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THE LOSS OF WATER FROM RESERVOIRS BY SEEPAGE AND EVAPORATION.

Approved by the Station Council.

ALSTON ELLIS, President.

FORT COLLINS, COLORADO.

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THE LOSS OF WATER FROM RESERVOIRS BY SEEPAGE AND EVAPORATION.

By L. G. CARPENTER.

For convenience of reference the principal paragraphs are numbered. A summary and conclusions are given on the last pages of the bulletin.

§ 1. This bulletin was intended to give the results of a series of observations made to determine the loss from seepage on reservoirs near Fort Collins, during the winters of 1895-6 and 1896-7, and to give such of the related observations on evaporation as were necessary to throw light on the measurements from the lakes. As the losses from seepage were less than expected, the losses from evaporation were correspondingly more important. Without intending, or desiring, in this place, to enter upon a discussion of the mass of evaporation observations, this fact has led to a fuller statement of the observations of evaporation than were at first thought necessary or desirable.

§ 2. The loss from the lakes may be due to evaporation from the water surface, and seepage or filtration through the dam and bottom of the reservoir. The leakage through imperfectly fitting gates can be prevented or remedied by better construction. Gain may come from rainfall on the lake, the drainage from the water shed tributary to the lake and the seepage from irrigated lands above the lakes. The aggregate of these gains and losses is desired by the companies as much, or more, than a knowledge of each, but the aggregate can best be told when a knowlege of the amount of loss or gain from each cause is determined. The losses from seepage in many cases deserve most attention, as they may vary between wide limits, and to some extent are preventable. The amount of loss from evaporation may be estimated with considerable certainty. The loss from seepage is more uncertain, as it must vary with the conditions of each basin, and the amount is peculiar to that particular site. Its determination is surrounded with difficulty, and requires accessory investigations, so that attempts to determine the loss by seepage from reservoirs seem not to have been made, or if so, I have been unable to find any records of the attempt or of the results. But while evaporation depends upon various circumstances some of which can be controlled, the amount of evaporation cannot be materially modified at any practicable cost.

§ 3. Generally the scarcity of sites for reservoirs makes the selection depend on their availability, nevertheless the possibility of an undue loss from seepage needs to be borne in mind in making the selection. In most of the sites found in Colorado, the strata form a natural basin from which the loss by seepage is small. There are places in which the strata of rock incline both ways from the reservoir, an anticlinal in the term of the geologist. This condition or when the strata dip in one direction from the site should be avoided, although when the rocks are deeply covered with soil undesirable effects may be small. I have seen reservoirs in Algeria with the strata inclining from the reservoir, where all the exposed rock has been cemented in order to prevent the loss of water through the strata. With a bottom of sand, the loss may be large for a time, but the action rapidly grows less after the sand layers are once saturated.

EVAPORATION.

§ 4. The general conditions of evaporation are well known. The amount of evaporation depends upon the temperature of the water, upon the dryness of the air (not directly upon the temperature of the air), upon the wind. The wind brings fresh, unsaturated air in contact with the water surface and gives opportunity for more vapor to be absorbed. Unless the temperature of the water surface is warmer than the dew point of the air, evaporation cannot proceed; if lower, condensation may take place. The wind also causes waves and increases the area subject to evaporation.

§ 5. The temperature of the water affects the evaporation much more than is usually realized. A shallow lake evaporates faster than a deep one, because its temperature is higher. Likewise the evaporation from the shallow parts of a lake is greater than from the deep portions. I have often found the temperature of the water in the shallow areas much higher than at the deep places. The temperature of the water, and the wind exposure, may differ so much between bodies of water in the same neighborhood that a general statement must be accepted with reserve. It is entirely possible for two tanks side by side to have very different losses from evaporation. In the evaporation tank, which has now been maintained for eleven years, the loss from evaporation averages 41 inches per annum. From lakes during the summer months the evaporation has been fouud to be as much as twice that from the tanks, an increase of temperature of ten degrees, or enough to change the temperature from 70° to 80°, may be sufficient to double the amount.

§ 6. Evaporation proceeds from ice, but at a diminished rate. When our tanks are frozen they show a loss of from 1 to $1\frac{1}{2}$ inches per month, solely from the frozen surface.

The evaporation at night, contrary to common opinion, is almost the same as during the day, and this is nearer equality as the body of water is larger. Even in our tanks, the evaporation during the nights of a month is often found to be more than during the days for the same period.

THE LOSS FROM SEEPAGE.

§ 7. For two winters observations were made to determine the loss from reservoirs by seepage. In many cases water runs into the reservoirs until late in the fall and the filling begins early in the spring, hence the period during which the losses can be found without measurements of inflow and outflow is short. Nearly a dozen reservoirs were visited. Bench marks were established, and levels run to the surface of the water. Some of those selected were filled during the winter, and the record was of no value. Perhaps half a dozen gave some basis for estimating the loss.

Most of the reservoirs under observation are natural basins situated within twelve miles of Fort Collins, and at an elevation from 5,000 to 5,500 feet above sea level. The sites have been ponds in wet weather, and the extreme bottom is covered with thin silt, which when soaked is nearly impervious to water. On the sloping sides the soil consists of a gravelly loam or sandy clay, but lacking the natural impervious coating.

METHOD OF OBSERVATION.

§ 8. At the first visit of the season, some well marked and permanent object was selected as a reference point. If none was convenient, a stake was driven where it would remain undisturbed through the winter; the top was used as a reference point. The elevation of the water surface was compared with the height of the top of the stake by an engineer's level. In case of ripples or waves, the observer was instructed to take the mean water level as near as it could be estimated. Any heaping of the water on one side of the lake from wind was not eliminated. Such cause may effect some of the observations, but the effect has been slight, and can affect but few. April 17, 1897, was windy, and the greatest effect is thought to have been on that day. As the reservoirs were filled immediatly thereafter, this was the last observation that could be made, and has been used.

For a portion of the winter the lakes were covered with ice. When this was the case, holes were cut, and the elevation of the water surface taken. In almost no case did the water rise to the surface of the ice.

DESCRIPTION OF THE LAKES.

§ 9. Loomis lake is one and one half miles west of the Agricultural College. It is a shallow natural basin, which by the construction of an embankment on the north side has been converted into a reservoir. The Larimer County Canal No. 2 runs close to the west side of the lake, and for rods the embankment of the canal forms the only separation between the two. The basin is but little below the plain. Trees and brush on the ditch embankment protect the lake to some extent from west winds. The lake may receive water by seepage from lands to the west, principally lands irrigated from the Pleasant Valley and Lake Canal. Any surface drainage is intercepted by the New Mercer and the Larimer Co. No. 2 Canals, with the exception of that from a strip on the south and east covering but a couple of acres. The lake receives the waste water from some of the neighboring farms. The lake showed a gain in the winter of 1895-6, and a loss in the winter of 1896-7. It is probable that some water wasted into the lake the first winter.

No Name lake is a lake of about an acre, to the east of the reservoir of the Larimer and Weld Reservoir Company, about two miles north of Fort Collins. It has but a small drainage area. It is filled from the Larimer County Canal.

The Rocky Ridge reservoir is situated several miles farther north, on the east side of the Larimer County Canal, which here passes on a ridge on the west and south side of the lake. To the east of the lake is a cliff of sandstone several hundred feet high. The outlet of the reservoir is by a short tunnel under the canal, through a ridge to the west of the lake. The reservoir was being filled during the second winter of observation, so that a record was not taken.

The North Poudre Canal reservoirs, of which three were observed in the winter of 1895–6 and four in the winter of 1896–7, are natural basins, most of which have an embankment thrown up on one side. These lakes are of considerable size, some having an area of several hundred acres. Before they were converted into reservoirs, they held storm waters and collected some flood water, so that the bottoms were covered with silt. There are no trees to shield them from the wind.

Rigden lake is a natural basin one mile east and two miles south of the Agricultural College. It has neither inlet nor outlet. Some seepage shows on the inclined sides of the basin during the summer season, and the ground is soft in places. The lake collects the waste and seepage waters from irrigated land to the west. The nearest ditch that is more than a small lateral, is over a mile away. The lake is not fully exposed to the wind, being below the surface of the plain, and protected by a grove of cottonwoods a few rods to the west, and another a short distance to the east.

Warren lake lies a mile and one half south of Rigden lake, and is used as a reservoir. It has an embankment on the northeast side. Some seepage water enters at the west side, and also waste water from irrigation. Observations on evaporation were carried on in this lake for several years. The observations on loss by seepage were of no result, as the company found it convenient to fill the lake, and the filling, together with the seepage inflow, made the observations inconclusive.

TABLE I.—SUMMARY OF OBSERVATIONS ON LOSSES FROM RESERVOIRS.

1896.

NAME OF LAKE.	Period.	No. of days.	Net loss—inches.	Rain during period—inches.	Total loss—evaporation and seepage—inches.	NOTES.
Rigden Lake	Feb. 18—Mar. 20.	31	3.24	1.21	4.45	Feb. 18, little ice in lake. Water 46° 4 p. m. No water running in.
	Mar. 20—April 11.	22	3.36	.67	4.03	Mar. 20, no ice. April 11, water 63° at 11 a. m.
Loomis Lake	Feb. 18—Mar. 20.	31	3.40 g	1.21	2.19 g	Feb. 18, no water running in.
	Mar. 20—April 11.	30	8.84 g	.67	8.17 g	Mar. 20. no ice. April 11, water running in adjacent canal; water in canal April 5.
No Name Lake	Feb. 19—Mar. 12.	21	2.04	.66	2.70	Small drainage area.
	Mar. 12—April 14.	33	4.08	1.22	5.30	April 14, temperature 62° at 9 a. m. Soil moist for 4 in.
Rocky Ridge Lake	Feb. 20—Mar. 12.	21	....	.66	....	Filled in this interval. March 12, ice mostly gone.
	Mar 12—April 14.	33	2.65	1.22	3.87	April 14, temperature water 54° at 10 a. m. Waves cause change of level of ⅛ in. during measurement. Ground moist 3 in. deep.
Reservoir No. 1, North Poudre Canal	Feb. 20—Mar. 12.	21	1.33	.66	1.99	Drainage area about 2 square miles.
	Mar. 12—April 14.	34	.76	1.22	1.98	April 14, temperature water 59° at 11 a. m. Level affected by waves.
Reservoir No. 2, North Poudre Canal (Demmel Lake)	Feb. 20—Mar. 12.	21	1.64	.66	2.30	Drainage of about 2 square miles.
	Mar. 12—April 14.	34	3.31	1.22	4.56	April 14, temperature 53° at 12 m.
	Dec. 5, '95—April 10.	127	4.00	2.19	6.19	From record of Mr. E. J. Gregory, Supt.
Reservoir No. 3, North Poudre Canal (Tenney Lake).	Feb. 20—Mar. 12.	21	9.90	.66	10.56	April 14, water running in lake.
	Dec. 5, '95—April 10.	127	4.00	2.19	6.19	From Mr. Gregory, Supt.
Reservoir No. 4, North Poudre Canal	Dec. 5, '95—April 10.	127	6.00	2.19	8.19	From Mr. Gregory, Supt.

