long as the surface of the underground water is below the bottom of the canal there will be loss of water by seepage. Where the ground water rises above the bottom the canal may then act as a drain and carry away a portion of the ground water, and the canal is thus found to increase in volume by seepage.

Circumstances prevented making as extensive measurements of canals as desired, but a distance of some forty miles has been measured, which is sufficient to reveal the extent of the losses and some of the conditions.

The Empire canal is one of the largest canals taken from the Rio Grande river. It heads on the south side some miles east of Monte Vista. It is cut rather deeply in the plain. In the first five miles there is found a gain of six-cubic feet per second.

The Blackmore ditch is a small ditch on the north side of the river, heading nearly opposite the town of Monte Vista and extending east. It starts above the region that is showing sub-irrigation and for a portion of its length its channel is a little above the plain. It was found to lose nearly four cubic feet per second in two miles.

The Prairie ditch was measured for some miles from its headgate directly east. The change in volume seems to be irregular, there being a gain of 1.42 feet in three miles, passing across the river bottom, then a loss of 1.80 feet in one and one-half miles through a gravelly soil; then as it strikes the region that is more or less sub-irrigated, a gain of a little over two feet in the first two miles and a gain of a little over a foot in the next two miles. The last mile measured showed a loss of nearly two cubic feet per second.

The North Farm lateral is a branch of the Rio Grande canal. The Rio Grande canal takes water from the Rio Grande river near Del Norte and with a northeast course runs almost at right angles to the river to Saguache, forty-five miles northeast. The North Farm lateral passes nearly parallel to the river. Its course is through the gravelly soil and the excavation extends into the boulder gravel for most of the length measured. Mile posts are placed along the ditches belonging to the company, so that distances could conveniently be told. The first measurement was made at the second mile post from the main canal and then at each subsequent mile post along the line of the lateral. Two measurements were made at different times, on July 6th and August 3rd. At the first date the amount of water in the lateral was nearly twice as great as at the last date, and the loss of water was found to be about twice as much. The measurement was carried on until the canal reached the border of the sub-irrigated region.

Laterals 1F and 1C, which were measured, are branches of the same system.

A measurement was made on the loss of water from the Blackmore ditch early in May, in a stretch east of the "Gun-barrel road" and included in the measurement otherwise reported. The amount of water in the lateral was measured by floats at two points nearly one-half mile apart. The discharges were found to be 2.85 and 2.43 cu. ft. per second in two places, or a loss of .93 cu. ft. per sec. per mile of ditch, or equivalent to a depth of 3.72 feet over the surface of the ditch. If the gravel consists of one-third voids this would be equivalent to a velocity of 12 feet per day through the soil.

TABLE II a.

LATERAL 1C RIO GRANDE CANAL SYSTEM.

Measurement by R. E. Trimble.

Date and Hour.	Place of Measurement.	Amount Measured Sec. Feet.	Outtake. Sec. Feet.	Gain or Loss. Sec. Feet.	Distance in Miles.
August 2, 4:30 p. m	3½ miles	18.79	....	....	....
" 4:00 p. m	4th mile post	21.17	....	+2.38	0.5
" 3:45 p. m	5th mile post	17.66	....	-3.51	1.
" 3:20 p. m	6th mile post	15.06	....	-2.60	1.
" —	Lateral 100 yards below 6-m	....	7.56	....	....
" —	Lateral ½ mile below 6-m	....	0	....	....
" 2:30–2:45 p. m	At 7th mile post	7.30	....	-0.20	1.
	PRAIRIE CANAL.				
1897—					
July 13, 3:20 p. m	Near headgate	36.41	....	....	....
" "	McDonald lateral	....	2.25	....	....
" "	Small ditch	....	.08	....	....
" " 4:20 p. m	1½ mi. west Gunbarrel road	35.50	....	+1.42	3.5
" "	Lateral	....	1.79	....	....
" "	Lateral	....	0.13	....	....
" "	At Gunbarrel road	31.91	....	-1.80	1.5
" 14, 8:20 a. m	At Gunbarrel road	29.25	....	....	....
" " 9:10 a. m	North of North Farm	31.39	....	+2.14	2.
" "	3 Laterals	....	2.81	....	....
" " 10:25 a. m	4 miles east	29.62	....	+1.04	2.
" " 11:00 a. m	5 miles east	27.80	....	-1.80	1.

TABLE II b.

LATERAL 1C RIO GRANDE CANAL SYSTEM.

Date and Hour.	Temp. of Water.	Area of Section. Sq. Feet.	Average Depth. Feet.	Greatest Depth, Feet.	Surface Width, Feet.	Gain or Loss. Sec. Ft.	Distance in Miles.	Corresponding Depth of Loss.
Aug. 2, 4:30 p. m.	70°.8	10.48	.65	0.89	16.	....	....	....
" 4:00 p. m.	72°.3	9.38	.59	0.90	16.	+2.38	0.5	+4.95
" 3:45 p. m.	75°.4	6.94	.73	1.10	9.5	-3.51	1.0	-3.88
" 3:20 p. m.	78°.0	8.96	.75	1.04	12.	-2.60	1.0	-3.60
" 2:30 p. m.	81°.0	10.04	.89	1.32	11.3	+0.35	1.0	+.48
			PRAIRIE CANAL.					
July 13, 3:20 p. m.	....	38.30	1.38	1.70	27.7	....	0	....
" " 4:20 p. m.	....	17.42	.67	1.40	26.	+1.42	3½	+.85
" " 5:15 p. m.	....	19.60	.98	1.28	20.	-1.80	1½	-.86
" 14, 8:20 a. m.	62°	18.32	.92	1.20	20.	....	....	....
" " 9:10 a. m.	65°	14.20	.42	0.80	23	+2.14	2	+.79
" " 10:25 a. m.	67°.5	12.30	.57	0.65	21.6	+1.04	2	+.38
" " 11:00 a. m.	71°	15.12	.57	0.65	26.	-1.80	1	-1.24

TABLE III a.

NORTH FARM LATERAL.

First and Second Measurements.

Date and Hour.	Am't.	Out-take.	Gain or Loss.	Distance in Miles	Place of Measurement.	Date and Hour.	Amt	Out-take	Gain or Loss.
July 6, 1897.						Aug. 3, 1897			
11:00 a. m.	199.50				150 feet above mile post 2*	9:45 a. m.	90.50		
11:30 a. m.		85.085			North branch	11:00 a. m.		40.75	
11:40 a. m.	123.81		+9.41	2.	South " near 4th mile post		53.29		+3.52
1:10 p. m.	124.45	0	+0.63	1.	5th mile post	11:30 a. m.	52.14		-1.15
2:15 p. m.	117.55	0	- 6.90	1.	6th mile post	12:50 p. m.	49.33		-2.81
2:45-3:00 p.m.	103.32	0	-14.23	1.	7th mile post	1:30 p. m.	44.92		-4.41
		23.00			Lateral	1:50 p. m.		12.76	
3:40 p. m.	89.38		+9.06	1.	8th mile post	2:10 p. m.	5.96		+3.80
4:00 p. m.	78.50		-10.88	1.	9th mile post	2:35 p. m.	34.10		-1.86
		29.33			Lateral about ¼ mile below			7.67	
		2.11			" " ⅜ " "			.01	
		4.72			" " ½ " "			0.60	
		10.10			"			1.70	
5:00 p. m.	32.54		+0.30	1.	10th mile post	3:35 p. m.	22.92		-1.14
		0.43			Lateral 200 yards below			.39	
		1.51			" " " "			.01	
		.22						.02	
5:30 p. m.	30.44		.06	1.	11th mile post	4:20 p. m.	20.89	.40	-1.21
					* Bottom of boulder gravel, size of man's fist.				
					Gage height .13				

TABLE III b.

