DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 7

SEEPAGE WATER OF NORTHERN UTAH.—FORTIER

WASHINGTON
GOVERNMENT PRINTING OFFICE
1897

IRRIGATION REPORTS.

The following list contains the titles and brief descriptions of the principal reports relating to water supply and irrigation prepared by the United States Geological Survey since 1890:

1890.

First Annual Report of the United States Irrigation Survey, 1890, octavo, 123 pp.

Printed as Part II, Irrigation, of the Tenth Annual Report of the United States Geological Survey, 1888-89. Contains a statement of the origin of the Irrigation Survey, a preliminary report on the organization and prosecution of the survey of the arid lands for purposes of irrigation, and report of work done during 1890.

1891.

Second Annual Report of the United States Irrigation Survey, 1891, octavo, 395 pp.

Published as Part II, Irrigation, of the Eleventh Annual Report of the United States Geological Survey, 1889-90. Contains a description of the hydrography of the arid region and of the engineering operations carried on by the Irrigation Survey during 1890; also the statement of the Director of the Survey to the House Committee on Irrigation, and other papers, including a bibliography of irrigation literature. Illustrated by 29 plates and 4 figures.

Third Annual Report of the United States Irrigation Survey, 1891, octavo, 576 pp.

Printed as Part II of the Twelfth Annual Report of the United States Geological Survey, 1890-91. Contains a report upon the location and survey of reservoir sites during the fiscal year ending June 30, 1891, by A. H. Thompson; "Hydrography of the arid regions," by F. H. Newell; "Irrigation in India," by Herbert M. Wilson. Illustrated by 93 plates and 190 figures.

Bulletins of the Eleventh Census of the United States upon irrigation, prepared by F. H. Newell, quarto.

No. 35, Irrigation in Arizona; No. 60, Irrigation in New Mexico; No. 85, Irrigation in Utah; No. 107, Irrigation in Wyoming; No. 153, Irrigation in Montana; No. 157, Irrigation in Idaho; No. 163, Irrigation in Nevada; No. 178, Irrigation in Oregon; No. 193, Artesian wells for irrigation; No. 198, Irrigation in Washington.

1892.

Irrigation of western United States, by F. H. Newell; extra census bulletin No. 23, September 9, 1892, quarto, 22 pp.

Contains tabulations showing the total number, average size, etc., of irrigated holdings, the total area and average size of irrigated farms in the subhumid regions, the percentage of number of farms irrigated, character of crops, value of irrigated lands, the average cost of irrigation, the investment and profits, together with a résumé of the water supply and a description of irrigation by artesian wells. Illustrated by colored maps showing the location and relative extent of the irrigated areas.

1893.

Thirteenth Annual Report of the United States Geological Survey, 1891-92, Part III, Irrigation, 1893, octavo, 486 pp.

Consists of three papers: "Water supply for irrigation," by F. H. Newell; "American engineering and engineering results of the Irrigation Survey," by Herbert M. Wilson; "Construction of topographic maps and selection and survey of reservoir sites," by A. H. Thompson. Illustrated by 77 plates and 119 figures.

A geological reconnoissance in central Washington, by Israel Cook Russell, 1893, octavo, 108 pp., 15 plates. Bulletin No. 108 of the United States Geological Survey; price, 15 cents.

Contains a description of the examination of the geologic structure in and adjacent to the drainage basin of Yakima River and the great plains of the Columbia to the east of this area, with special reference to the occurrence of artesian waters.

1894.

Report on agriculture by irrigation in the western part of the United States at the Eleventh Census, 1890, by F. H. Newell, 1894, quarto, 283 pp.

Consists of a general description of the condition of irrigation in the United States, the area irrigated, cost of works, their value and profits; also describes the water supply, the value of water, of artesian wells, reservoirs, and other details; then takes up each State and Territory in order, giving a general description of the condition of agriculture by irrigation, and discusses the physical condition and local peculiarities in each county.

Fourteenth Annual Report of the United States Geological Survey, 1892-93, in two parts, Part II, Accompanying papers, 1894, octavo, 597 pp.

Contains papers on "Potable waters of the eastern United States," by W J McGee; "Natural mineral waters of the United States," by A. C. Peale; "Results of stream measurements," by F. H. Newell. Illustrated by maps and diagrams.

(Continued on third page of cover.)

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UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

SEEPAGE WATER OF NORTHERN UTAH

BY

SAMUEL FORTIER

WASHINGTON

GOVERNMENT PRINTING OFFICE

1897

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DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, April 13, 1897.

SIR: I have the honor to transmit herewith a paper entitled Seepage Waters of Northern Utah, by Samuel Fortier, professor of irrigation engineering at the Agricultural College at Logan, Utah. The facts herein presented are based upon field work carried on mainly during the summer of 1896, and have special value in illustrating conditions which prevail to a greater or less degree throughout all irrigated lands, especially within inclosed valleys or on long, narrow drainage systems.