TABLE II.—SUMMARY OF OBSERVATIONS ON LOSSES FROM RESERVOIRS.

1897.

NAME OF LAKE.	Period.	No. of days.	Net loss—inches.	Rain during period—inches.	Total loss—evaporation and seepage—inches.	NOTES.
Loomis Lake	Feb. 3—Mar. 6.	31	.64	.72	1.36	Feb. 3, ice covered. Little snow on ice. Ice 5 in. thick.
	Mar. 6—Mar. 17.	11	.96	.08	1.04	March 6, ice covered.
	Mar. 17—April 17.	31	.92	2.90	3.82	March 17, most ice gone. Sides of basin wet from frost coming out of ground.
No Name Lake	Feb. 2—Mar. 5.	31	.49 g	.72	.23	Ice 5 in. thick. About 1 in. snow on ice. Water rises same height as ice.
	Mar. 5—Mar. 17.	12	.70	.08	.78	March 5, ice 6 in. thick. No appearance of water having run in. Little crusted snow on ice—about ½ or ¾ in. March 12, some open water.
	Mar. 17—April 17.	31	1.54	2.90	4.44	April 12, windy, poor measurement and not used. April 17, measurement all right.
Reservoir No. 1, North Poudre Canal	Feb. 2—Mar. 5.	31	.62	.72	1.34	Feb. 2, ice 6 in. thick. Some snow. Water rises above ice in hole.
	Mar. 5—Mar. 17.	12	.96 g	.08	.88 g	March 5, little open water. Ice 6 in. thick. No appearance of water having run in.
	Mar. 17—April 12.	26	4.88 g	2.74	2.14 g	March 17, snow all gone. April 12, heavy wind from northwest.
Reservoir No. 2, North Poudre Canal (Demmel Lake.)	Feb. 2—Mar. 5.	31	.43	.72	1.15	Feb. 2, thin layer of snow on some parts of ice.
	Mar. 5—Mar. 17.	12	.48	.08	.56	March 5, ice 8 in. thick. Very little open water. Think no water entering from any source.
	Mar. 17—April 12.	26	3.20 g	2.74	.46 g	March 17, considerable open water. Drove stake to level of water for measurement. April 12, windy, measure uncertain.
Reservoir No. 3, North Poudre Canal	Feb. 2—Mar. 5.	31	.18	.72	.90	Feb. 2, strip open water near edge.
	Mar. 5—Mar. 17.	12	....	....	....	March 17, filling lake. Small amount running out of lake.
Reservoir No. 4, North Poudre Canal	Feb. 2—Mar. 5.	31	.41	.72	1.13	Feb. 2, ice about 5 in. thick. About 1 in. snow on ice. Water rises same level as ice.
	Mar. 5—Mar. 17.	12	.48	.08	.56	March 5, some crusted snow on ice.
	Mar. 17—April 12.	26	3.82 g	2.74	1.08 g	March 17, snow gone. April 12, ground around lake moist and muddy. Small amount of water running in from snowbank.

§ 10. The total loss given in Table 2 is the combined loss from seepage and evaporation. The records, given later in the bulletin, form the basis of the estimated evaporation given in the column so headed in the following table. The difference, unaccounted for by evaporation, is the loss due to filtration or seepage. In forming this table, only those cases where a loss was shown have been taken. It is noticeable that there are many cases in which the total loss was less than the amount of evaporation; in other words, the reservoirs were gaining water from the run-off of the water sheds running into the lake, or from seepage entering the lakes, or perhaps, in a few cases, from water in the supplying ditches, which had been reported dry. This is shown in the following table:

TABLE III.—LOSSES DUE TO SEEPAGE ALONE.

Name of Lake.	Total Loss—Inches.	Evaporation (estimated)—Inches.	Remainder (seepage)—Inches.	No. Days.	Seepage per Day—Inches	Per Year, at Same Rate.
Rigden Lake, 1896	4.45	2.39	2.06	31	.067	24.25
	4.03	2.58	1.45	22	.066	24 06
Loomis Lake, 1897	1.36	2 43	1.07 gain	31	Gain	Gain
	1.04	.85	.19	11	.017	6.30
	3.82	2.97	.85	31	.027	10.01
No Name Lake, 1896	2.70	1.70	1.00	21	.048	17.38
	5.30	3.66	1.64	33	.050	18.16
	.23	2.43	2.20 gain	31	Gain	Gain
	.78	.93	.15 gain	12	Gain	Gain
1897	4.44	2.97	1.47	31	.0475	17.31
Rocky Ridge Lake	3.87	3.66	.21	33	.006	2.32
Res. No. 2, North Poudre Canal 1896	1.99	1.63	.36	21	.016	6.26
	1.98	3.66	1.68 gain	34	Gain	Gain
1897	1.34	2.20	.86 gain	31	Gain	Gain
Demmel Lake, 1896	2 30	1.63	.67	21	.032	13.21
	4.56	3.66	.90	34	.0265	9.67
1897	1.15	2.20	1.05 gain	31	Gain	....
	.56	.93	.37 gain	12	Gain	....
Res. No. 3, North Poudre Canal. 1896	10.56	1.63	8.93	21	.42	155.00
1897	.90 gain	....	....	....	....	....
Res. No. 4, North Poudre Canal, 1897	1.13	2.43	1.30 gain	....	Gain	....
	.56	.93	37 gain	....	Gain	....
	1.08 gain	2.97	4.05 gain	....	....	....
For the whole winter, from the records of the Canal company, there must have been gain from inflow.						
Demmel Lake	6.19	10.26	4.07 gain	127	Gain	....
Res. No. 3, North Poudre Canal	6.19	10.26	4.07 gain	127	Gain	....
Res. No. 4, North Poudre Canal	8.19	10.26	2.07 gain	127	Gain	....

§ 11. It appears that the leakage from these particular reservoirs is very small. After allowing for evaporation, we find that several lakes must have gained water from outside sources, either by some water coming through the supply ditches, or from the water sheds. The three lakes, Rigden lake, Loomis lake and No Name lake, where the loss is most evident, are cases where the water sheds are small. In the other cases, it was not thought that water could have come from the water shed, but it may be possible.

§ 12. The loss from seepage during the months the lakes were measured, is evidently small. During the remainder of the year the loss will not be much more rapid, but the greater depth of water usually in spring increases the rate. When the lakes are nearly full, the water then covers some ground less completely protected by silt, but in the course of repeated fillings the whole lake bottom will reach much the same condition.

§ 13. In the Rigden lake, the loss from seepage appears to be about 2 feet per year; in the case of the No Name lake not quite so much; in reservoir No. 2, during the period when gain was not noticed, at the rate of 13 feet per year. The loss from the last lake is looked upon with doubt, but no cause other than seepage has been established.

§ 14. As a whole, the losses from the lakes under observation have been small; less than the evaporation, and less than expected. In some other places that have not been subjected to careful observations, the loss has been much greater than found in these reservoirs. Numerous small reservoirs known to the writer have been abandoned for storage purposes, because the loss was so great. In the southern part of the state, one instance was found where a depth of 27 feet is reported to have disappeared between October and the following March. Yet in these cases much of the loss has doubtless been due to filling the adjacent subsoil, as well as to seepage proper.

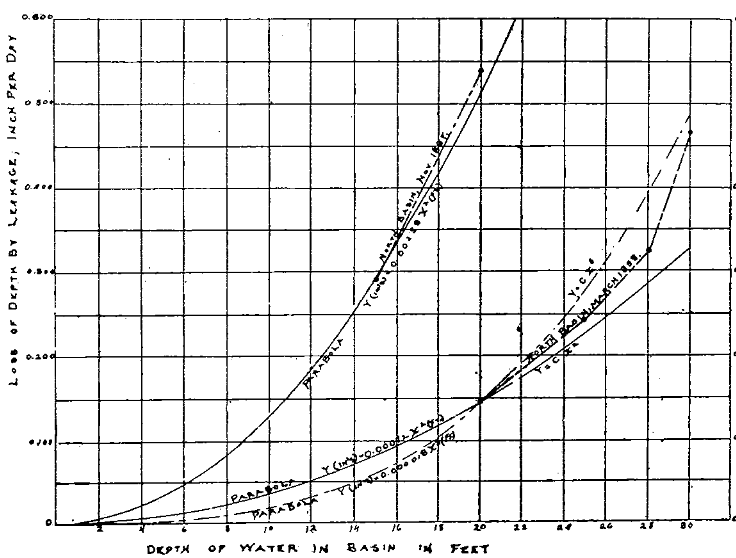
§ 15. In most of such cases, though the loss is so large at first, it may grow less with succeeding years after the adjacent subsoil is once filled. This may be expected to be the case where there are extensive beds of sand under and surrounding the reservoir. These beds absorb about one third of their volume of water, and continue to absorb as long as there are connected bodies of sand into which it can flow, or other outlets. Where the reservoir is small and the sand bed is large, the amount of water taken up in this way may be large and cause the loss from the lake to be excessive. When, however, the sand is filled, the draft on the lake is much less, the loss is reduced, and the sand holds water with success, as is shown by the lakes in sand hills, or by the holding power of sand embankments.