NORTH FARM LATERAL.

First Measurement.

(By R. E. Trimble and J. D. Stannard.)

Date and Hour.	Temp. of Water.	Area of Section. Sq. Feet.	Average Depth in Feet.	Greatest Depth in Feet.	Surface Width in Feet.	Gain or Loss. Sec. Ft.	Distance in Miles.	Corresponding Depth of Loss.
July 6.—								
11:00 a. m.		69.16	1.47	2.00	47.			
11:40 a. m.	61°.5	34.55	1.19	1.65	29.	+9.41	2.	+2.04
1.10 p. m.	65°	36.70	0.92	1.40	40.	+0.63	1.	+.3
2:15 p. m.		35.15	1.40	1.90	25.	- 6.90	1.	-3.0
2:45 p. m.		31.30	1.30	1.70	24.	-14.23	1.	-9.6
3:40 p. m.		23.15	0.93	1.20	25.	+9.06	1.	+6.1
4:00 p. m.	68°	25.02	1.32	1.85	19.	-10.88	1.	-8.1
5:00 p. m.		11.95	0.80	1.25	15.	+0.30	1.	+.3
5:30 p. m.		12.95	1.44	1.10	9.	+0.06	1.	+.08
Average			1.20		26.			
Total loss						-12.55		

Second Measurement — By R. E. Trimble.

Date and Hour.	Temp. of Water.	Area of Section. Sq. Feet.	Average Depth in Feet.	Greatest Depth in Feet.	Surface Width in Feet.	Gain or Loss. Sec. Ft.	Distance in Miles.	Corresponding Depth of Loss.
Aug. 3, 1897.—								
10:10 a. m.	62°.0	33.56	1.12	1.95	30.0			
11:00 a. m.	64°.0	20.64	0.94	1.85	22.0	+3.53	2	+.62
11:30 a. m.	65°.2	21.97	1.04	1.41	21.2	-1.15	1	-.88
12:50 p. m.	67°.3	22.54	0.88	1.26	23.0	-2.81	1	-2.1
1:30 p. m.	71°.0	20.23	0.91	1.75	22.2	-4.41	1	-3.2
2:00 p. m.	70°.2	14.68	0.67	0.89	22.0	+3.80	1	+2.85
2:35 p. m.	71°.8	15.73	0.94	1.28	16.7	-1.86	1	-1.6
3:20 p. m.	72°.3	9.36	0.67	1.08	14.0	-1.15	1	-1.2
4:20 p. m.	72°.0	11.06	0.74	.95	15.0	-1.23	1	-1.4
Average		18.86	0.88		20.7			
Total loss						-5.28	9	

TABLE IV a.

EMPIRE CANAL.

Measurement by R. E Trimble and R. D. Blakey.

Date and Hour.	Place of Measurement.	Amount	Outtake	Loss or Gain.	Distance.
1897—					
June 11, 2:40 p. m	At head	124.99			
	Davis lateral		1.90		
	Davis No. 2		0		
	Metzger No. 1		0		
	Metzger No. 2		0		
	Metzger No. 3		3.12		
June 11, 4:35 p. m	Above Loveland lateral	135.97		+16.00	5

BLACKMORE DITCH.

Date and Hour.	Place of Measurement.	Amount	Outtake	Loss or Gain.	Distance.
June 17, 2:40 p. m	At bridge	11.54			
June 17, — p. m	At lateral		1.16		
June 17, 3:30 p. m	South of North Farm	6.78		-3.60	2.03 m
May	At bridge	2.85			½ "
"	½ mile east by floats	2.43		-.42	

LATERAL 1 F.

Date and Hour.	Place of Measurement.	Amount	Outtake	Loss or Gain.	Distance.
Aug, 4, 10:30 a. m	At head	12.93			
10:10 a. m	2½ miles from G. B. road	11.29		-1.64	2½ m...
	Lateral		1.67		
	"		0.37		
	"		0.39		
9:25 a. m	1 mile	8.82		-.04	1½ m...
	Lateral		1.70		
	"		0.51		
	"		.01		
9:00 a. m	Near Gunbarrel road	7.84		1.24	1 m.

TABLE IV b.

EMPIRE CANAL.

Date and Hour.	Temp.	Area.	Average Depth.	Maximum Depth.	Breadth.	Gain or Loss.	Corresponding Depth in Feet.
1897—							
June 11, 2:40 p m		79.6	1.82	2.41	44		
4:35 p m		70.2	1.40	1.70	50	+16.00	+1.1

BLACKMORE DITCH.

Date and Hour.	Temp.	Area.	Average Depth.	Maximum Depth.	Breadth.	Gain or Loss.	Corresponding Depth in Feet.
June 17, 2:40 p. m		10.35	.94	1.21	11.0		
3:30 p. m		4.61	.62	.84	7.4	-3.60	-7.2

LATERAL 1 F, RIO GRANDE CANAL SYSTEM.

Date and Hour.	Temp.	Area.	Average Depth.	Maximum Depth.	Breadth.	Gain or Loss.	Corresponding Depth in Feet.
Aug. 4, 10:30 a. m	67°.2	6.24	0.48	0.80	13.		
10:10 a. m	67°	6.30	0.63	0.86	10.	-1.64	-.95
9:25 a. m	65°	5.93	0.66	0.99	9.	-.04	-.05
9:00 a. m	63°.2	4.20	0.54	0.76	7.8	+1.24	+2.4

OTHER CASES.

The loss on a section of the Fort Morgan canal given in table V, is the loss in a section between the headgate and Bijou creek, some ten miles down the line of the canal, and about four miles from Fort Morgan.

The canal is on the south slope of the Platte valley and for much of the way is a loose sandy soil. It is in partial excavation and with an embankment on the lower or northern side.

The loss in this canal amounted to twenty cubic feet per second in 1895 in a distance of 7.4 miles In 1896 the upper measurement was made nearly two miles further up the canal, and the lower measurement at the same place as in 1895. The loss amounted to 23.11 cu. ft. per second.

These measures are referred to later, as they afford a basis for seeing the effect of slightly silting the canal.

TABLE V.

FORT MORGAN CANAL.

Date and Hour.	Temp. of Water.	Area of Section Sq. Ft.	Aver'ge Depth in feet.	Greatest Depth in feet.	Surface Width in feet.	Gain or loss. Sec. Ft.	Distance in Miles.	Corresponding Depth in Feet.	Notes.
1895—									
Oct. 25, 7:30-8:25 a.m.	41°	108.9	2.42	3.20	45	....	....	....	Opposite Shaffer's Ford.
" " 11:00 a. m.	44°	69.	1.82	2.34	38	-20.08	7.4	-1.1	Head Bijou flume. 10,100 ft. new channel; 400 ft. is flume. No leak from flume.
" " 12:30 a. m.	....	110.	2.55	3.65	34	-11.48	2	-2.6	

FORT MORGAN CANAL.