One of the matters which most complicate and embarrass the adjudication of water rights and the strict enforcement of priorities of appropriation arises from the fact that a considerable volume of water available for irrigation during the critical season of the year, when the crops are maturing, comes from the seepage from lands higher upstream to which water has been applied earlier in the year. In some cases these lands have been irrigated in defiance of a strict construction of the law regarding the priority of right to use water, but it has been claimed that such use, instead of being a detriment to the lands below, has been a benefit, and, in fact, that there has been more water available in consequence of this use than could otherwise be had. The determination of these matters requires careful measurement and study in each case, but the work of Professor Fortier serves to indicate what may be expected under similar conditions and illustrates methods applicable to this examination.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

SEEPAGE WATER OF NORTHERN UTAH.

By Samuel Fortier.

LOCATION AND PURPOSE OF THE INVESTIGATION.

The term "seepage water" is used by the irrigators of the West to designate the water which reaches the lowest grounds or the stream channels, swelling the latter by imperceptible degrees and keeping up the flow long after the rains have ceased and the snow has melted. The word "seepage" is applied particularly to the water which begins to appear in spots below irrigation canals and cultivated fields, usually some months or even years after irrigation has been introduced, and which tends to convert the lowlands into marshes and gives rise to springs, which in turn may be employed in watering other fields.

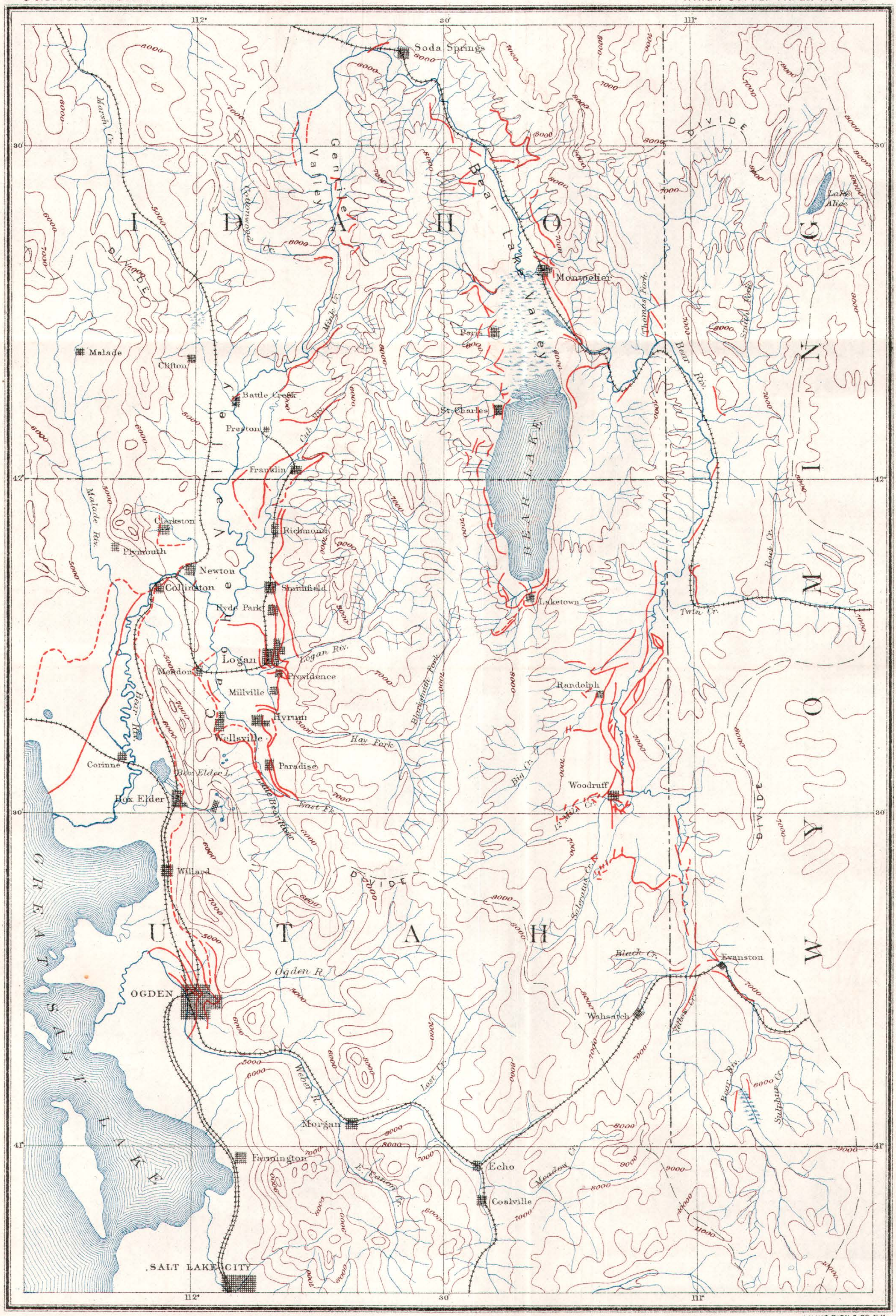
The importance of a thorough knowledge of the behavior of seepage water is obvious when consideration is given to the close relationship which exists between the available water supply and the material prosperity of the arid region where irrigation is practiced. This is particularly true of Utah, where every readily available source of supply has long since been utilized and where the rapidly increasing agricultural population necessitates the complete utilization of all fresh waters.