§ 16. In these and other cases the losses may be lessened. For since clay or fine material offers great resistance to the passage of water, only a thin layer of clay or fine sediment is required to greatly diminish the loss of water. One of the most efficient means, therefore, of lessening the loss is to change the character of the surface of the lake bottom by the deposit of a thin stratum of fine material. Since flood waters often contain a large percentage of silt, their use and the deposit of such silt, seals the bottom and may make the basin nearly water tight.

The success of the silting process may be expected to be greater with small reservoirs than with large ones. Much of the silt is deposited where the speed of the water is checked, or near the inlet. Near the outlet, where the seepage is usually the greater, less silt is deposited. Yet if the sediment is fine much benefit may be expected by application of this process.

In many cases the water may be made artificially muddy by throwing clay into the inflowing stream, taking pains that it is finely subdivided and is carried in suspension.

§ 17. The loss by seepage from sites, for reasons already mentioned, may be expected to increase with an increase of depth of water in the reservoirs, and to become less with the lapse of time.



Effect of Depth and of Sediment on Loss of Water from Reservoirs.
Observations under J. C. Trautwine, Jr., 1897–98.

The observations reported were during the winter, with the surface of the lakes nearly stationary, and do not show the effect of variation in depth. Several cases, where the loss has been measured from canals, show that the loss increases with the depth of water in the canal, but the loss seems to be greater than shown from theoretical considerations. From Darcy's experiments the writer deduces an expression for the leakage through embankments, which seems to be proportional to the square root of the cube of the depth. Much of the loss may take place through the bottom, and this would tend to make the leakage increase at a higher rate.

Through the courtesy of John C. Trautwine, Jr., Chief of the Bureau of Water, Philadelphia, I am enabled to quote some recent and valuable observations on one of the reservoirs belonging to that city, and which clearly show the effect of increased depth. The Queen Lane reservoir has considerable trouble on account of leakage, and during the summer of 1897 had been lined with asphalt, the lining being completed August 16th.

The diagram shows the observations at different depths, the two curves representing the losses before and after partially silting the reservoir by pumping into the reservoir water laden with anthracite coal dust.

November, 1897. (Before Silting.)		March, 1898. (After Silting.)	
Depth.	Loss per Day.	Depth.	Loss per Day.
15 feet.	.29 inches.	20 feet.	.15 inches.
20 feet.	.54 inches.	25 feet.	.24 inches.
....	....	28 feet.	.32 inches.
....	....	30 feet.	.46 inches.

These observations show in both cases a more rapid increase in the leakage with depth than would seem to be indicated by the uncertain theory.

That a portion of the rapid increase is due to some change in the conditions is shown by still more recent observations. Under date of April 7th, Mr. Trautwine adds that observations, extending over ten days, with a nearly constant head of about 30 feet, have shown an increase in the daily loss to .55 inch.

Since that date the reservoir has been drawn down to 20 feet, and under date of April 16th, Mr. Trautwine writes that the average daily loss at that depth for eleven days was .28 inch, or about double the amount shown in March.

These interesting facts would seem to show that the conditions remaining the same, the effect of an increase in leakage due to an increase in depth, would be at a much less rapid rate than indicated in the curve shown.

As an explanation of the increase in rate with increased depth, and the continued increase after the depth is reduced, Mr. Trautwine suggests that there may be a velocity of percolation at which the sediment-bearing water ceases to deposit its sediment in the pores and begins to carry away that which has already been deposited, thus permitting an increase under large heads with time.

EVAPORATION.

§ 18. The following table shows the amount of evaporation that has been observed from our standard tank during the past eleven years. The tank is of galvanized iron, three feet square, originally two feet deep, but since 1889, three feet deep. During the summer months, the height of the water is measured by the hook gage to the nearest thousandth of a foot, twice daily. After September, darkness interferes with the observation at 7 p. m. and readings are made only at 7 a. m. After ice forms the tank is undisturbed except at the beginning of the month. The ice is then loosened from the sides of the tank, and the elevation of the water surface, which is then the same as if the floating ice were melted, is measured. Ice sometimes forms of considerable thickness, and punctures in separating it from the sides have caused the loss of the record for several months. The rainfall is measured by standard gages near the tank. The amount given as the evaporation, is the loss from the water surface after allowing for the rainfall, or is the fall of the surface plus the rainfall. The amounts here given are subject to slight corrections, as critical examination may cause the rejection of some days of heavy showers.

TABLE IV.—EVAPORATION FROM WATER SURFACE.

Tank 3x3x3 feet, flush with ground, at Fort Collins, Colorado. Elevation 4,990 feet above sea level: latitude 40° 34', longitude 105°. Amounts are given in inches.

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
1887........	2.46	3.23	4.60	5.55	5.19	5.75	5.23	4.24	4.12	3.26	1.48	1.60	46.71
1888........	....	....	....	....	4.45	7.70†	7.00†	4.06	3.94	2.17	1.35	.99	.....
1889........	1.08	1.03	2.75	4.06	3.72	4.34	5.20	5.15	5.19	3.28	.62	1.42	37.84
1890........	.86	2.36	3.48	3.50	4.32	5.71	5.44	5.76	3.69	2.71	1.32	1.10	40.25
1891........	1.89†	1.90	2.23	2.24	5.03	4.97	5.72	4.91	4.12	3.62	1.74	.75	39.12
1892........	2.51	2.15‡	2.78	2.58	3.49	4.20	4.69	5.64	5.11	3.33	1.93	1.13	40.54
1893........	p.	1.52*	3.79	5.40	5.12	6.12	6.41	4.73	5.04	3.79	1.05	1.38	.....
1894........	1.14†	1.15†	1.95	4.61	4.66	5.01	5.74	4.88	3.77	3.75	1.64	1.22	39.52
1895........	1.19†	1.19†	p	4.91	4.27	4.13	4.57	4.52	4.06	2.24	1.53	1.68	.....
1896........	2.64	2.25	2.39	4.71	5.91	5.09	5.23	5.80	3.34	2.94	1.62	1.25	43.17
1897........	1.80	2.20	p.	3.33	4.13	4.26	4.64	4.76	3.97	2.88	1.47	.94	.....
Average....	1.73	1.90	3.00	4.19	4.57	5.21	5.44	4.95	4.21	3.09	1.43	1.22	40.94

* Record from part of month.
† Deduced from loss in two months.
‡ From record from February 17.
p. Tank punctured, record lacking.

§ 19. As the temperature of the water is an important factor in the amount of evaporation, the average temperature of the water for the corresponding time is given in Table 5. The temperature given is the mean of the surface temperatures at 7 a. m. and 7 p. m. The maximum and minimum temperatures at the surface have also been taken by self-recording instruments in the water in early spring or late fall. Their record is not so complete and is not given here. The average derived from the 7 a. m. and 7 p. m. observations, as shown by hourly readings, is lower than the average temperature of the tank by about 3.5°. The difference is due to the fact that while heating, the surface heats rapidly and the lower layers slowly. But in cooling, the whole mass of water cools. The mean of the maximum and minimum temperatures is much closer to the true average temperature.

TABLE V.—MEAN TEMPERATURE OF WATER IN EVAPORATION TANK.

Surface temperatures. Average of 7 a. m. and 7 p. m.

NOTE—The means thus found are less than the true average by 3 or 4 degrees.

Year.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1887	....	....	46.6	49.5	62.3	69.8	73.0	71.5	64.7	59.0	38.9	....
1888	....	....	....	....	....	....	....	....	....	....	...	....
1889	....	....	....	....	....	66.6	72.0	70.5	61.1	52.7	....	....
1890	....	....	....	....	58 9	68.4	75 1	69.9	62.0	49.0	...	....
1891	....	....	....	....	59.4	68.5	74.1	70.5	64.3	50.8	43.1*	....
1892	....	....	....	46.7	54.4	66.9	71.8	70.0	63.2	49.5	....	....
1893	....	....	....	47.0	55.5	68.9	73.9	70.3	63.2	49.0	....	....
1894	....	....	....	49.9	59.8	67.7	73.0	71.8	63.1	51.1	42 8†	....
1895	....	....	....	50.4	59.4	65 6	69.4	70.7	62.8	48.1	....	....
1896	....	....	....	51.1	58.9	69.6	74.1	71.4	63.3	50.9	....	....
1897	....	....	....	48.2	61.4	66.6	70.9	71.4	66.4	51.5	....	....
Average	....	....	....	49.0	58.9	67.9	72.7	70.8	63.4	51.2	41.6	

* First fifteen days.
† First thirteen days.

§ 20. Observations have also been made on the evaporation from reservoirs. Tanks one foot square and eighteen inches high were used and floated by pontoons, and filled with water to 3 or 4 inches from the top. It was intended to maintain the water in the tank at the same level as the water on the outside. In order to break the waves the whole was surrounded by a triangular float of boards, which was anchored so that the angle would face the waves and prevent them washing into the tank. The device was not always completely successful in this respect. At times boys interfered with the tanks. Observations were carried on for several years in Warren's lake, but the interference was so great the observations at that place were abandoned. For the last two years tanks were placed in other lakes, convenient of access, and chosen because the lakes were partially closed to the public and the observations less likely to be interfered with.

§ 21. The lakes used in 1896 and 1897 were Lee's lake, Loomis lake and Claymore lake.

The Lee lake is a small reservoir owned by Dr. E. A. Lee of Fort Collins, and situated about four miles from the College. The lake is shallow and exposed to the wind. Weeds grow freely in the lake, and late in summer form a mass which is difficult to pass through, and greatly hinders the formation of waves. The water has varied from about six to ten feet in depth during the season.

Loomis or Sheldon lake is the same as previously mentioned in the observations on loss from seepage. It is a little over a mile west of the College. The depth has varied from five to ten feet. This lake is free from weeds.