Date and Hour.	Temp. of Water.	Area of Section Sq. Ft.	Aver'ge Depth in feet.	Greatest Depth in feet.	Surface Width in feet.	Gain or loss. Sec. Ft.	Distance in Miles.	Corresponding Depth in Feet.	Notes.
1896—									
Oct. 23, 9:15-10 a. m.	48°	67.60	2.01	2.05	33.7	....	0	....	At rating flume.
" " 3:05-3:50 p.m.	....	110.20	2.75	3.40	40	....	....	....	Opposite Shaffer's Ford.
" " 3:30-4:00 p.m.	49°	95.6	2.45	3.50	39	-23.11	9.3	-1.0	Head of old flume.
" " 4:20-5:00 p.m.	....	102.3	2.38	3.50	43	- 5.70	2	-1.1	At lower end old flume, 10,100 feet used one year. As ditch changed slightly during night measure at Shaffer's Ford is not used.

HOOVER DITCH.

Date and Hour.	Temp. of Water.	Area of Section Sq. Ft.	Aver'ge Depth in feet.	Greatest Depth in feet.	Surface Width in feet.	Gain or loss. Sec. Ft.	Distance in Miles.	Corresponding Depth in Feet.	Notes.
1895—									
Oct. 22, 7:30 a. m.	....	5.45	.65	.85	8.4	....	....	....	
....	....	10.2	1.4	1.80	7.4	-0.15	¼	-1.2	Fine sand of Platte river bed.

GREELEY NO. 3 CANAL.

Date and Hour.	Temp. of Water.	Area of Section Sq. Ft.	Aver'ge Depth in feet.	Greatest Depth in feet.	Surface Width in feet.	Gain or loss. Sec. Ft.	Distance in Miles.	Corresponding Depth in Feet.	Notes.
1895—									
Oct. 16.	....	17.49	1.03	1.56	17	....	....	....	Above and below gully in west part of City of Greeley. Instance referred to in bulletin 33 pp. 49-50.
....	51°	21.03	1.45	1.65	14.50	5.06	760 ft.	-55.0	

In the case of the ditch of the City of Fort Collins, carrying water from the Cache a la Poudre river to the city water works, a distance of 4100 feet, the ditch lost 4.34 cu. ft. per sec., equivalent to a loss of 5.7 feet in depth per day. The ditch runs through the bottoms and along the side of a hill rising some 20 feet above the bottom lands below. Immediately above the city ditch, as near the slope as the embankment will permit, is another canal, the New Mercer ditch, which, at the time of measurement, was dry. The Pleasant Valley and Lake canal is still higher, over one-half mile distant, but the seepage from this canal is carried in another direction by the local configuration of the country.

The loss from canals has not been extensively studied and there seem few instances available where the results of measurements are given. In bulletin 33 several cases are referred to.

MISCELLANEOUS OBSERVATIONS.

The following cases are derived from other observers:

On the Muzza canal, Italy, the loss is equivalent to a depth of 1.7 feet in 24 hours.* The canal is the first built near Milan solely for irrigation purposes, the other large canals including navigation as an object in their construction. The Muzza has a heavy fall, giving the current too large velocity for navigation. The canal carries several thousand cubic feet of water per second, and under conditions as seen by the writer in 1892, that would seem favorable to percolation, so that the reported loss seems small.

The Naviglio Grande loses 10 inches daily in depth. This canal was built over 700 years ago, about the same time as the Muzza. The canal Martesana loses 1.5 feet daily.*

The Centreville and Kingsburg canals, California, in a stretch of six miles lost a depth of 6 feet per day. The King river and Fresno canal lost in different portions depths of 1.5 feet, 1.7 and .6 feet.

Portions of the Fresno canal lost depths of 2.8 feet, .25 ft. and .4 ft. in depth, and some laterals from 1.2 to 6.4 feet.†

In the case of several canals in Kern county, California, the loss was found to be from .39 to 2.6 feet in depth in 24 hours, ranging from 1 to 2 feet in sandy soils and averaging 1.6 feet; in sandy loam and firm, compact alluvial soil, from .39 to 1.30 feet averaging .87 feet in depth.‡

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* Baird Smith, Italian Irrigation.

† On authority of C. E. Grunsky, C. E. of San Francisco, given in Bulletin 33

‡ Report Cal. State Engineer, 1880, App. B. by J. D. Schuyler p. 92 The results are changed to depths by the writer.

Mr. J. Keelhoff made some experiments on the absorption of small ditches.*

From the facts given by him, we find that the loss in the sandy soil of the Campine from irrigation ditches, 10 inches wide with water 11 inches deep, was over 10 feet in depth in 24 hours; but when the depth of water in the ditch was but two inches, the loss was reduced to six feet per day. In the distributing laterals, 10 inches deep and two feet wide, the loss was over four feet in depth per day. In the principal lateral, with water 2 feet deep and 8 feet wide, the loss was over 2 feet per day. One reason for less loss in the last case, though the water was deeper, is that the bottom remains undisturbed from year to year. At the time of the test the silt had not been removed for four years. The other ditches were cleaned annually, thus giving a raw surface for the water to pass through.

Geo. W. Rafter, C. E. in a report on the water supply of the Western division of the Erie canal,† refers to a number of determinations of the losses from seepage and evaporation on stretches of that canal.

On a section of 18 miles near Schenectady through an alluvial soil containing a large proportion of vegetable matter, and leaky in places, the loss as measured by J. B. Jervis in 1824, was 2 cu. ft. per second per mile. The canal was 28 feet wide on bottom, 40 feet wide on top and 4 feet deep. This is equivalent to a loss in depth of 10 inches in 24 hours over the whole surface.

Mr. David S. Bates in 1823 concluded that a mile of new canal, such as the Erie then was near Brockport, would require 1⅔ cu. ft. per sec. per mile. This included evaporation. The dimensions of the canal are presumably the same as the above, in which case the loss would be equivalent to 8 inches in depth per day. On the Chenango canal in Aug. 1839, the amount was found to be 1.09 second feet per mile, corresponding to a depth of 6 inches in 24 hours.

On the Erie canal near Wayneport, in 1841, in a distance of 8 miles, when the soil was open and porous, the loss was 1.8 cu. ft. per second per mile; on the Clyde level, a length of 28 miles, with more retentive soil, the loss per mile was only .6 cubic feet per second. These correspond to depths of 9 inches and 3 inches per day respectively.

In comparing with the results found on irrigation canals, it should be remembered that the conditions on the

* Traite Pratique de l'Irrigation des Prairies. 2d ed.

† Report of the State Engineer and Surveyor of N. Y., 1896.

Erie canal are more favorable to small losses than are those of irrigation canals. The Erie canal is in a more humid climate, with a rainfall about 2½ times as great as that of Colorado and this tends to keep the water table nearer the surface and thus lessen the percolation. More than that, the Erie canal in this stretch is almost level (3 ft. fall in 60 miles) and the slow movement of the water is favorable to silt deposition. The irrigation canals have falls ranging from 2 ft. upward per mile, and the beds are scoured by the running water.

Mr. Walter James, who has been for many years the engineer of the canals in Kern county, California, writes* that their experience shows that they deliver 70 per cent of the water turned in at the head of the canals at the lateral side gates, measurements sometimes being made from one to three miles from the main ditch at the lands where the water is used. There is one point on the Calloway canal where there is a loss of 75 cu. ft. per sec. in a distance of half a mile.†

The canals referred to by Mr. James are from 6 to 25 miles in length, and from two to three feet in depth. In their experience they find that an allowance of 2 per cent. per mile of main canal approximates fairly well to the loss to be counted upon.