The measurements and investigations of seepage water described in this paper have been confined mainly to Cache Valley, being included within three counties in northern Utah, Weber, Boxelder, and Cache, and one county, Oneida, in Idaho. The conditions may be taken as fairly typical of those in the entire State, and to a less extent of those of adjacent States. A full knowledge of the seepage water will be of inestimable value in the development of Cache Valley, owing to the conditions now existing. The towns and farming communities were settled for the most part from 30 to 40 years ago. The tributaries of Bear River have supplied all irrigating waters, and many of the ditches and canals have water rights extending over a period of 30 years. These early ditches were the first built to divert water from Bear River and its tributaries, and according to the law of prior appropriation which prevails in Utah, Wyoming, and Idaho, the three States through which Bear River flows, the early canals of Cache Valley have water rights prior to all others. Boxelder County has at least a quarter of a million acres of fertile irrigable land, and with the exception of Boxelder Creek, Willard Creek, and other small streams whose aggregate summer flow does not exceed 40 second-feet, it is entirely dependent upon Bear River for the water necessary to irrigate its extensive area.

The time is not far distant when conflicts over water rights must arise between the irrigators of these counties, and it is therefore highly important to collect and record now all the physical data possible pertaining to the capacities of the irrigating ditches, the areas watered by each, and the general behavior of all sources of supply. To put off the collection of such facts until litigation has begun, and to attempt to render court decisions upon the conflicting testimony of interested witnesses only, is full of danger. Moreover, a study of the hydrography of Bear River and its tributaries is complicated, owing to the fact that three States obtain water from this one source. During the next drought many of the irrigators of northern Utah are liable to suffer serious loss from a scarcity of water in Bear River, caused by its diversion through canals in Wyoming and Idaho. If the law of prior appropriation is to be accepted for interstate priorities, it is of the utmost importance that all existing water rights be clearly defined.

There is still another important question which such work may aid in solving. It may be stated thus: How much of the water diverted and utilized in the upper valleys returns to the river channel in time to be diverted by lower irrigators? On account of variations in climate, soil, and topography, the results obtained in one section may be worthless when applied to others, and the only way to determine the behavior of irrigating waters is to make the necessary measurements in each valley. Until this work is at least partially accomplished there can be neither a just nor a permanent apportionment of appropriated waters.

The facts upon which this paper is based were obtained during investigations made in the summer of 1896. In this work the writer was ably assisted by Messrs. J. L. Rhead, Thomas H. Humphreys, and John S. Baker. The expenses were borne jointly by the Utah Agricultural Experiment Station, the Division of Hydrography of the United States Geological Survey, and the board of county commissioners of Cache County, Utah. Owing to the large cost of transportation, it was necessary to confine the greater part of the work to Cache County, Utah. In Cache Valley, which comprises the cultivated portions of this county and the southeastern part of Oneida County, Idaho, the field operations consisted in the measurement of every stream flowing into the valley at three different times during the season; also the determination of the capacity of every ditch and canal in the same valley at least three times, and accurate current-meter measurements and daily records of the outflow of the valley through "The Narrows" on Bear River. While this work was in progress an attempt was also



DRAINAGE BASIN OF THE BEAR RIVER

JULIUS BIEN & CO. N.Y.

made to locate the head gate and determine approximately the route of each ditch and canal. The results of such surveys are reproduced in the accompanying map (Pl. I). The progress of the field work throughout the season is fairly well shown by the number of streams and canals measured each month. From June 15 to 30, 1896, there were 58 measurements; in July, 131; in August, 112; in September, 106; and in October, 19; making a total of 426.

The chief object which the writer had in mind in making a partial hydrographic survey of Cache Valley was to determine, if possible, by daily and semiweekly gagings, the ratio existing between the inflow (diminished by the volumes used in irrigation) and the outflow. This ratio being known for a continuous period of three months, an opportunity is afforded to compare the loss of water due to evaporation with the gain due to seepage. Other objects held in view, of minor importance to the student of hydrography but possessing great value to the irrigator, were the average flow of the various ditches and canals, the amount of the surplus waters of the larger streams, and the duty of the irrigating waters.