Claymore lake is situated six miles northwest of the College and close to the ridge of Dakota sandstone which rises immediately from the water on the west side. The lake is a reservoir connected with the Pleasant Valley and Lake Canal. The ridge of sandstone to the west rises at an angle of about 20° and to the height of 400 feet. This ridge interferes with the wind slightly, but because of the downward movement of most of the west winds, it lessens the evaporation very little, if any. This lake is the largest of the three on which observations were taken. The depth of water has varied from 6 to 15 feet. There have been few or no weeds observed, but floating plant life has been abundant.

METHODS OF OBSERVATION.

§ 22. The observations were made weekly in 1896 and semi-weekly in 1897. The distance to the surface of the water in the tank was measured by placing a rule across the top of the tank and measuring down to the surface of the water by a rule graduated to tenths of inches, a rule such as is used in rain gages being used. In order to eliminate the effect of tipping the tank when grasped by the observer, the readings were made at two opposite sides or at the center of the tank. The tanks were filled to two or three inches from the rim and evaporation allowed to proceed until the water had fallen to three to five inches, then again filled from the lake. The measurements cannot be considered as exact, but the error is nearly eliminated in the differences.

RAINFALL.

§ 23. The rainfall as given in the table is that observed at the Agricultural College. The lakes are several miles distant. At times the rainfall is undoubtedly greater or less than that observed at the College. Gages were placed on the floats, but as they could be read only once or twice weekly, the rain record at the College, where the observations are made twice daily, is used instead. The greatest difference is found on days of local thunder storms in July and August, but in only a few cases is there any material difference.

§ 24. The temperature of the surface of the water in the tank, of the surface of the lake, and of the bottom of the lake, was taken. To obtain the temperature at the lake bottom, a sampling instrument was used. This consisted of a brass cylinder with valves at top and bottom, arranged to open as the cylinder descended in the water, and open as it rose. By churning the instrument up and down in the water it was easy to fill it with a sample of water from any desired depth, and bringing the instrument rapidly to the surface, the temperature was immediately taken. It will be noticed that the bottom of the lake is cooler than the surface, as was to be expected. Table 6 shows the changes during the day at the bottom and surface of Lee lake, the measurements being made at fifteen minute intervals for eight hours. From hourly observations on the smaller evaporation tanks at the College, there is reason to believe that late at night the bottom and surface become of the same temperature, and that at times the bottom is warmer than the surface.

To show the changes in the temperature of a lake during the day the following observations are given. They were made Aug. 6, 1896, on the Lee lake, by Mr. R. E. Trimble:

TABLE VI.

Hour of Observation.	Clouds, in Tenths.	Wind.	Temperature of Water.		
			Tank.	Lake Surface.	Lake Bottom.
9:00 a. m.	....	....	71.0	70.2	68.8
9:15 a. m.	Few	....	72.0	70.5	68.2
9:30 a. m.	Few	Light S. E.	72.0	70.7	68.0
9:45 a. m.	Few	Light S. E.	72.0	71.2	67.7
10:00 a. m.	Few	East.	72.0	71.0	68.0
10:15 a. m.	1	....	72.8	71.7	68.8
10:30 a. m.	1	Light S. E.	73.3	72.2	69.0
10:45 a. m.	2	Light S. E.	74.0	72.9	68.6
11:00 a. m.	2	Light S. E.	74.0	73.0	68.5
11:15 a. m.	3	Light S. E.	74.0	73.0	68.2
11:30 a. m.	3	Light S. E.	73.2	72.9	68.5
11:45 a. m.	3	Light S. E.	74.0	73.1	69.1
12:00 p. m.	2	Light S. E.	74.2	73.2	69.2
12:15 p. m.	2	Light S. E.	74.8	74.0	68.8
12:30 p. m.	2	Light S. E.	74.4	74.0	68.8
12:45 p. m.	3	Light S. E.	74.5	74.2	69.1
1:00 p. m.	4	Light S. E.	74.0	73.9	68.3
1:15 p. m.	6	....	74.2	74.2	68.7
1:30 p. m.	7	Brisk N.	73.8	73.8	69.1
1:45 p. m.	5	Light E.	74.0	74.0	69.4
2:00 p. m.	4	Light S.	74.9	74.7	69.8
2:15 p. m.	3	W.	75.7	76.0	69.4
2:30 p. m.	2	W.	75.5	76.0	69.5
2:45 p. m.	2	....	76.0	77.0	70.0
3:00 p. m.	1	S. E.	76.6	77.2	69.3
3:15 p. m.	2	S. E.	76.2	76.4	69.8
3:30 p. m.	2	S. E.	76.2	76.0	69.0
3:45 p. m.	2	S. E.	76.0	76.0	69.3
4:00 p. m.	1	S. E.	76.0	76.0	68.8
4:15 p. m.	2	E.	75.8	76.0	68.2
4:30 p. m.	3	None	76.0	76.2	69.0
4:45 p. m.	5	N.	75.6	76.7	68.7
5:00 p. m.	....	....	75.5	76.8	68.6

The temperature of the surrounding lake was taken to detect whether the tank caused any material change in the temperature of the water in the tank. The difference is slight, and in that respect, the small tanks seem to affect the temperature less than larger tanks. The water in the tank was sometimes warmer than the surrounding lake, occasionally as much as 3° to 5°, but usually less than 1°. The consequence of this increase in temperature is to increase the evaporation, and therefore the amounts measured may be considered slightly greater than evaporation from the lake itself.

§ 25. The wind record is from the anemometer at the Experiment Station of the Agricultural College. The anemometer at that point is exposed on a tower sixty feet from the ground, but with trees, not in all directions, at a moderate distance. The supposition that this record represents the wind at the lakes is subject to the same uncertainties as the similar use of the rain record. The error cannot be great. In the present discussion the wind is not used in the comparison, but is given to exhibit the conditions. The effect of the wind is to increase the amount of evaporation by bringing unsaturated air in contact with the water, and to give opportunity for the diffusion of the water vapor. From the working formula derived from the observations in 1889, each mile of wind increased the evaporation by about 2 per cent. Mr. Fitzgerald's experiments at Boston, indicate an increase of 2 per cent for each mile of wind. The amounts are to be taken subject to investigations since made. A reduction of the observations made at this place during the past ten years should give a more satisfactory and useful formula than that mentioned in the Annual Report of the Experiment Station for 1891. High winds may affect the record by blowing spray into the tank, notwithstanding the protecting shelter. The greatest velocity between the different observations is given. Heavy rainfalls may introduce uncertainties also.

The observations on Claymore lake for three months in the summer of 1897 have not been used, because it was found that a leak existed in the tank, and the record involving nearly thirty trips to the lake is rejected. The record from August 21 to November, after the tank was repaired, is given, as also a few weeks in May.

EXPLANATION OF THE TABLES.

§ 26. The column giving the net loss gives the depression of the water surface observed in the period given in the second column. The rain during the same period as measured at the Agricultural College at Fort Collins, is given in the next column. The total loss is the sum of the loss observed in the lake, increased by the amount of rainfall which has fallen in the meantime, or is the sum of the two preceding columns.

TABLE VII.—EVAPORATION OBSERVATIONS, LEE'S LAKE.—1896.

DATE.	No. of Days Interval.	Temperature of Water. Degrees, Fahrenheit. In Tank.	At Surface of Lake.	At Bottom of Lake.	Wind—Miles. Av. Movement per 24 hrs.	Maximum hourly Velocity.	Fall of Water Surface since Previous Obs.	Rainfall at College since Previous Obs.	Total Loss since Previous Obs.	Average Loss per Day.	REMARKS.
———— June 15.....	..	76.0	76.0	....	....	....	....	....	....	....	Put tank in lake.
9:20 a. m. June 17.....	2	75.5	73.7	....	113*	48	.50	T	.50	.250	
4:10 p. m. June 20.....	3	75.8	75.8	....	160	30	1.60	T	1.60	.533	
1:15 p. m. June 24....	4	73.5	73.5	70.0	166	30	.20	.70	.90	.225	Rain gage at lake, 0.65 inches.
9:05 a. m. June 30.....	6	72.5	72.5	69.0	126	40	-.20	.36	.18	.030	Rain gage at lake, 0.62 inches.
3:45 p. m. July 3....	3	75.3	75.3	71.0	151	16	.90	T	.90	.300	Rain gage at lake, 0.02 inches.
9:30 a. m. July 7.....	4	76.0	....	72.0	122	12	1.00	.03	1.03	.258	Rain gage at lake, 0.02 inches.
9:30 a. m. July 8.....	1	76.0	75.8	72.0	105	7	.20	T	.20	.200	Rain gage at lake, 0.02 inches.
4:00 p. m. July 11.....	3	83.0	83.5	76.0	113	13	1.30	0	1.30	.433	
9:20 a. m. July 14.....	3	75.0	74.8	73.0	146	17	.90	0	.90	.300	
10:40 a. m. July 18.....	4	74.0	73.7	71.0	156	17	1.05	.28	1.33	.332	Rain gage at lake, 0.10 inches.
9:00 a. m. July 21.....	3	73.0	73.0	70.5	152	14	.70	.37	1.07	.357	Rain gage at lake, 0.13 inches.
9:50 a. m. July 28.....	7	74.0	71.0	68.8	126	21	-.60	2.30	1.70	.243	Rain gage at lake, 3.84 inches.
3:25 p. m. August 1..	4	79.0	79.0	70.0?	126	20	.90	.07	.97	.242	
9:30 a. m. August 4..	3	72.0	70.8	69.0	136	15	.80	0	.80	.267	
5:00 p. m. August 6..	2	75.5	76.8	68.6	147	24	.85	T	.85	.425	Rain gage at lake, T.
3:15 p. m. August 8..	2	74.0	74.2	71.2	176	15	.25	0	.25	.125	
9:00 a. m. August 11..	3	65.8	66.2	64.2	202	22	1.45	0	1.45	.483	
4:45 p. m. August 15..	4	71.5	72.0	67.2	150	17	.85	.02	.87	.217	Rain gage at lake, 0.02 inches.
9:00 a. m. August 18..	3	....	....	....	139	17	.40	0	.40	.133	Rain gage at lake, 0.20 inches.
3:45 p. m. August 22..	4	67.2	67.5	65.9	136*	17*	-1.35	2.02	.67	.168	Rain gage at lake, 1.90 inches.
9:40 a. m. August 25..	3	65.8	66.0	64.2	124	18*	.60	.02	.62	.207	
3:00 p. m. August 29..	4	74.6	74.8	65.8	119	17	.60	0	.60	.150	
9:30 a. m. Sept. 1....	3	70.2	70.8	66.2	111	16	.60	.14	.74	.247	Rain gage at lake, 0.06 inches.
3:35 p. m. Sept. 5....	4	74.0	74.2	65.6	157	15	.90	.04	.94	.235	From this on the rain gage at lake was so
9:35 p. m. Sept. 8....	3	65.0	65.2	63.9	148	20	1.30	0	1.30	.433	near the water that waves washed water in.
3:30 p. m. Sept. 12....	4	69.8	69.0	59.6	124	14*	-.10	.48	.38	.095	It seemed to rain more west of town.
10:00 a. m. Sept. 15....	3	67.6	66.8	61.8	112	....	.40	0	.40	.133	
9:15 a. m. Sept 22....	7	60.2	60.2	58.0	140	19*	.20	.55	.75	.107	
3:00 p m. Sept. 26....	4	58.0	58.0	55.0	195	24	.30	.47	.77	.192	
9:50 a. m. Sept. 29....	3	58.0	57.8	56.0	118	10	.30	.01	.31	.103	
3:30 p. m. Oct. 3.....	4	56.0	55.8	59.8	113	9	.70	0	.70	.175	
9:00 a. m. Oct. 5.....	2	57.7	57.5	56.0	144	13	.20	0	.20	.100	
12:00 m. Oct. 13....	8	54.8	54.8	52.0	149	19*	1.30	.02	1.32	.165	Wind blowing.
3:30 p. m. Oct. 17.....	4	57.5	56.3	54.2	140	15*	1.20	0	1.20	.300	
10:45 a. m. Oct. 20.....	3	55.2	54.0	52.2	133	12	.20	0	.20	.067	
3:05 p. m. Oct. 24.....	4	52.0	52.0	51.8	133	12	.30	.28	.58	.145	
10:15 a. m. Oct. 27.....	3	49.0	48.8	48.2	124	15	.30	0	.30	.100	
3:00 p. m. Oct. 31.....	4	44.8	44.2	42.2	256	26	-.10	.19	.09	.023	