On the Carpentras canal of Vaucluse in France, taking water from the Durance, the loss was found to be great, though the waters of the Durance are thick with mud ordinarily. The canal passes along the flank of calcareous slopes. The soil is generally thin. The banks were walled and the canal paved in many places. After these remedies, the loss is still considered to be about 30 per cent of the amount taken by the canal.‡

The canal carries 210 cu. ft. per second. The loss corresponds to a depth of 1.2 feet over the length of the canal, which is 40 miles.

The Marseilles canal in Southern France, which had cost $9,000,000 up to 1878, at first lost about 20 per cent., notwithstanding that the water supplying the canal is exceptionally muddy, so much so that it was necessary to build settling basins at considerable cost. The loss was reduced to 10 per cent. by works protecting the banks, made at a

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*June 13, 1898.
†This is equivalent to a daily loss of 30 feet in depth.
‡Salvador, Hydraulique Agricole. (1898) 2:492.

cost of $400,000.* The loss under these favorable circumstances still amounts to about 5 inches in depth per day.

Where the Cavour canal crossed the valley of the Dora river it was confined by artificial banks and the losses at first were found to be enormous, being not less than 210 cu. ft. per sec. in a distance of but little over one mile.† This corresponds to a depth of 20 feet per day over the entire width of the canal.

This great loss was remedied by using sand in the bottom, using water made muddy with clay, and lime water, and after repeating the application several times the losses were found to be much less. After continuing the application for a couple of months, keeping the water stagnant to allow the material to settle, the losses were very much reduced.

CONTINUOUS RECORDS.

For two years a self recording nilometer was maintained on a ditch four miles long, belonging to the North Poudre Land and Canal company. The lateral had no outlets for that distance. Weirs were placed at the upper end near the reservoir from which the water was drawn, and also near the lower end about four miles from the reservoir. No water was used at intermediate places. The record was made to ascertain the loss there might be from seepage and evaporation during the time. The lateral is built in a soil mostly of clay, which does not wash unless the velocity is considerable. The seepage was not expected to be great because of the character of the soil. Two weirs were put in place and instruments were put in place at the side of the ditch, with floats so arranged that as the water rose or fell a pen rose or fell on the paper correspondingly. The clockworks would run a week without rewinding. At the end of each week the instruments were visited, the clock rewound, the papers changed, and check readings of the height of water over the weirs taken.

After the instruments were in service it was found that about ten acres of ground was supplied from the lateral above the lower weir. The cases when water was drawn for this tract are eliminated from the table, but the conditions were not entirely satisfactory, and, as the funds to meet the small expense of removing the weir above this lateral were not available for the department at that time, the measurement was dropped. A ditch in the southern part

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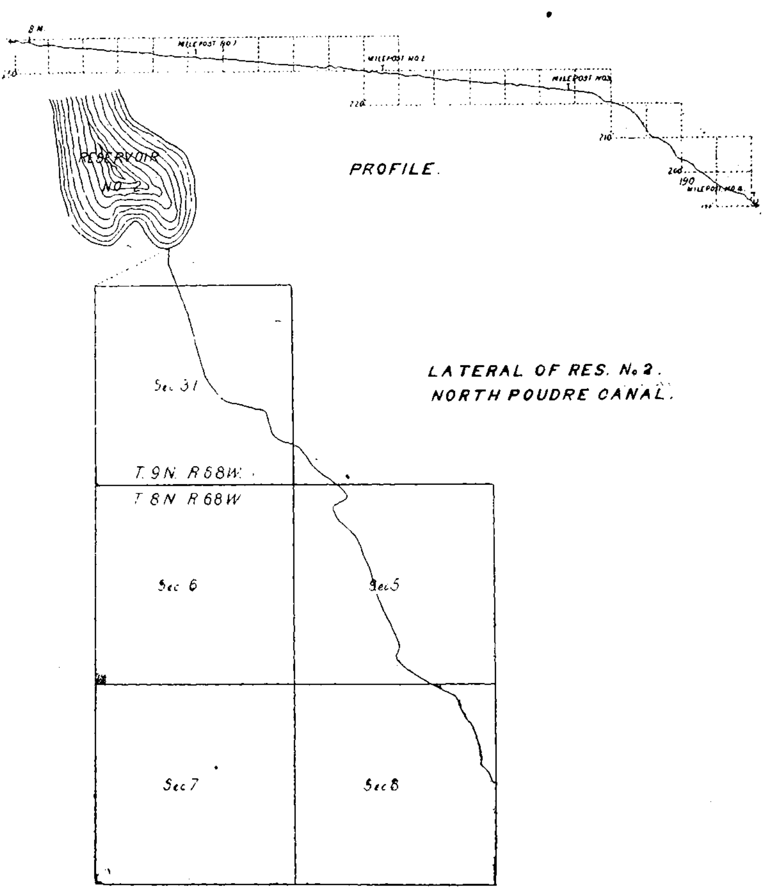
*Salvador, Hydraulique Agricole. 2:42.

† Herrisson, Les Irrigations de la Vallee du Po. p. 77.

of the state, 40 miles in length without an outlet, has been put at our service and records are to be made on it, giving, it is hoped, information on a more extensive scale.

The line and profile of the canal is shown in the figure.



For the first mile the canal had a fall of 5.4 feet, in the econd mile 4.8 feet, in the third mile 5.8 feet and in the last nile 34 feet. The reason for this rapid increase of grade s, that for the first three miles the ditch skirts the side f a divide, while a short distance after passing the third nile post it reaches the ridge of the divide and descends vith the slope of the country which is quite abrupt.

The soil through which the canal runs may be termed a eavy clay. Where the water is rapid, as during the last nile, the sides of the channel become smooth with the action of the water and comparatively little washing takes place. In the course of years, however, the washing is sufficient to deepen the channel several feet below the surrounding country. As the water comes from a reservoir, it is clear except for the turbidity due to a slight amount of organic matter. The water retains its clearness for the greater length of the canal, but at the lower end contains some sediment from the scour of the channel. The soil is probably underlaid with sand and gravel at a depth of 8 or 10 feet—true of most of the surrounding country—but no opportunity to test was afforded along this line.

For the first three miles the seepage would be to the west; for the remainder of the distance it might take place both to the right and left of the channel. Some seepage showed near the northeast corner of section 8 where an area of a few acres gave evidence of water-logging. Because of the sand carried by the rapid fall at the lower end, the space in front of the lower weir is filled with sediment. This increases the discharge by increasing the velocity of approach. Near the lower end of the canal a small lateral irrigating about 10 acres of land conveyed water to the north. When water was running in this lateral notes were taken and this time was not taken into account.