There are several hundred natural and artificial water channels in Cache Valley if the main laterals are included. It is safe to assert that prior to June 15, 1896, less than six measurements had been made of these canals and streams. This record does not include the work done since 1889 by the United States Geological Survey, which perhaps comprises fifty stream measurements in Cache Valley alone. It was thought that if each canal and small stream were measured first in June, then during the latter part of July, and lastly about September 1, the results of the three measurements would represent, with some exceptions, the greatest, medium, and least flow during the season, and that the average of the three results might be taken as the average flow of such canal or creek.

ORIGIN OF SEEPAGE WATERS.

The water contained in the open spaces occurring in clay, sand, gravel, and other materials of which soils and subsoils are composed, is known by various names, such as soil moisture, ground water, ground storage, subsurface supply, and the like. When this ground water moves down an inclined stratum of porous materials, the term seepage water seems to be more appropriate than that of ground flow, which many writers have recently used. Seepage water conveys the idea of lateral motion, but when one uses the terms "soil moisture," "ground water," or "underground water," this conception is usually not implied.

The water content in dry soils may be so small as to admit of only a slight vertical movement due to the forces of capillarity and evaporation. On the other hand, portions of soils and subsoils may be completely saturated, but so located that the water confined therein is stagnant. In such cases there can be no lateral flow. Seepage waters as herein defined may be regarded as coming from three sources, which, however, are not always distinct: (1) from uncultivated hillsides and mountain slopes; (2) from irrigated land; (3) from the beds and side slopes of water channels.

It will be readily understood that a complete determination of the quantity of water which comes from that which is stored in the ground, on any particular drainage basin, involves more than a knowledge of the results of the stream measurements made in such basin. It is possible, for example, to ascertain with considerable accuracy the amount of surface water which flows into a valley, the volume used in irrigation, and the outflow, but without knowledge of the losses occasioned by evaporation, the problem of seepage waters is indeterminable. For the want of much necessary information in relation to the precipitation and evaporation of northern Utah, there is herewith introduced in outline some of the more recent observations made elsewhere in connection with the quantities of water evaporated from water surfaces and from ground surfaces or transpired from plant foliage.

In examining the water supply of any section, such as Cache Valley, it is desirable to begin with a study of the rainfall. If the complete history of each raindrop or snowflake were known from the time it falls to the ground until it again returns, in the form of vapor, to the atmosphere, water problems could be readily solved. The total volume of water which falls as rain or snow on any particular watershed may be subdivided into four parts, which vary widely in accordance with local conditions. Of these, one portion runs off the surface and fills the streams, especially during the spring months; a second sinks into the soils and subsoils, enters the fissures of rocks, is absorbed by porous strata, such as sandstones, and is the chief source from which wells and springs derive their supplies and streams their late summer and autumn discharges; a third part of the annual precipitation is evaporated from ground and water surfaces; and the fourth part develops plant growth. From the standpoint of the farmer, that portion utilized in developing plant growth is the most important. Cultivated plants are chiefly dependent on the water which sinks into the ground; hence the importance of the latter to the irrigator.

Relatively too much attention has been given to the surplus flow in springtime and too little to that derived from ground storage. A reference to Logan River may serve to illustrate the difference between that portion of the rainfall which rushes off the surface of drainage basins, either when snow melts in spring or when cloud-bursts occur in summer, and that which sinks into the porous covering of the mountain slopes to issue later as the flow from the ground storage, maintaining the streams during the late summer and autumn months. During June, July, and August of 1893, the rainfall as measured at the Experiment Station on the basin of Logan River was only one-fourth inch. The snow on the mountain ranges had all melted before the end of July, yet on the 3d of September there was a flow in Logan River of 250 second-feet. Where did this supply come from? The slight rainfall need not be taken into account, for it is safe to assume that an amount many times greater than the rainfall was evaporated. It could not have come from melted snow, because the snow had disappeared as vapor, had run off, or had sunk into the ground long before the expiration of the time named. The only available source was the flow from the ground storage; in other words, the seepage from the mountain slopes.

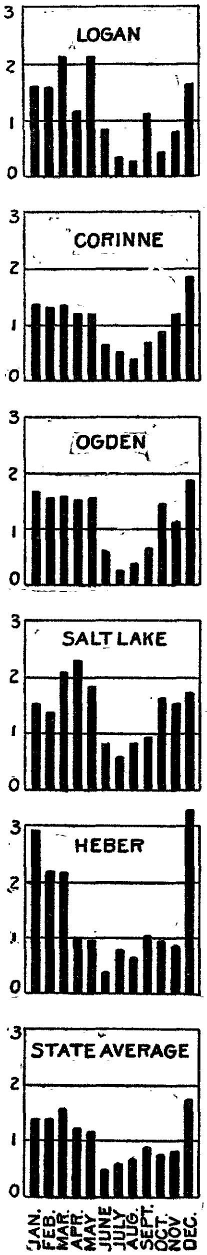


FIG. 1.—Diagram showing mean monthly rainfall in inches at stations in Utah.

PRECIPITATION.