* Days when electrical recorder was out of order, Some estimates included.

TABLE VIII.—EVAPORATION OBSERVATIONS, LEE'S LAKE.—1897.

Date.	No. of Days Interval.	Temperature of Water. Degrees, Fahrenheit. In Tank.	At Surface of Lake.	At Bottom of Lake.	Wind—Miles. Av. Movement per 24 hrs.	Maximum hourly Velocity.	Fall of Water Surface since Previous Obs.	Rainfall at College since Previous Obs.	Total Loss since Previous Obs.	Average Loss per Day.	Remarks.
11:30 a. m. May 8....	..	57.0	57.0	....	....	....	....	....	....	....	Put tank in lake.
9:20 a. m. May 11....	3	60.8	59.7	59.2	188	30*	0	.10	.10	.033	
9:15 a. m. May 18....	7	67.8	66 8	65.7	148	20*	1.50	.04	1.54	.220	Shower before measuring.
3:45 p. m. May 22....	4	71.4	71.2	69 8	143*	22*	-1.10	1.50	.40	.100	
9:30 a. m. May 25....	3	74.0	68.6	66.8	161*	19*	.60	.04	.64	.213	A few waves.
3:20 p. m. May 28....	3	68 8	67.4	64.6	136*	18*	.20	.21	.41	.137	
9:00 a. m. June 1....	4	....	....	....	142*	17*	-.10	.35	.25	.062	No thermometer.
3:40 p. m. June 4....	3	64.0	63.8	64.0	144	14	3.00	.63	(3.63)	....	A few waves.
9:45 a. m. June 8....	4	72.8	65.2	64.5	121	11	.30	.39	.69	.172	
10:00 a. m. June 11....	3	64.5	64.5	64.6	184	29	1.90	.10	2.00	.067	
9:25 a. m. June 15....	4	72.0	71.2	70.6	114*	11*	4.70	0	(4.70)	....	
9:15 a. m. June 18....	3	66.5	66.3	65.8	233*	27*	1.00	0	1.00	.330	Pulled ashore and nailed on boards so would
9:00 a. m. June 22....	4	72.5	72.5	72.0	119	20	.70	.11	.81	.202	float higher.
10:00 a. m. June 25....	3	68.5	69.0	69.4	149	14	.90	.28	1.18	.393	A few waves.
9:35 a. m. June 29....	4	73.5	71.5	71.7	185	14	1.00	T	1.00	.250	
9:40 a. m. July 2....	3	75.0	73.5	73.0	129	16	-.10	.05	-.05	....	
9:40 a. m. July 6....	4	70.5	69.5	69.8	193	25	1.30	0	1.30	.325	A few waves.
2:10 p. m. July 9....	3	71.8	71.3	71.0	136*	19*	-.40	1.18	.78	.260	
9:50 a. m. July 13....	4	80.0	75.5	76.0	109*	10*	2.00	.32	(2 32)	....	
4:25 p. m. July 16....	3	75.0	74.8	73.5	138	12	.90	0	.90	.300	Put rain gage on float.
10:25 a. m. July 20....	4	68.5	67.0	66.3	141*	16*	.10	.89	.99	.247	Rain record at lake, .74 inches.
9:35 a. m. July 23....	3	72.5	71.3	71.3	122*	9*	.70	0	.70	.233	Rain record at lake, 0.
9:45 a. m. July 27....	4	73.1	71.2	71.6	133	18	.90	.21	1.11	.278	Rain record at lake, .19 inches.
9:30 a. m. July 30....	3	75.0	73.0	72.1	121	22	-.90	0	-.90	....	
10:05 a. m. Aug. 3....	4	73.1	71.6	72.0	142	24*	.80	.06	.86	.215	Rain record at lake, .33 inches.
9:25 a. m. Aug. 6....	3	73.8	71.6	70.3	97	9*	.20	.37	.57	.190	Rain record at lake, .43 inches.
9:50 a. m. Aug. 10....	4	75.0	72.5	71.1	107	8*	.40	.53	.93	.233	Rain record at lake, .34 inches.
11:30 a. m. Aug. 13....	3	74.8	73.7	72.5	100	14	.85	.03	.88	.293	Rain record at lake, T.
10:00 a. m. Aug. 17....	4	74.0	72.9	71.0	103	13	1.00	T	1.00	.250	
9:30 a. m. Aug. 20....	3	69.8	69.2	68.2	116	10	.85	.67	1.52	.507	Rain record at lake, .13 inches.
9:30 a. m. Aug. 24....	4	69.9	68.8	68.0	120	11	1.20	0	1.20	.300	Rain record at lake, 0.
9:40 a. m. Aug. 27....	3	69.9	68.7	67.7	131	11	.85	T	.85	.283	Rain record at lake, 0.
9:30 a. m. Aug. 31....	4	71.5	69.0	67.2	138	22	.95	.13	1.08	.270	Rain record at lake, .08 inches.
10:30 a. m. Sept. 6....	6	71.0	70.8	67.0	99*	12*	1.10	0	1.10	.183	Rain record at lake, 0.
9:30 a. m. Sept. 11....	5	65.0	66.0	....	129*	16*	1.70	.01	1.71	.342	
4:30 p. m. Sept. 22....	11	71.0	72.4	60.0	115*	19*	....	.74	....	....	Rain gage full of water.
9:45 a. m. Oct. 1....	9	63.6	63.9	62.0	97	12*	4.85	T	5.59	.280	
10:00 a. m. Oct. 19....	18	49.0	47.5	45.8	131*	28*	2.50	.49	2.99	.166	
1:35 p. m. Oct. 27....	8	46.7	46.5	....	182*	27*	.20	.26	.46	.058	
9:30 a. m. Nov. 2....	5	47.0	45.0	43.2	193	19*	1.30	0	1.30	.260	
9:45 a. m. Nov. 11....	....	....	....	....	....	....	....	....	....	....	Hole shot into pontoon.

* Electrical register out of order for portion of period.

TABLE IX.—EVAPORATION OBSERVATIONS, LOOMIS LAKE.—1897.