1893. June.	Av. Flow per Sec. over Weir.		Av. Loss per Sec. cu. ft.	Loss per Cent.	Maximum Flow over Weir.		Minimum Flow Over Weir.		Air Temperature at College.		Av. Rel. Humid'y at College.	Wind at College. Miles per Day.	NOTES ON WEATHER.
	Upper.	Lower.			Upper.	Lower.	Upper.	Lower.	Average.	Max.			
14	4.42	4.31	0.11	2.4	4.72	4.57	4.13	4.16	69.0	80.0	47.0	165	Sunshine to 3 p. m.
15	4.04	3.87	.17	4.2	4.72	4.17	4.13	4.13	62.6	81.8	56.5	138	Sunshine all day.
16	4.51	3.79	.83	18.0	4.72	4.10	4.51	3.74	64.5	85.2	47.9	155	Sunshine nearly all day.
17	6.65	5.21	1.44	21.6	8.95	7.18	4.43	3.74	68.7	90.9	53.9	163	Sunshine all day.
18	8.77	6.91	1.86	21.2	8.95	7.18	8.52	6.77	71.0	93.7	45.1	167	" " "
19	8.12	6.48	1.64	20.2	8.52	6.77	7.68	6.37	72.0	94.0	44.9	158	" " "
20	6.20	6.02	.18	2.8½	7.67	6.37	3.47	5.69	68.8	92.3	49.3	285	" " "
21	7.35	5.47	1.88	25.6	7.43	6.13	5.83	4.79	74.7	87.4	28.9	236	Sunshine nearly all day.
22	5.12	4.25	.86	16.9	5.83	4.79	4.57	3.81	67.6	90.8	50.6	164	" all day.
23	4.42	3.67	.75	16.9	4.57	4.36	4.17	3.40	74.3	91.1	19.3	257	" nearly all day.
24	6.26	4.80	1.46	23.4	7.76	5.57	4.57	4.36	64.1	80.2	48.0	212	" most of day.
25	5.92	4.94	.98	16.6	6.62	5.57	5.23	4.29	68.0	88.3	58.9	171	" all day.
26	3.78	3.32	.46	12.2	5.23	4.29	1.90	1.62	67.5	84.7	54.4	147	Rather cloudy.
27	1.82	0.96	.86	47.1	1.90	1.62	1.73	.34	67.7	88.1	40.6	144	Sunshine most of day.
28	1.81	.47	1.34	74.0	1.73	.82	1.47	.22	70.1	92.0	49.1	148	" " "
29	1.11	.41	.70	63.1	1.47	.70	.12	.28	65.2	73.6	71.8	192	Rather cloudy.
30	.63	.51	.12	19.2	1.13	.58	.25	.31	65.7	83.9	49.8	190	Sunshine nearly all day.
1894. June.													
22	3.73	3.47	.26	6.9	3.83	3.62	3.72	3.32	65.9	81.9	65.2	143	Rain T. cloudy after 11 a. m.
23	3.72	3.30	.42	11.3½	3.72	3.42	3.72	3.18	64.6	80.7	53.7	163	" T. partly cloudy after 9 a. m.
24	3.72	3.24	.48	12.9½	3.72	3.22	3.72	3.06	63.2	77.4	58.0	188	" .10 in partly cloudy.
25	2.10	2.06	.04	2.0	3.72	3.13	....	....	63.2	80.4	58.6	138	" T. partly cloudy.
July.													
16	2.55	0.77	1.78	69.9	4.79	3.32	2.99	2.99	71.5	90.0	53.5	126	Partly cloudy in p. m.
17	5.68	4.04	1.64	28.8	7.14	5.55	4.14	2.99	74.0	89.0	59.7	128	Partly cloudy all day.
18	6.44	5.55	.89	13.7	7.02	5.55	6.17	5.55	68.3	79.7	75.1	121	Rain .15 in., cloudy.
19	6.15	5.55	.60	9.8	6.20	5.55	5.73	5.55	68.6	77.6	74.3	120	Cloudy p. m.
20	6.12	5.72	.40	6.5	7.39	6.29	5.73	5.55	66.7	82.7	69.4	131	Partly cloudy in p. m.
21	6.18	5.99	.18	3.2	6.53	6.29	5.64	5.55	67.8	87.8	48.8	160	Rain T. partly cloudy in p. m.
22	2.49	2.77	Gain	Gain	6.29	5.55	0	0	67.6	89.2	54.8	159	Gain from saturated banks.
30	2.19	1.49	.70	32.3	4.90	3.52	4.46	3.42	69.5	90.4	52.5	166	Partly cloudy p. m.
31	4.33	3.52	.80	18.7	4.46	3.52	4.25	3.52	71.2	59.2	61.4	194	Rain .19 in. p. m., partly cloudy.
Aug. 1	2.85	2.73	.12	4.5	4.25	3.52	2.02	1.85	68.0	82.2	58.5	205	Rain T. cloudy.
Ave.	**4.49**	**3.73**	**.80**	**20.9**	....	....	....	....	**68.1**	....	**53.5**	**169.**	....

The average loss amounts to .80 cu. ft. per sec. As the amount turned into the ditch averaged 4.49 cu. ft. per sec. the loss amounted to 18 per cent. on this basis, or 22 per cent. by taking the average of the losses by days.

As the surface of the water of the canal was about three acres in area, this amount of loss corresponds to a depth of slightly over 6 inches per day.

The variations in the loss on different days is noticeable. A part of the difference is due to the fact that a fluctuation in the amount of water in the canal does not affect the lower weir until a couple of hours after the upper weir has been affected, and as the civil day was used with both weirs, some discrepancy is due to this fact. The days when the changes were noticeable were excluded from the table though the effect is not thereby entirely elminated from the individual day's record.

The days when water was used through the small lateral above the lower weir could easily be detected by comparison of the records at the two weirs, and are likewise excluded from the table.

Showers affected the record to some extent in 1894, and while the amount of rain entering the canal is unknown, there is reason to suppose that its effect caused the apparent losses to be less than in 1893, whose record for the time reported was free from such disturbance.

RECAPITULATION OF CASES OF LOSS.

Pleasant Valley and Lake Canal: Loss of 11.46 sec.-ft. in 23 miles, after being increased by over 8 ft. gain.	Depth.
Average depth of loss, with low head.......	0.66 ft.
Excluding gains, loss of over...............	1.00 "
At places, over..............................	5.00 "
North Farm Lateral: Lost 12 5 ft. in 9 miles, with head of 200 sec. ft.	
Average depth of loss.......................	0.80 "
With head of 90 ft. lost 5.28 sec. ft. or depth.	0.43 "
Fort Morgan Canal...........................	1 to 2.60 "
Hoover Ditch	1.00 "
Greeley No. 3, special case	30.00 "
" " " July 20, 1898	18.00 "
North Poudre Lateral................6 to 1.00	0.80 "
Muzza Canal, Italy...........................	1.70 "
Naviglio Grande..............................	0.80 "
Martesana	1.50 "
Centreville and Kingsburg....................	6.00 "

King's River and Fresno		6 to 1.70	"
Fresno Laterals		1.2 to 6.40	"
Kern county canals		.39 to 2.60	"
Kern county, sandy soils	1. to 2.	1.60	"
Kern county, sandy loam	.39 to 1.3	0.87	"
Campine, Belgium, sandy		2 to 10.00	"
Erie Canal	.25 to .80	0.60	"
Carpentras Canal, France		1.20	"
Marseilles Canal		0.40	"

GAINS FOUND IN CANALS.

In many cases the canals serve as drainage ditches and are found to gain in volume instead of loss. Several examples may be noticed in the tables, as the Empire canal, the North Farm lateral for a portion of its length, the Prairie Ditch, the Pleasant Valley and Lake canal, etc. It is frequently noticed that some canals have water even when their supply from the river is shut off. This is often found to be true with the ditches in river bottoms, originally built to take water from the river, but which, with the irrigation of the upper lands, have now become practically drainage ditches. Every old irrigated valley in the state has such instances.