The records from a number of important localities where the observations are most reliable have been tabulated by Mr. James Dryden, meteorologist of the Utah Experiment Station. These records extend over past periods varying from three to thirty-three years, and represent quite accurately the precipitation on the valleys and table lands.

The diagrams and tables herein given are compiled principally from information obtained from Mr. Dryden. Fig. 1 is a graphic representation of the precipitation for each month of the year at each of five northern stations. At Corinne, Boxelder County, the month of greatest rainfall for twenty-five years has been December,

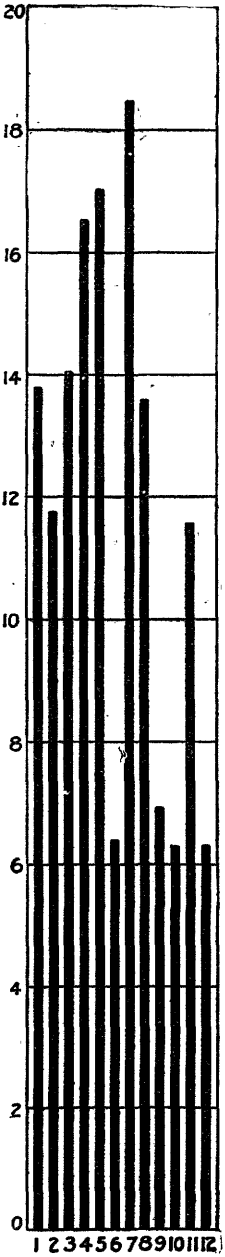


FIG. 2.—Diagram showing mean annual rainfall in inches at 12 stations in Utah.

averaging 1.8 inches. January, February, March, April, and May have remained nearly constant at about 1.25 inches each, while the dry months have been June, July, August, and September, which have not averaged one-half inch each. This distribution of the annual precipitation is typical of nearly every section of Utah. A glance at the diagrams of fig. 1 is sufficient to show that June, July, August, and September are the dry months, and as these constitute the greater part of the period between seed time and harvest, the rain evidently falls at the wrong time.

Salt Lake County, as represented by the rainfall of the city of Salt Lake, has averaged during the past thirty years 16.53 inches, but during the four summer months, beginning June 1, the total average rainfall has been less than 3 inches. From 1870 to 1895, Weber County, as represented by the station at Ogden, has had an average annual precipitation of 14.02 inches, but the four summer months have not averaged one-half inch. The diagram at the bottom of fig. 1 gives the mean monthly precipitation for the State as obtained by averaging the results of the more important stations scattered in various parts and located at different altitudes. This exhibits the deficient rainfall during June and the gradual increase through July, August, and September. Fig. 2 gives the average annual precipitation at twelve important stations, these being arranged in a general geographic order from north to south, the most northerly being Logan, in Cache County, and the most southerly St. George, in Washington County, in the southwestern corner of the State. The numbers at the bottom of the figure refer to the stations named in the table below.

The following table gives for the 12 selected stations the approximate elevation above sea level, the length of the record in years, and the mean annual rainfall during this time:

Mean annual rainfall at 12 stations in Utah.

No. in diagram.	Place.	County.	Above sea level.	Length of record in years.	Mean annual rainfall.
			Feet.		*Inches.*
1	Logan	Cache	4,500	5	13.81
2	Corinne	Boxelder	4,232	26	11.73
3	Ogden	Weber	4,340	26	14.02
4	Salt Lake	Salt Lake	4,354	33	16.53
5	Heber	Wasatch	5,500	3	16.97
6	Fort Duchesne	Uinta	4,941	8	6.35
7	Levan	Juab	5,100	7	18.45
8	Fillmore	Millard	5,100	8	13.60
9	Moab	Grand	3,900	7	6.95
10	Loa	Wayne	6,900	4	6.28
11	Parowan	Iron	5,970	5	12.55
12	St. George	Washington	2,880	15	6.31

Below is given the mean monthly rainfall for the same period:

Mean monthly precipitation at twelve stations in Utah.

Place.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Logan	1.55	1.52	2.05	1.12	2.06	.78	.27	.21	1.60	.36	.74	1.55
Corinne	1.27	1.26	1.29	1.12	1.12	.58	.44	.31	.63	.84	1.07	1.80
Ogden	1.65	1.51	1.57	1.47	1.49	.58	.25	.40	.68	1.42	1.12	1.88
Salt Lake City	1.46	1.31	2.01	2.24	1.76	.78	.55	.75	.91	1.60	1.48	1.68
Heber	2.89	2.16	2.15	1.01	.95	.35	.75	.61	1.08	.94	.80	3.28
Fort Duchesne	.38	.50	.71	.77	.79	.25	.48	.63	.60	.24	.23	.77
Levan	1.63	1.83	2.33	2.22	2.07	.69	.40	.77	1.39	1.04	.76	3.32
Fillmore	1.47	1.68	1.65	2.25	1.11	.53	.51	.83	.98	.45	.73	1.41
Moab	.68	.73	.86	.32	.33	.08	.64	.51	.72	.42	.59	1.07
Loa	.57	.74	.63	.15	.33	.08	.87	1.08	.49	.46	.43	.45
Parowan	1.27	1.56	2.03	1.35	.95	.17	1.09	1.06	1.04	.71	.57	1.00
St. George	1.01	.91	.60	.27	.33	.03	.33	.29	.41	.31	.44	1.38

More than the usual amount of rain fell in Cache Valley during 1896, as shown by the following table, which gives the precipitation for June, July, August, and September of that year, and also the averages of all past records for the same months:

Precipitation at Logan, Utah, for four months.