Date.	No. of Days Interval.	Temperature of Water. Degrees, Fahrenheit.			Wind—Miles.		Fall of Water Surface since Previous Obs.	Rainfall at College since Previous Obs.	Total Loss since Previous Obs.	Average Loss per Day.	Remarks.
		In Tank.	At Surface of Lake.	At Bottom of Lake.	Av. Movement per 24 hrs.	Maximum hourly Velocity.					
11:00 a. m. May 12	..	61.0	61.0	58.2	....	....	....	....	....	....	Put tank in lake.
9:45 a. m. May 19	7	67.8	65.0	62.8	146	22*	1.65	.04	1.69	.241	
2:25 p. m. May 22	3	67.5	69.0	66.0	141*	22*	-.60	1.50	.90	.300	
3:00 p. m. May 25	3	68.8	68.7	68.0	159*	19*	.80	.04	.84	.280	
2:30 p. m. May 28	3	57.2	57.0	62.5	148*	18*	.50	.21	.71	.237	
2:30 p. m. June 1	4	....	....	....	132*	17*	.60	.35	.95	.238	
2:15 p. m. June 4	3	63.3	63.2	63.0	138	14	.20	.63	.83	.277	
3:30 p. m. June 8	4	69.8	69.0	63.7	121	11	.30	.39	.69	.172	
9:50 a. m. June 11	3	63.0	63.0	62.2	172	29	2.30	.10	(2.40)	(.800)	
4:00 p. m. June 15	4	71.0	71.0	65.5	119*	11*	1.10	0	1.10	.275	
2:45 p. m. June 18	3	67.3	67.0	66.2	238*	27*	2.20	0	(2.20)	(.733)	
3:00 p. m. June 22	4	76.5	75.0	69.0	114	20	1.10	.11	1.21	.302	
9:05 a. m. June 25	3	67.3	67.5	68.6	150	11	.60	.28	.88	.393	
4:10 p. m. June 29	4	75.0	75.5	71.5	138	14	1.40	T	1.40	.367	
12:00 m. July 2	3	72.0	71.5	71.0	133	19	.70	.05	.75	.250	
3:25 p. m. July 6	4	....	....	....	192	25	....	0	....	...	
11:00 a. m. July 9	3	....	....	....	167*	19*	....	1.18	....	....	
10:00 a. m. July 14	5	....	72.0	71.0	116*	12*	....	.32	....	....	
8:45 a. m. July 16	2	72.5	71.3	69.0	126	12	.90	0	.90	.450	
3:20 p. m. July 16	½	75.5	74.5	69.3	165	10	.20	0	.20	.400	
9:00 a. m. July 20	3½	66.8	65.2	66.0	142*	16*	.30	.89	1.19	.297	Rain record at lake, .69 inches.
8:45 a. m. July 23	3	69.5	69.0	67.0	123*	7*	.70	0	.70	.233	
8:50 a. m. July 27	4	69.5	69.3	69.1	133	18	1.40	.21	1.61	.402	Rain record at lake, .15 inches.
8:40 a. m. July 30	3	70.5	70.2	70.3	122	22	1.80	0	1.80	600	
9:10 a. m. Aug. 3	4	71.5	71.0	69.8	143	24	1.20	.06	1.26	.315	Rain record at lake, .08 inches.
8:40 a. m. Aug. 6	3	72.3	71.2	69.8	97	9*	.10	.37	.47	.157	Rain record at lake, .22 inches.
9:00 a. m. Aug. 10	4	72.5	71.7	70.1	108	11*	.50	.53	1.03	.258	Rain record at lake, .49 inches.
12:45 p. m. Aug. 13	3	73.3	73.6	72.8	108	14	1.00	.03	1.03	.343	Rain record at lake, .02 inches.
9:15 a. m. Aug. 17	4	71.8	70.7	70.3	119	13	1.15	T	1.15	.288	Rain record at lake, T.
8:45 a. m. Aug. 20	3	70.0	68.8	67.2	117	11	.60	.67	1.27	.423	Rain record at lake, .22 inches.
8:40 a. m. Aug. 24	4	69.3	69.2	68.2	119	11	1.20	0	1.20	.300	Rain record at lake, 0
8:45 a. m. Aug. 27	3	68.0	68.1	67.9	131	11	.90	T	.90	.300	Rain record at lake, .04 inches.
8:45 a. m. Aug. 31	4	68.8	68.2	67.2	138	22	1.00	.13	1.13	.282	Rain record at lake, .09 inches.
5:30 p. m. Sept. 22	22	68.0	68.2	68.9	120	19*	....	.73	....	....	Rain gage, considerable water in.
6:00 p. m. Sept. 26	4	66.4	66.2	62.7	110*	9*	-.75	0	-.75	-.187	Rain record at lake, .01 inches.
8:50 a. m. Oct. 1	5	63.5	64.0	63.2	101*	12*	2.20	T	2.20	.440	Rain record at lake, T.
9:10 a. m. Oct. 19	18	47.0	47.3	46.8	136*	28*	2.80	.49	3.29	.183	Rain record at lake, .46 inches.
1:55 p. m. Oct. 27	8	46.5	45.5	....	181*	27*	-.20	.26	.06	.008	Rain record at lake, .32 inches.
1:30 p. m. Nov. 2	6	50.0	45.5	45.5	161	19*	1.70	0	1.70	.283	
4:00 p. m. Nov. 11	9	42.5	42.5	41.6	244	75	....	.04	....	....	Storm drove ashore and upset; put out again.
3:35 p. m. Nov. 18	7	42.0	41.0	40.0	130	19	.05	.34	.39	.056	

* Electrical recorder out of order for portion of period.

TABLE X.—EVAPORATION OBSERVATIONS, CLAYMORE LAKE.—1897.

Date.	No. of Days Interval.	Temperature of Water. Degrees, Fahrenheit. In Tank.	At Surface of Lake.	At Bottom of Lake.	Wind—Miles. Av. Movement per 24 hrs.	Maximum hourly Velocity.	Fall of Water Surface since Previous Obs.	Rainfall at College since Previous Obs.	Total Loss since Previous Obs.	Average Loss per Day.	Remarks.
12 : 00 m. May 1.....	.	59.2	59.2	....	....	....	....	....	....	....	Tank put in lake.
9 : 55 a. m. May 4.....	3	63.0	58.0	....	206	26	.63	0	.63	.210	
1 : 10 p. m. May 11.....	7	62.0	60.4	58.2	181	30*	1.52	.10	1.62	.231	
1 : 25 p. m. May 18.....	7	67.5	65.5	63.3	150	20*	-.10	.04	(-.06)	-.009	
3 : 45 p. m. May 22.....	4	71.4	71.2	69.8	131*	22*	-1.30	1.50	.20	.050	Waves on lake. Shower before measuring.
10 : 00 a. m. Aug. 21....	..	68.2	68.2	....	....	....	....	0	....	....	
12 : 30 p. m. Aug. 24....	3	74.8	70.3	69.3	123	11	1.15	0	1.15	.383	Rain record at lake, .14 inches.
10 : 20 a. m. Aug. 27....	3	72.0	69.0	67.6	131	11	.60	T.	.60	.200	Rain record at lake, .01 inches.
1 : 00 p. m. Aug. 31....	4	74.0	70.0	68.8	137	22	1.00	.13	1.13	.282	Rain record at lake, .16 inches.
11 : 30 a. m. Sept. 6....	6	73.0	70.0	67.3	121*	12*	1.00	0	1.00	.167	
5 : 45 p. m. Sept. 11....	5	71.0	71.0	67.0	129*	16*	1.25	.01	1.26	.252	Rain record at lake, .04 inches.
2 : 40 p. m. Sept. 21....	10	65.0	67.0	62.0	119*	19*	-1.05	.74	(-.31)	....	Rain gage filled by water from lake
10 : 40 a. m. Oct. 1.....	10	64.2	64.6	61.9	105	8*	.90	T.	.90	.090	Rain record at lake, .06 inches.
1 : 20 p. m. Oct. 19.....	18	54.0	51.0	50.8	143*	28*	.03	.48	.52	.029	Rain gage full of water.
1 : 00 p. m. Oct. 27.....	8	45.0	45.0	....	182*	27*	-1.10	.26	(-.84)	....	Rain gage full of water.
12 : 15 p. m. Nov. 2.....	5	54.0	47.0	45.2	190	19*	....	0	.70	.140	
2 : 30 p. m. Nov 11.....	..	....	....	....	....	....	....	....	....	....	Tank damaged and brought in.

* Days when electrical register was out of order. Some estimates included.

§ 27. A tank similar to those used as a basis of measurement in the lakes already mentioned, was placed in Warren's lake, four miles southeast of the College, floated by pontoons and observed weekly during 1889 and 1890. The lake was a resort for fishing, and the tank was often interfered with, so that the observations were abandoned after the two years experience.

TABLE XI.

1889.	No. Days.	Temperature. Degrees, Fahrenheit.	Loss—Inches.	Rain at College—Inches.	Total Loss—Evaporation—Inches.	Loss per Day—Inches.
June 25 to July 11	16	72—74	2.65	.40	3.05	.19
July 11 to July 19	8	74—74	1.31	.39	1.70	.21
July 19 to July 27	8	74—73	2.50	.50	2.50	.31
July 27 to August 1	5	74—72	1.56	0	1.56	.31
September 4 to September 9	5	66—68	1.34	0	1.34	.27
September 9 to September 20	11	68—62	2.39	.28	2.67	.24
September 20 to September 28	8	62—60	1.86	.10	1.96	.25
September 28 to October 4	26	60—59	1.28	0	1.28	.21
October 4 to October 17	13	59—54	1.46	.44	2.00	.15
October 17 to October 25	8	54—52	1.92	.02	1.94	.24

TABLE XII.

1890.	No. of Days.	Temperature. Degrees, Fahrenheit.	Loss—Inches.	Rain at College—Inches.	Total Loss—Evaporation—Inches.	Loss per Day—Inches.
April 30 to May 6	6	57	.86	.40	1.26	.21
May 25 to June 1	7	62—66	1.98	0	1.98	.28
June 14 to June 21	7	74	1.90	0	1.96	.28
June 28 to July 5	7	76—74	.83	.42	1.25	.18
July 5 to July 12	7	74—78	1.52	.05	1.57	.22
July 19 to July 26	7	76—79	1.82	.42	2.24	.32
July 26 to August 2	7	79—77	.05	.35	2.40	.34
August 2 to August 9	7	77—72	2.15	.06	2.21	.32
August 9 to August 23	14	72—74	1.13	3.08	4.20	.30
August 23 to September 1	10	74—70	1.40	T	1 40	.14
September 22 to September 26	4	63—62	1.96	0	1.96	.49
September 26 to October 3	7	62	1.73	T	1.73	.25

The observations were taken in the afternoon between 2 and 5 p. m., generally about 3 p. m., or near the highest temperature of the day.

A similar tank was placed in the Arthur ditch where it passes through the College grounds. Observations were taken daily. While not the same as reservoir conditions, it gives data for comparison:

June, 1889	2.89 inches	Record based on	16 days
July, 1889	4.13 "	" "	31 "
August, 1889	3.94 "	" "	21

§ 28. From the above data we obtain the basis for estimating the evaporation at the same rate for the calendar months :

TABLE XIII.