In the case of the Hottel mill race at Fort Collins, not elsewhere mentioned, which was measured in the fall of 1897, a gain of over 4 sec. ft. was found in a distance of two miles.

The gains are manifestly more likely to be found in deep canals than in the shallow laterals.

VARIATION OF LOSS WITH DEPTH.

The amount of seepage increases with the depth of water in the channel. This is principally from theoretical considerations, but has observational confirmation. The exact relation must depend on the relative losses through the banks and through the bottom or on the relative width and depth of the channel. As the soil is rarely uniform for any considerable distance, the results from theoretical considerations can only be a guide as to what to expect. When the loss is solely through the banks there is reason for thinking it may vary nearly as the cube root of the square of the depth, that is, on doubling the depth, the loss would be nearly three times as much; on quadrupling the depth the loss would be nearly eight times as much.

Some interesting observations by J. C. Trautwine, Jr., Chief of the Bureau of Water of Philadelphia, are given in

Bulletin 45, on Losses from Reservoirs, page 12. It was found when the water was 20 ft. deep, the loss amounted to .15 inches per day; when 25 feet to .24 inches; when 30 ft. to .46 inches, but on lowering the water it was found that the loss did not become as small as the same depth before the reservoir had been filled. The loss at 20 ft., after the reservoir had been full, remained at .28 inches instead of reducing to .15 inches observed before.

Some observations by Keelhoff on small ditches have already been mentioned. In these more loss was found when the water was 10 inches deep than when 2 inches deep.

In the case of the North Farm Lateral, where two measurements were made with different amounts of water in the canal, a greater depth of loss is shown with the larger head. The depth of loss averages .8 with the head of 200 sec.-ft., and .4 ft, with a head of 90 sec.-ft.

By arranging the losses according to the amount of water in the canal, we find that the observations given in table VI show clearly that the smaller the amount of water the less is the depth of loss, though the greater the per cent. the loss is to the amount in the ditch.

Omitting the days on which the water had dropped, in which cases the water returning from the saturated banks reduces the apparent loss, and likewise leaving out of account those days in 1894 on which doubt is cast by showers, the following table is obtained:

Amount of Water. in Ditch.	No. Cases Taken.	Loss in Carriage. per Cent.	Loss in Depth. Inches.
0 to 2 sec. ft.	4	50	4.5
2 tc 4		estimated 26	6.3
4 to 6	6	19	7.5
6 to 9	6	17	8.5

THE EFFECT OF TEMPERATURE ON LOSSES.

It is undoubtedly true that the amount of seepage will be affected by the temperature of the water, and though the temperature was always taken, no attempt is made to allow for the temperature in the present report. The effect of temperature is evident in the increased flow into streams as shown in Bulletin 33, in drains, and it causes a corresponding effect on the loss from canals.

Using the equation representing the effect of temperature on the velocity of flow as given in bulletin 33, p. 46, and considering the amount of seepage at freezing temperature as unity, the loss at other temperatures may be expected to be approximately as the following amounts:*

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*Note in Engineering News, by L. G. Carpenter, 39:422. Also note 40:26, July 14, 1898, by Allen Hazen, giving practically same ratios from his own measurements.

Temp., F.	Velocity.	Temp., F.	Velocity.
32°	1.000	72°	1.860
42°	1.195	82°	2.109
52°	1.403	92°	2.372
62°	2.109	102°	2.649

In warm weather the loss is therefore greater than in cold, and the loss at 80° temperature of the water would be twice as much as if it was at freezing temperature; or the loss at 70° would be about one-third more than at 50°.

LESSENING SEEPAGE.

Of the conditions affecting seepage, the one which can most readily be controlled, and in fact the only one, is the character of the canal bottom or the bottom and sides. No soil is absolutely water-tight, but there is a great difference between the perviousness of the different soils, which range through all degrees of clay to sand and gravel. Clay of the quality known as adobe, essentially a clay from which all vegetable matter has been extracted by action of alkaline carbonates, is well known to be nearly water-tight.

A layer of fine material, as of fine silt, makes the passage of water so much more slow and difficult, that its effect is well known and is shown in a number of cases in the measurements reported in this bulletin. Even water that is apparently clear contains enough matter to lessen the rate of filtering in a few weeks time in the large filters for city water supplies.

The silt carried by canal waters is sufficient to greatly lessen, and in many cases to practically stop the seepage, but to do this the velocity of the water must be slow enough to permit the silt to be deposited.

A constant current tends to prevent the settlement of sediment. If the current is swift enough to erode the bed then not only is the sediment kept from dropping and filling the pores, but the surface is swept and the losses will remain large.

Hence defective alignment of the canal, too sharp curves causing the current to strike and erode the banks, are conducive to losses. Some canals have found it desirable to straighten the line of their canal to lessen the troubles of maintenance, and in so doing have also lessened the loss from seepage.

Any way in which the canal may be silted up, or be permitted to form a layer of silt, thin though it be, will tend to lessen the seepage.

Hence checks which some canals have found it necessary to construct for water distribution, cause slack water and thus permit the deposit of silt. There are many places where the effect has been immediately shown. The water-soaked lands become dryer and land which had been impassable became dry enough for passage and cultivation. So as silting lessens the seepage, on the other hand the re-removal of the silt coating may cause the leakage to be as great as ever.

A case in point is the Greeley canal No. 3, as mentioned in Bulletin 33, pp. 49-50. When first built considerable damage was done from the rising of the ground waters and flooding of cellars in some parts of the town. After a few years the cause of complaint disappeared, silt having filled the bottom of the canal. In 1895 sand was obtained for building purposes from the bottom of the ditch at the crossing of a ravine. The top layers of the ditch bottom were found to be partially cemented. Within a few months after water was again turned into the ditch complaint arose regarding the influx of water in the town cellars. When water was turned out of the canal, the water in the cellars began to go down within ten days and in three weeks had fallen 6 inches, and in two months 18 inches. A measurement made above and below the suspected point showed a loss of 5.06 sec. ft. in a distance of 760 feet, or equivalent to a depth of 30 feet per 24 hours over the surface covered by the canal.

A drain sewer had been built by the City of Greeley to drain the region below this part of the town. It was stopped up at the time of the measurement, but v hile thus failing to remove the water, the loss from the canal was excessive as shown by comparison with the losses from other canals. The damage led to requests from the people in that part of town to correct the defects in the ditch. The city feared that an attempt to remedy the condition would be a confession that it was to blame. In 1896 a team worked for part of a day in hauling in clay and puddling this section of the canal, and the complaint in 1896 and 1897 was small.*

In the case of the Fort Morgan canal, given in table 5, there is an opportunity to compare the losses from a channel when freshly used, and after having been used for a year, silt presumably having settled.

In 1895, at the time of measurement, water had been turned into a new section two miles long for a couple of weeks. The loss was found to be 11.48 cu. ft. per second.

*July 20, 1898, this portion was again measured and loss still is a depth of over 18 feet daily.

Almost a year later the same section gave a loss only one-half as much, the change being ascribed to the silting which had taken place in the meantime.

The use of sediment is the most practicable method of reducing the loss from seepage. In California both the main ditches and the laterals are often cemented, as they are in Mexico. Their canals are much smaller than the canals in Colorado, the value of water is much greater, and hence the amount which could be expended for the saving of water would be greater than could be profitably expended under Colorado conditions.

On some California canals the channels have been lined by cementing directly on the earth. This would not be possible to do successfully under the colder winters of Colorado.