	1896.	Prior to 1896.
	Inches.	*Inches.*
June	0.46	0.78
July	1.40	0.27
August	1.49	0.21
September	0.91	1.60
Total	4.26	2.86

EVAPORATION.

Many tests have been made in different parts of the world to ascertain the amount of water evaporated from water surfaces. The utilization of this information is, however, limited chiefly to hydraulic engineers who wish to determine the losses from reservoir and lake surfaces. A knowledge of the actual volumes of water evaporated from such surfaces is of little direct value to Western irrigators, for the reasons that the operating forces are entirely beyond their control and the evaporated water is borne away by the prevailing winds. It might be some satisfaction to know that the evaporation from the surface of Great Salt Lake was only 60 inches yearly instead of 80 inches, as some would have us believe; but that knowledge alone might not enable us to reclaim an additional acre of land in Utah, although the difference of 20 inches yearly over the entire surface of the lake would comprise a volume of water sufficient to irrigate a million acres. There is good reason to believe that little of the moisture withdrawn from the Utah lakes returns in the form of rain or snow within the confines of the State. Tooele County borders on Great Salt Lake, but with a probable annual evaporation of 6 feet near its shore line, the parched soil receives yearly on an average only about 6 inches from rainfall.

Comparatively few measurements of evaporation have been made in Utah. The most important were those carried on at the reservoir in the rear of Fort Douglas, immediately east of the city of Salt Lake.

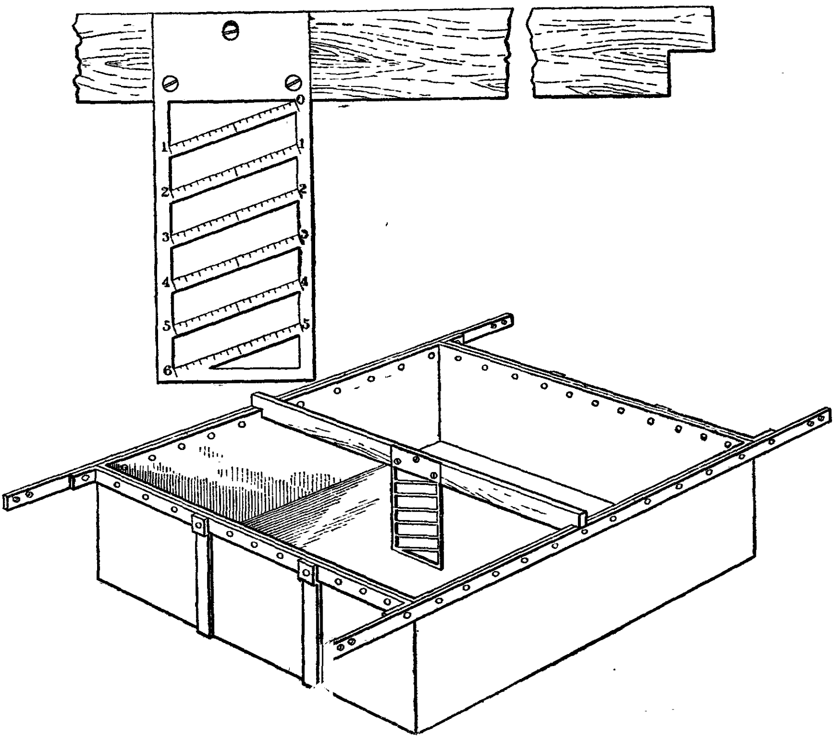


FIG. 3.—Evaporating pan and scale.

These observations are mentioned in the Eleventh Annual Report of the United States Geological Survey, Part II, on pages 30 to 34, and the results are given briefly in the Fourteenth Annual Report, page 154. Similar measurements were made for a few months at Provo and Nephi.

The apparatus used by the Geological Survey in making observations of evaporation consists of a galvanized-iron pan 3 feet square and 10 inches deep, immersed in water and kept from sinking by means of floats of wood or hollow metal. Into this pan water is poured until the surface is within from 1 to 2 inches of the top, the attempt being made to keep the pan as full as possible without spilling over the edge. The temperature of the water inside the pan has been found by experience to be practically uniform with that of the surrounding water in the ditch or pond in which the pan is placed, varying from it usually not more than 1 or 2 degrees. If the pan is kept full, so that the edge or rim does not offer an obstruction to the wind, the evaporation from the surface inside the pan should be approximately the same as that from the surface of the water outside.