Lee Lake—1896.			Lee Lake—1897.		
Month.	Evaporation —Inches.	No. Days Record.	Month.	Evaporation —Inches.	No. Days Record.
....	....	..	May	4.31	24
June..........	6.36	15	June.....	9.55	21
July	9.11	32	July	8.53	21
August	7.25	31	August	8.61	32
September.....	5.20	32	September.....	8.40	31
October	4.17	28	October	4.60	32
Loomis Lake—1897.			**Claymore Lake—1897.**		
May	7.89	20	May	5.22	14
June.	7.91	26	June..........	....	..
July..........	11.87	20	July..........	....	..
August	9.02	32	August	8.93	10
September.....	....	..	September.....	4.81	21
October	4.89	32	October	1.62	23
Warren's Lake—1889.			**Warren's Lake—1890.**		
May	....	..	May...........	7.71	13
June..........	....	..	June	8.40	7
July	7.37	37	July	5.41	29
August	....	..	August	8.06	38
September.....	7.25	30	September.....	....	..
October	5.61	21	October	....	..

§ 29. It will be noticed that the evaporation from the tanks as given is much greater than the corresponding tank on the grounds of the Agricultural College. This difference is partially but not entirely due to temperature. The tanks in the lakes are more freely exposed to the wind than the standard tank, and this would therefore make a great difference. The tanks are more or less agitated by waves, and in consequence the water surface exposed to the air is larger than the cross section of the tank. A film of water is also left on the metal sides of the tank with every movement, and this is apt to be of higher temperature than the water in the lake or in the tank, and evaporates more rapidly. The influence has been noticed by Mr. Trimble, who made the observations in 1896 and some of those in 1897, and suggested as a cause of some of the excess of evaporation observed from the lakes. The effect may be considerable, but how much is uncertain. The wave action differs in the different lakes. In Lee lake the weeds extend so near the surface that there is little opportunity for wave formation. In the other two lakes the effect is greater. As the wave also increase the area of the surface of the lakes which is exposed to the air likewise, the result is possibly closer to the loss from a lake exposed to the wind than if the tank had been stationary.

§ 30. The effect of such increase of surface may be considerable. We have made no experiments to determine the possible effect. The only ones reported are some by Maurice Aymard, a French engineer stationed in Algeria, whose report on Irrigation in Spain as preliminary to the construction of a reservoir which has but recently been built, is classic in irrigation literature. The observations were carried on for less than four days in 1849. Tanks 20 inches (50cm) in diameter and 2 feet high were made. In one the water was still; in the other an iron disk nearly of the same diameter as the tank, with holes through it, was slowly raised and lowered in the tank. The water passing through the numerous small holes, kept the surface in agitation, something like the surface in small ditches with rapid fall. The loss under these conditions was more than a third more from agitated than from the quiet water, or a loss of 1.66 inches from the quiet water. and of 2.32 from the rough water.*

ESTIMATE OF EVAPORATION FROM RESERVOIR.

§ 31. From the preceding data we may estimate the amount of evaporation under reservoir conditions. Any such estimate is subject to the uncertainties already mentioned, and to the condition that the evaporation may vary much from year to year, and from one body of water to one immediately adjacent. Nevertheless we may make what may be considered a reasonable estimate from the observations.

	Evaporation.		Evaporation.
January	1.5 inches.	July	9.5 inches.
February	2.0 "	August	8.5 "
March	3.5 "	September	6.5 "
April	5.0 "	October	4.5 "
May	6.5 "	November	2.5 "
June	8.0 "	December	1.5 "
Total			59.5 inches.

§ 32. The following are other cases of evaporation which have been observed. On several lakes in California, observations were made in 1879 by J. D. Schuyler, now consulting engineer, of Los Angeles, Cal. They are reported in William Ham Hall's report as State Engineer of California in 1880, and in Physical Data and Statistics of California:

Reeder lake is a narrow lake with wooded shores, water 12 to 15 feet deep. Evaporation pans two by two feet square and one foot deep were used. They were protected from the wind but exposed to the sun. From June 25th to July 11th, a total of sixteen days, the loss was 1.21 inches, or an average of .24 inch per day. The temperature of the water from five observations taken late in the afternoon, varied from 82° to 92°, which would be higher than the average temperature.

In Panama Slough, California, July 9th to August 20th, 1879, a loss of 2.46 inches in a little over seventeen days, was noticed, or an average of .145 inch per day. The temperature of the water was from 64° to 72°.

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* Debauve, Manuel de l'Ingenieur, Des Eaux en Agriculture, p. 170. Parrochetti, Manuale pratico di Idrometria, pp. 256-8.

In Kern lake, Mr. Schuyler also made observations from Aug. 4th to Sept. 29th. In a tank near the shore, the daily evaporation was .30 of an inch. In a tank near the shore in a depth of 5 feet of water, the daily loss during the same time was .21 of an inch per day. The temperature of the water as given was the same in each case, and varied from 78° to 88°. About noon the air was considerably warmer. From Oct. 2nd to Dec. 20th, a period of seventy-nine days, evaporation amounted to 9.66 inches from Kern river, Cal. This was determined from weekly observations. The temperature of the water in the pan varied from 55° to 80°. The average daily loss was .12.

At Sweetwater reservoir, near San Diego, California, an evaporation tank was put in place by J. D. Schuyler and has since been continued by and under the direction of H. N. Savage, C. E. The reservoir was visited by the writer in 1891. At that time a circular tank, floated in the lake, was used. A Piche evaporometer was used for comparison. When the pan gave out in 1892, it was not renewed, and the records were made from the Piche instrument until 1897, when Mr. Savage had the pan replaced. As the records with the Piche evaporometer do not show the evaporation from free water surface, they are not used in the table which follows, and only those depending on the records from the tank are given. Mr. Savage has furnished the record up to date.

TABLE XIV.—EVAPORATION FROM SWEETWATER RESERVOIR.

Near San Diego, California. Latitude, 32° 40'; longitude, 117°; elevation, 220 feet.

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
1889........	1.99	3.34	3.38	4.96	5.82	6.81	8.22	7.26	7.81	4.52	3.96	.95	59.02
1890........	1.59	2.21	3.28	4.14	6.14	7.30	7.38	9.02	6.48	4.92	5.54	1.84	59.84
1891........	3.61	1.35	3.08	3.71	5.60	6.03	6.50	8.89	6.15	6.31	4.10	2.75	58.08
1892........	2.54	1.39	3.08	5.82	4.67	6.48	8.81	6.54	6.27	6.56	4.77	2.61	59.54
1897........	2 12	1.64	2.91	5.99	5.69	7.90	6.25	6.61	5.53	6.27	4.24	3.75	58.90
Mean......	2.37	1.99	3.15	4.92	5 58	6.90	7.43	7.66	6.45	5.72	4.52	2.38	59.07

The water temperature ranged from an average of 80 to 82 degrees, in the warmest month, to 50 degrees, in the coolest.

§ 33. A valuable series of observations is being carried on by H. B. Hedges, C. E., of San Bernadino, Cal., at the Arrowhead reservoir in Little Bear valley. This is at an elevation of 5,160 feet above sea level, and near enough to San Diego to furnish some comparison between the evaporation at those two places and indicating the effect of elevation.

In this case the evaporation was measured in a three-foot pan floated in a concrete basin separate from the reservoir. Measurements are made twice daily at 6 a. m. and 6 p. m. in summer. It will be noticed that the evaporation is much less than at San Diego.

TABLE XV.—EVAPORATION FROM THE ARROWHEAD RESERVOIR.

Little Bear Valley, California. Latitude, 34° 16'; longitude, 117° 11'; elevation, 5,160 feet. By H. B. Hedges, C. E.

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
1895........	....	....	1.12	1.84	5.30	6.60	6.30	6.20	5.05	2.80	1.20	.34	......
1896........	.09	.81	.94	3.39	2.86	6.50	5.04	5.50	4.01	4.05	1.28	1.23	35.70
1897........	.57	.24	....	3.01	4.75	6.17	7.62	5.17	5.00	4.01	1.24	1.21	......
Average...	.33	.53	1.03	4.12	4.30	6.42	6.32	5.62	4.69	3.62	1.24	.93	39.15

§ 34. The following are records of the average evaporation from floating tanks made at Rochester, New York, and at Boston Mass. The former were made under the direction of Emil Kuichling, chief engineer of the water works, and were made in small indurated fiber tubs, about 10 inches in diameter and six inches deep. At Boston the observations were made under the direction of Desmond Fitz-Gerald on the Chestnut Hill reservoir. Those at Rochester are dependent on records from one to five years of the different months, at Boston upon a much longer period. Those at Boston are not the actual means of observation, but the smoothed values determined by the application of Bessell's formula to reduce periodic series:

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
Rochester.	.45	.45	.91	2.67	4.05	4.93	5.65	5.28	4.07	3.13	1.50	1.22	34.31
Boston.....	1.12	1.20	1.81	3.01	4.48	5.55	5.98	5.50	4.20	3.14	2.22	1.50	39.71

THE EFFECT OF ELEVATION ON LOSSES.

§ 35. Are the losses more or less at high elevations? Is it more economical to store water at low or high elevations?

For increase of elevation the evaporation, if the wind conditions are the same, is greatly diminished. Practically the opportunities for storage are confined to basins not over 10,000 feet in elevation, and the question of the evaporation is of most importance for elevations below that height. Observational data are almost entirely lacking. Such observations as have been made are not under the same methods and not strictly comparable.

As far back as 1890, I made attempts to obtain such data and furnished evaporation tanks to several places, distributing some tanks coming from the U. S. Irrigation Survey of 1889–90 and also some new tanks. The highest point was at the U. S. Fish Hatchery near Leadville, at an elevation of nearly 10,000 feet. Few results were obtained except from the sub-stations connected with the College in the San Luis valley and on the Divide, at elevations of 7,600 and 7,200 feet respectively. The other observers were voluntary, and as there were no funds to replace the broken instruments or repair the damaged tanks, the observations were abandoned. In the absence of observations, we may consider the probable effects.

§ 36. We may dismiss the losses from seepage from consideration. They depend upon the character of the site and nothing in the mere elevation would increase or diminish the seepage, unless the lower temperature of the soil should lessen the rapidity of seepage, and this, as shown in Bulletin 33, may be considerable. In general the rock strata are nearer the surface in the mountains and more attention may well be given to the geological characteristics of the site.