Under some conditions, as where water is exceptionably valuable, it may become profitable to go to considerable expense to save the loss from seepage; to pave the sides or bottom if necessary, to concrete the canal through in our climate this is not likely to be satisfactory, or to pipe the ditch.

Evidently the question returns to the value of water and the amount of loss. The commercial value of a cubic foot per second of water is not less than $500 in any place in the state, and in few places would it be considered as high as $3,000. This is the nominal second-foot which actually is not constant in flow. Under farming conditions $1,200 would probably represent the average value. The annual value may be considered as not less than $50. To the farmer using the water its productive value is far more; or the individual who uses the water can profitably expend more than any one else.

The farmer who could thus save as much as 2 cubic feet per second could afford to expend $100 per year if necessary for that purpose. But until fully convinced of the efficacy of methods of saving water, few would care to risk so much.

In many cases the losses are excessive. Under fair conditions they be as much as two feet per day.

The losses vary with the different formations through which the canal passes, or the different character of the soil. Porous gravels are notoriously leaky, while the clayey soils, or gravel with a suitable admixture of finer material and clay, may hold water satisfactorily. In some cases the section of the channel can be enlarged at the leaky place and filled with finer material, or silt allowed to settle, for in most cases a thin layer is sufficient to check the leakage very much.

LOSSES AT DIFFERENT FORMATIONS.

The effect of different strata is shown in the measurements of the seepage increase of streams. In the case of the Cache a la Poudre there are several stretches in which, notwithstanding the large gains in the river as a whole, there is an apparent loss of water.

In the Rio Grande river in Colorado marked losses were found for a portion of its length in the San Luis valley, amounting to 75 cu. ft. per second in a distance of 15 miles. The loss was noticed in 1896 and verified in 1897.

Similarly in the case of the Arkansas river, a loss is found in several places, but of less amount than found in the Rio Grande.

EFFECT OF PREVIOUS CONDITION ON LOSS.

The previous conditions of the bed of the canal, or stream, will materially affect the loss experienced in the canal or river bed. If the bed has been dry and has become heated as well, the amount of water which is absorbed by the bed when water is turned into the canal, is surprising to one who is not acquainted with the peculiarities of the flow of water under such conditions. The layer of dry soil absorbs the water with avidity. It will take up about one-third of its volume of water, and the amount of water thus absorbed is in addition to the amount which is flowing through the soil under steady conditions. The effect is to greatly increase the time required to send water through a ditch after having been dry, and on the longer ditches days may be taken to send water through the ditch, while when already soaked up a very slight change at the headgate is quickly felt throughout the length of the canal. It is because of the loss from this source that the attempts to run a moderate amount of water through streams with sandy beds have not been successful.

On the other hand, with falling water, a considerable amount of saturated soil is exposed. Water oozes from the banks and the supply thus received retards the fall of water. Sometimes when the banks are gravel, the outflow appears in streams and is so rapid and abundant that it may cause a slipping of the bank. Experienced canal men have a well founded objection to lowering water suddenly and considerably and though some, mistakenly, think that the pressure of the water holds the gravel in place, the effect observed is a real one.

In consequence a canal with rising water will have more and with falling water less than the normal loss, or more than the normal gain. This is shown in numerous cases with the records on the North Poudre canal. The length of time during which this will affect the conditions depends on the area and extent of the gravel beds near the channel. The principal effect passes off in a short time, for as the line of saturated soil becomes further removed from the channel, the movement of water is much more slow.

One consequence often realized in practice is that if water is to be run through a long canal, the division can be made better and fairer if the water is run completely through the canal before opening the lateral gates. The whole of a small stream of water may be required to satisfy the thirsty sand. A large stream may accomplish the same purpose in a shorter time and with less loss. Hence often it is better to use the whole stream if necessary to wet the bottom of the canal for its whole length, before beginning the division of water, and if the canal is run in sections, to begin the distribution at the lower end of the canal is the better way. If a small stream only is used, nearly all may be taken to wet up the channel and leave little for the lower users.

CONCLUSIONS.

1. The losses from evaporation are relatively insignificant compared with the seepage losses from most canals. In the cases most favorable to evaporation and least favorable to seepage the evaporation is not over 15 per cent. of the seepage.

2. In the case of reservoirs it was concluded in bulletin 45 that the seepage was less important than the evaporation. This is different from the results found in ditches, not because the evaporation is less, but because the seepage is much more.

3. The losses are sometimes enough to cover the whole canal 20 feet deep per day.

4. The loss in clay soils is less than in sandy or gravelly soils, but rarely as small as 3 inches daily.

5. The loss is greater when water is first turned in than after the bed has become saturated.

6. Sometimes the canals are found to gain for the whole or part of their length, or the canals may act as drains. This is more likely to be the case when the canal

is deep in the ground, when crossing lines of drainage, or when located below other ditches or irrigated tracts.

7. In the prevailing Colorado soil, when not intercepting seepage, the loss may be put provisionally at from 1 to 2 feet per day over the whole surface of the canal. In clay soils it is less, but still nearly one-half as much.

8. The loss in carrying water in small quantities, is relatively larger than in carrying large amounts. The increased depth of water means increased leakage, but the carrying capacity increases faster than the leakage.

8a. From the standpoint of economy, it is wasteful to run a small head. It is more economical to run a large head for a short time. In the management of small ditches the time system of distribution can be introduced to advantage, saving time and labor as well as water.

9. It is wasteful to use two ditches or laterals when one would serve.

10. The loss increases with higher temperature, being about twice as much at 80° as at 32°.

11. The loss increases with greater depth of water, but the exact relation needs further investigation.

12. The loss will be lessened by any process which forms or tends to form an impervious lining or coating of fine material, as of clay or silt. The silt, consisting of fine sand, improves many soils. Clay is better and especially limy clay, the lime with the clay forming an almost impervious coating.

13. Cement linings as used in California and Mexico are not warranted by the conditions in Colorado, nor would the weather conditions be favorable. Nor is the use of wooden stave piping for this purpose likely to be profitable in many places in the State, if at all on the larger canals at present. The silting process applied with discrimination will accomplish much at smaller cost.

14. On small laterals glazed sewer pipes may save annoyance often connected with the carrying of water in laterals for considerable distances, which, with the saving of water, may make its use an object. One of the supply laterals of the Colorado Agricultural College is of vitrified sewer pipe, over 4,000 feet of 12-inch pipe being used.

15. Some particular sections in canals are subject to much greater loss than the canal as a whole. Hence water can be saved by locating the leaky place and remedying it. This may be desirable to do while it would be unprofitable to treat the whole canal.

16. There are many places where it would be advan-

tageous to combine two ditches, by this means saving not only the loss of water, but saving superintendence and maintenance charges. With increased confidence in the accuracy of water measurement, reluctance to such consolidations should lessen.

17. The depth of losses from laterals is probably greater than in the main ditches. The laterals are less permanent, are steeper, have less silt, and are more poorly cared for.

18. There must be some arrangement of ditches and laterals which is the most economical for given conditions, so that the aggregate of the losses of the whole system will be a minimum. Certainly the location and arrangement of the laterals for carrying water from the main ditch is worthy of consideration by the management of the main canal and the importance increases with the size of the canal and the width of the strip it serves.