The amount of water evaporated is determined by measuring the decrease in height of water, observations being usually taken once or sometimes twice a day. These are made by means of a brass scale hung in the middle of the pan and provided with diagonal bars upon which the reading is magnified about three times. By the use of this scale it is possible to read differences in vertical height of one one-hundredth of an inch. This method of observing the height of water is probably not so good as that by means of a hook gage, but is somewhat simpler and the apparatus is less expensive. An improvement[1] has been proposed, consisting of a rod fixed rigidly in the center of the pan and rising to within 1 or 2 inches of the top. Water is put into the pan until the point of this rod is about to be submerged, as shown by the meniscus. As the water evaporates more is added by means of a tin cup made of such capacity that one cupful is equivalent to a depth of one one-hundredth of an inch on the surface of the pan. The observer has only to record the number of times the cup is filled and emptied into the pan.

The following table gives the results of the measurements at Fort Douglas, the observations beginning on August 23, 1889, and ending in May, 1893. They were made by a soldier, Charles M. Lowry, detailed for the purpose. Owing to numerous disturbing influences, such as heavy wind splashing water into the pan or rainfall adding to the quantity, or, during winter, the freezing of the surface, it was rarely possible to continue observations consecutively for more than a few days at a time. The table gives, therefore, the number of days in each month during which fairly reliable results were obtained, and also the average of these daily observations. This average is assumed to be that for all the days of the month, and is therefore multiplied by the number of these to obtain the approximate monthly total.

[1] Physical data and statistics of California, 1886, p. 373.

Evaporation at Fort Douglas, Utah, in inches.

Month.	1889.			1890.			1891.			1892.			1893.		
	Days.	Mean daily.	Total.	Days.	Mean daily.	Total.	Days.	Mean daily.	Total.	Days.	Mean daily.	Total.	Days.	Mean daily.	Total.
March	----	----	----	----	----	----	----	----	----	15	.067	2.1	----	----	----
April	----	----	----	----	.123	3.7	19	.107	3.2	14	.075	2.3	3	.083	2.5
May	----	----	----	----	.133	4.1	15	.153	4.8	----	.132	4.1	8	.169	5.2
June	----	----	----	----	.170	5.1	22	.174	5.2	25	.177	5.3	----	----	----
July	----	----	----	16	.240	7.6	10	.246	7.6	26	.211	6.5	----	----	----
August	11	.340	10.5	20	.210	6.5	20	.210	6.5	10	.235	7.3	----	----	----
September	18	.190	5.7	23	.153	4.6	17	.174	5.2	25	.174	5.2	----	----	----
October	7	.157	4.9	21	068	2.1	15	.081	2.5	15	.068	2.1	----	----	----
November	2	.035	1.0	18	041	1.2	15	.047	1.4	10	.055	1.6	----	----	----

Observations were conducted in a similar manner at Provo during a portion of the month of October, 1889, giving an average daily evaporation of 0.10 inch, and at Nephi, at intervals during a part of the same year, giving a mean daily evaporation for June of 0.13 inch; for July, 0.16 inch; for August, 0.15 inch, and for September, 0.10 inch. Similar fragmentary results have been obtained for localities in other parts of the West.[1] The longest series, however, is that begun in 1887 by Prof. L. G. Carpenter at the Experiment Station at Fort Collins, Colorado. The evaporating pan at this place is 3 feet square and 3 feet deep, sunk into the ground, the height of water being measured by means of a hook gage. The results have been published only up to the end of 1891.[2]

Monthly evaporation at Fort Collins, Colorado, in inches.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
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	0.99	----
1889	1.09	1.03	2.75	4.06	3.72	4.34	5.20	5.15	5.19	3.28	0.62	1.42	37.83
1890	0.86	2.36	3.48	3.50	4.32	5.71	5.44	5.76	3.69	2.71	1.32	1.10	40.24
1891	1.20	2.79	2.23	2.24	5.03	4.97	5.72	4.90	4.12	3.62	1.73	0.75	39.12

At the experiment station located at Laramie, Wyoming, Prof. J. D. Conley noted a total evaporation from April 17 to October 22, 1895, of 37.02 inches, distributed as follows: April 17–30, 2.53; May, 7.33; June, 6.24; July, 7.29; August, 6.07; September, 4.94; October 1–22, 2.62 inches. In this test the evaporation was measured by means of a hook gage within a tank lined with galvanized iron, and holding when full a cubic meter of water.[3]

Prof. T. Russell, in the Monthly Weather Review for September,

[1] Eleventh Ann. Rept. U. S. Geol. Survey, Part II, p. 34.
[2] Fourth Ann. Rept. State Agricultural Experiment Station, Fort Collins, Colorado, 1891, p. 53.
[3] University of Wyoming Experiment Station Bulletin No. 27, March, 1896, Meteorology for 1895, p. 15.