§ 37. But elevation has an influence on evaporation, and as evaporation is shown to be of more importance in the cases examined, the effect of elevation on losses will be principally due to its effect on evaporation.

§ 38. The factors controlling evaporation, are:

First—The temperature of the surface of the water, which indicates the limit of the amount of vapor which the air in contact with the water will absorb.

Second—The amount of moisture present in the air. The difference between the moisture corresponding to the temperature of the water surface, and the moisture actually present, is a measure of the additional amount of vapor which the air will take up.

Third—The wind movement.

§ 39. The temperature of the air is decidedly lower at high elevations, though on individual days inversions may occur, and the air be warmer at the high elevations. This is often shown in comparing the observations taken at the College, with those taken by Mr. C. E. Lamb at the foot of Long's peak. This inversion occurs principally in the winter months, between November and April, and has less effect on evaporation than if occurring in the summer.

Taking the records from several places, we find the average temperatures as follows, where the lower temperature with increased altitude is to be noted:

	Latitude.	*Elevation.*	*Av. Temp.*
Agricultural College, Ft. Collins	40° 34′	5,000 ft.	47°.7
Denver	39° 45′	5,300 ft.	49°.5
Colorado Springs	38° 50′	6,100 ft.	47°.2
Lamb's, near Long's Peak	40° 20′	9,100 ft.	37°.0
Pike's Peak	38° 50′	14,147 ft.	19°.4

The difference of 8,000 feet in elevation between Colorado Springs and Pike's peak, causes a difference of 28° in mean annual temperature, equivalent to a difference of 1° for 300 feet rise.

§ 40. The temperature of bodies of water freely exposed to the air will not differ much from that of the air in contact with them. The temperature of the water surface averages higher than the whole body of water, because as the water warms, the heated layers remain on top for temperatures above 39°, while in cooling the water sinks as it cools and the whole mass cools together. Below 39° the colder water remains on the surface. In heating, therefore, above 39° the whole mass is heated, and the increase in temperature is slow, while in cooling the surface cools without the mass of water cooling materially. Hence for temperatures above 39° the surface averages of higher temperature than the body of water, and for temperatures between 32° and 39° it averages lower. In the one case it tends to make the surface warmer than the air, in the other cooler.

In our evaporation tank it is noticeable that the temperature of the surface shows an excess of from 6° to 7° above the air temperatures.

At higher elevations similar differences prevail, and in all probability the differences are nearly the same, though exact observation is lacking. But as the prevailing temperatures are lower, the water temperature is less than the critical temperature of 39° for a greater part of the year than at lower elevations. It seems probable, therefore, that the excess of the water temperature above the air temperature is less than at the lower elevations.

§ 41. But even if more, the evaporation, so far as this factor is concerned, may be less, for as the evaporation seems to vary directly with the difference of vapor pressure corresponding to the temperatures of the water surface and of the air, and as the vapor pressures decrease much faster than the temperatures, the same difference in degrees means a greater difference in vapor pressure, or a greater capacity for moisture at a high temperature than at a low. Thus the table shows the pressure of the water vapor corresponding to the ordinary air temperatures.

Temperature.	*Corresponding Vapor Pressure.*
100 degrees	1.91 inches.
90 "	1.40 "
80 "	1.02 "
70 "	.73 "
60 "	.52 "
50 "	.36 "
40 "	.25 "
30 "	.17 "
20 "	.11 "

From this table a difference of 10° would correspond to a difference of vapor pressure or capacity for moisture:

For 10 Degrees Difference.	*Difference of Vapor Pressure.*
Between 80 and 70 degrees	.29 inches.
" 70 and 60 "	.22 "
" 60 and 50 "	.16 "
" 50 and 40 "	.11 "
" 40 and 30 "	.08 "

Since the evaporation varies directly as this difference of vapor pressure, or, so far as this factor is involved, when the temperature of the water surface is 80°, the evaporation would be $3\frac{1}{2}$ times as fast as when the temperature is 40°, the excess above dew point being 10° in each case.

But at the low temperatures corresponding to high elevations, the dew points are nearer the air temperatures than at higher temperatures. In addition, there is reason to believe that the water temperature is not so much above the air temperatures as at higher temperatures. It is evident that the effect of these conditions is to make the difference of vapor pressures corresponding to the temperature of the water surface, and of the dew point to be less at high elevations than at low, and by so much to reduce the evaporation.

§ 42. On the other hand, the lessened air pressure at the higher elevations is favorable to increased evaporation, the increase in evaporation being proportional to the decreased pressure, and the influence of elevation being to increase the evaporation by the per cent given in the third column. This increase is due to the decreased barometric pressure alone.

Elevations.	*Pressures.*	*Increase in Evaporation Over Evap. at 5,000 Feet.*
5,000 feet	25 inches	00 per cent.
6,000 "	24 "	$3\frac{1}{2}$ "
7,000 "	23.2 "	7 "
8,000 "	22.3 "	11 "
9,000 "	21.4 "	14 "
10,000 "	20.6 "	18 "
11,000 "	19.9 "	20 "
12,000 "	19.1 "	24 "
13,000 "	18.4 "	26 "
14,000 "	17.7 "	29 "

§ 43. Confining these effects to elevations less than 10,000 feet, which is practically the limit of available storage sites, we find that the condition of air and water temperatures materially reduce the evaporation, the decreased barometric pressure increases, and the wind, if greater, would tend to increase it. The effect of lower temperatures is greater than the increasing effect of the barometric pressure and probably greater than the effect of the wind, except in exposed places. And when we take into account the fact that the water is frozen for a much longer period of the year, it is safe to conclude that the evaporation for the year is much less than at lower elevations.

§ 44. The amount of decrease cannot be stated with certainty. An increase in wind increases the evaporation, each mile of wind during the twenty-four hours, increasing the evaporation for that day by from 1 to 2 per cent.; 2 per cent. deduced from Fitz-Gerald's formula from Boston observations,† and nearly 2 per cent. for wind of 5 miles per hour, decreasing to 1 per cent. for each mile at 25 miles per hour, as deduced from Professor Russel's observations; ‡ 2 per cent. from Colorado observations of 1889, by L. G. Carpenter.*

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§45. SUMMARY AND CONCLUSIONS.

1. The losses from reservoirs are from seepage and evaporation.
2. The seepage losses are dependent on the condition of the reservoir site, therefore different for different sites.
3. The seepage losses were determined on a series of reservoirs near Fort Collins, in the winter of 1895–6 and 1896–7.
4. The seepage losses may be great. In the lakes under measurement, the losses in some cases were less than from evaporation alone.
5. In some cases, lakes may gain from seepage from irrigated lands, and the gain may be more than the combined loss from seepage and evaporation.
6. In the cases where loss from seepage occurred, the loss was at the rate of about 2 feet in depth over the area of the lake, per year.
7. This amount does not necessarily apply to other sites, and other observations are needed before general statements respecting loss from this source can be made.
8. The seepage decreases after the lake is first filled, from the effect of silting, and from having filled the porous ground underneath and connected with the site.
9. Even in sand, there is a limit to the amount of seepage, and the time during which the loss is large.
10. After sand beds connected with the reservoir are saturated, the losses from seepage will decrease.

10 *a*. The loss increases with the depth, probably nearly as the square.

11. The losses may be lessened, though not entirely prevented, by silting.
12. The silting process is more efficient with small reservoirs, because of the better distribution of the silt.
13. If the loss from seepage is not more than 2 feet per annum, the sites may be considered as practically water tight. In the case of canals, the losses often average more than that in twenty-four hours.

EVAPORATION.

14. The losses from evaporation, in the cases examined, are greater than those from seepage.
15. The evaporation is not necessarily the same from adjacent bodies of water.

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† Trans. Am. Soc. C. E., 1883. ‡ U. S. Weather Bureau. * Report Exp. Sta., 1889.

16. The amount of evaporation increases with the temperature of the water, with the wind, and diminishes with increased moisture in the air.

17. From the standard evaporation tank at the Experiment Station, the average evaporation for 11 years, has been 41 inches.

18. Evaporation proceeds when the water is frozen, but at a diminished rate, averaging about 1 to 1½ inches per month.

19. The evaporation at night is the same as during the day, the difference being less with the increase of the size of the bodies of water.

20. The loss by evaporation from several lakes exceeded that from the standard tank.

21. The loss from the lakes was about 60 inches per year.

22. The increase is due to higher temperature ot the water, and to freer exposure to the wind.

23. In some of the summer months, the lakes lost twice as much as the standard tank.

24. The lower temperature of water at high elevations, and the lower dew points, tend to decrease the evaporation.

25. The diminished barometric pressure tends to increase the evaporation, amounting to 14 per cent at 8,000 feet, and to 18 per cent at 10,000 feet, over the evaporation at 5,000 feet.

26. Every mile of wind movement in 24 hours increases the evaporation by from 1 to 2 per cent over the evaporation if calm.

27. The winter period is longer at the high elevations.

28. For the whole year, the evaporation in all probability is considerably less at the high elevations than at the low ones.

29. Evaporation is lessened by any influence which diminishes the wind or decreases the temperature of the water.

30. Protection of lakes by wind breaks is in many cases practicable, and in small lakes sometimes desirable. In the large lakes the benefit is by reducing the wind velocity; in small lakes both from effect on wind and by lessening action of sun.

31. The deeper the lake the cooler the water as a whole, the cooler the surface, consequently the less evaporation.

32. Assuming a loss of 5 feet in depth per annum, an area of 100 acres would require ¾ cubic feet per second for the whole year to make good the losses from evaporation; one of 500 acres would require 3½ cubic feet per second, considerably more than would be used to irrigate an equal area.

33. The net loss to the reservoir would be the sum of the above losses from seepage and from evaporation, diminished by the rainfall, a combined loss which may be considered as a depth of 6 feet in one year.

34. As irrigation reservoirs are usually full for a few months only, the loss is much less than this for the high water area.