19. It is not to be understood that the whole of the loss from the ditches is lost to the public wealth of the State. Some, perhaps much, of the loss, may re-appear as seepage in lower ditches or in the main stream and again be used. It is, however, lost to the particular ditch and incidentally is destructive to much land. With all practicable methods of prevention, there will still be abundant loss. It should be to the advantage of the individual ditch to prevent such loss as far as practicable.

20. A general statement of the total amount of loss of water must be made and accepted with reservation. It would appear that in the main canals from 15 per cent. to 40 per cent is lost, and in the laterals as much more. It would thus appear that not much over one-half, certainly not over two-thirds of the water taken from the stream, reaches the fields. In the most favorable aspect, the loss is great, and is relatively greatest when the loss can be least afforded, viz.: when the water is low and the ditches are running with reduced heads.

21. There are some 2,000,000 acres of land irrigated in Colorado and the value of the water rights at a low estimate is as much as $30,000,000. (The census estimates the water rights as worth $28.46 per acre.) On this basis, the capital value of the water lost by seepage in the canals and ditches may be put at from six to ten millions of dollars. From the evidence at hand at present this seems a low estimate.

PUBLICATIONS OF THE SECTION OF METEOROLOGY AND IRRIGATION ENGINEERING.

BULLETINS.

No. 13—On the Measurement and Division of Water. Oct, 1890, 46 pp.
Some principles applicable to dividing water. Conditions to be met by modules. Descriptions of weirs and their conditions for accurate use; first English description of the Cippoletti trapezoidal weir. Tables for the rectangular and trapezoidal weirs, with and without contractions.
Second edition July 1891. Editions exhausted.

No. 16—Artesian Wells and Their Relation to Irrigation. 1892, 28 pp.
Including maps showing the Denver and the San Luis basins, and indicating the probable limits of the latter, closely confirmed by the wells since sunk.
Edition exhausted.

No. 22—Preliminary Report on the Duty of Water. 1892, 32 pp.
Giving several years measurements on the amount of water used on crops of alfalfa, wheat, oats, native hay, and on canals irrigating many thousand acres, all in the Cache a la Poudre valley, with some discussion on the absurdly high duties sometimes reported, and on the ultimate duty of water.
Edition exhausted.

No. 27—On the Measurement and Division of Water. 1895, 42 pp.
Revised edition of No. 13, with additional matter, especially new tables computed for weirs of unit length and for depths measured in inches. Also tables for correcting for velocity of approach, so as to render the tables applicable to cases where the space in front of the weir becomes silted up.
Edition exhausted.
The tables have been reprinted in Report of the Colorado State Engineer for 1895-6.

No. 33—Seepage or Return Waters from Irrigation. Jan. 1896, 63 pp.
Reporting measurements in detail on the Poudre river and on the Platte river made to determine the increase in those streams from return waters from irrigation. Discusses the origin of that increase and the connection with the area irrigated and the amount of water applied in irrigation. Shows connection between the amount and the temperature, etc.
Copies still to be had on application.

No. 45—Losses from Reservoirs by Seepage and Evaporation. May, 1898, 32 pp.
Eleven years observations of evaporation at Fort Collins, and several years observations on floating tanks. Two winters observations on losses from seepage. Some discussion of economy of storage at high altitudes.

No. 48—On the Losses from Canals from Filtration or Seepage.

Annual Reports Forming Part of the Annual Reports of the Agricultural Experiment Station.

1888—First Annual Report of the Agricultural Experiment Station, 250 pp. C. L. Ingersoll director.
Report of Meteorologist and Irrigation Engineer, 70 pp.
Description with illustrations of instruments.
Meteorological observations in detail.
Table of observed sunshine by days and comparison with New York.
Table of soil temperatures.
(Tables reprinted in Report of Secretary State Horticultural Society, 1889.)

1889—Second Annual Report of the Agricultural Experiment Station, 1889, 136 pp. C L. Ingersoll, director.
Report of Meteorologist and Irrigation Engineer, 28 pp.
Table of extent of irrigated area in Colorado.
Monthly precipitation for several years and at various co-operating stations

Daily range of temperature.
Tables of amount of sunshine observed at Fort Collins, Rocky Ford and Del Norte.
Observed and computed evaporation from water surface.
Weekly means of soil temperatures at several places.

1890—Third Annual Report of the Agricultural Experiment Station, 228 pp. C. L. Ingersoll, director.
Report of the Meteorologist and Irrigation Engineer, 100 pp.
Table showing maximum and minimum flows of a number of streams for 1888 and 1890.
Table of the daily flow of the Cache a la Poudre.
Estimated amount required by months.
Notes on the duty of water.
Depths taken by the No. 2 canal.
Irrigation statistics, 1890.
Acres covered by ditch.
Mileage of canals.
Cost of irrigation works.
Irrigation bibliography, 10 pp.
Meteorological tables: Precipitation.
Daily dew point and relative humidity by days.
Evaporation, summary of results.
Evaporation at Del Norte.
Evaporation on a reservoir.
Sunshine by months at three stations, compared with New York.
Sunshine, forenoons and afternoons.
Sunshine for days, by sunrise to 9 a. m ; 9 to 12; 12 to 3; 3 to sunset.
Sunrise by days throughout the year, three stations.
Actinometer readings, 1890.
Daily temperatures, 7 a. m to 7 p. m., max., min., throughout the year.
Table of range, daily, throughout the year.
Table average and greatest range by months.
Weekly soil temperatures, depths from 3'' to 6 ft., three locations.
Table of extremes.
Daily mean barometer.
Annual summaries at Agricultural College, Del Norte, Rocky Ford.

1891—Fourth Annual Report of the Agricultural Experiment Station, 130 pp. W. J. Quick, director.
Reports of the Meteorologist and Irrigation Engineer, 69 pp.
Tables of precipitation for 15 years at Fort Collins, at 19 co-operating stations.
Change of precipitation due to elevation.
Dew point and relative humidity, 1891.
Return or seepage waters.
Evaporation, comparison of computed and observed.
Average daily evaporation.
Comparative evaporation at three stations.
Notes on duty of water, on actinometry.
Sunshine tables as in 1890.
Weekly means of soil temperatures.
Air temperatures by days.
Terrestrial radiation by days.
Average barometer by days.
Comparative tables observations at Fort Collins and Manhattan, 3,000 ft. higher.
Annual summaries, Fort Collins, Monument, Rocky Ford, Manhattan.

1892—Fifth Annual Report of the Agricultural Experiment Station, 68 pp. W. J. Quick, director.
Report of the Meteorologist and Irrigation Engineer. 6 pp.

1893—Sixth Annual Report of the Agricultural Experiment Station, 84 pp. Alston Ellis, director.
Report of the Meteorologist and Irrigation Engineer. 7 pp.

1894—Seventh Annual Report of the Agricultural Experiment Station. 112 pp. Alston Ellis, director.
Report of the Meteorologist and Irrigation Engineer. 6 pp.
1895—Eighth Annual Report of the Agricultural Experiment Station. 64 pp. Alston Ellis, director.
Report of the Meteorologist and Irrigation Engineer. 7 pp.
1896—Ninth Annual Report of the Agricultural Experiment Station. 113 pp. Alston Ellis, director.
Report of the Meteorologist and Irrigation Engineer. 5 pp.
1897—Tenth Annual Report of the Agricultural Experiment Station. 110 pp. Alston Ellis, director.
Report of the Meteorologist and Irrigation Engineer. 24 pp.
Discussion of operations of the year, results and investigations desirable to make.