1888, gives the results of one year's observations, from July 1, 1887, to June 30, 1888, of the Piche evaporometer.

From this article are obtained the following figures, which give the computed evaporation in inches at several points:

Estimated depth of evaporation in inches.

Station.	Jan.	Feb.	March.	April.	May.	June.	July.
Salt Lake, Utah	1.8	2.7	3.6	7.2	6.9	8.9	9.2
Boise City, Idaho	1.6	2.5	3.8	6.1	6.5	6.6	10.0
Winnemucca, Nev	0.9	2.8	6.2	9.1	9.3	10.1	11.5
Denver, Colo	2.8	3.7	3.5	7.6	5.8	10.5	8.3
Cheyenne, Wyo	3.3	5.7	4.0	8.2	5.2	10.4	8.0
Helena, Mont	1.1	3.6	2.1	6.1	4.3	5.5	7.2
Santa Fe, N. Mex	3.0	3.4	4.2	6.8	8.8	12.9	9.2
Yuma, Ariz	4.4	5.2	6.6	9.6	9.6	12.6	11.0

Station.	Aug.	Sept.	Oct.	Nov.	Dec.	12 mos. evaporation.	Precipitation in 1888.
Salt Lake, Utah	10.7	9.6	6.5	5.0	2.3	74.4	13.62
Boise City, Idaho	9.2	7.4	5.2	3.2	1.8	63.9	11.09
Winnemucca, Nev	12.0	9.9	6.6	3.7	1.8	83.9	4.89
Denver, Colo	8.5	6.1	4.9	4.2	3.1	69.0	9.51
Cheyenne, Wyo	7.7	8.6	5.8	6.1	3.5	76.5	14.51
Helena, Mont	7.7	6.4	4.3	3.0	2.1	53.4	10.14
Santa Fe, N. Mex	9.8	6.6	6.7	5.7	2.7	79.8	12.03
Yuma, Ariz	10.2	8.2	8.2	5.5	4.6	95.7	2.95

An estimate of the total amount of yearly evaporation from water surfaces in this State, based on the foregoing facts, would vary from 3 to 6 feet in depth, depending upon the temperature, frequency, and velocity of the winds, dryness of the atmosphere, and like conditions. From the same data we may conclude that, generally speaking, the evaporation during the four months of May, June, July, and August, or, in other words, the irrigation period of this section, is equal to that of the remaining eight months.

The comparatively large loss by the yearly evaporation from wet ground surfaces of the Western States is of far greater importance than the evaporation which takes place at water surfaces, for the reason that, in a measure, it can be controlled by man. Such conservation of the obtainable water supply results in having available a balance which can be utilized in reclaiming desert land and in increasing the productions of land now cultivated.

One of the cheapest and most effective methods of checking excessive evaporation is cultivation. In this regard Utah irrigators have an important lesson yet to learn. The custom of the majority is to apply large quantities of water to growing crops, making a paste of the top soil. In less than twenty-four hours the water in this top layer is evaporated, leaving the ground hard and baked. Under such conditions it is astonishing how rapidly the soil moisture is evaporated. If this top crust is left undisturbed for a few days, the soil becomes parched, the crops apparently suffer for lack of moisture, and the unskilled irrigator fancies the only remedy is to apply more water.

With the most careful attention while irrigating, it is not possible always to prevent the formation of paste by the mixture of fine soil and water and the subsequent baking; but the robbing the soil of its moisture through excessive evaporation can be avoided by breaking up the surface crust as soon as it forms and by keeping the surface layer thoroughly pulverized, thus effectively checking evaporation in even the hottest weather.

Recent experiments have shown that evaporation from the surface of soil can be greatly decreased by mulching. The effect, for example, of a 3-inch layer of broken, compacted oat straw, spread evenly over the surface of a strawberry field in Minnesota, was to decrease the evaporation by 605 barrels per acre, and the gain in moisture to the soil of a vineyard by a similar treatment was 1,600 barrels per acre, sufficient to cover the entire surface to a depth of nearly 2 inches.[1]

It has been repeatedly demonstrated that wind is a prime factor in increasing evaporation from both ground and water surfaces. While it is true that the frequency, course, and velocity of the winds lie beyond the control of the agriculturist, yet by planting suitable trees to form wind-breaks within and around cultivated fields, much benefit may be gained. The foliage of the trees will decrease the temperature, increase the humidity of the air, and break the force of the wind.

Perhaps the most complete test of the amount of water evaporated from soil and water surfaces was made in England by Charles Greaves,[2] M. Inst. Civ. Eng. His results are summarized by Fanning as follows:

> The mean annual rainfall during the time (1860 to 1873) was 27.7 inches. The annual evaporations from soil were—minimum, 12.07 inches; maximum, 25.14 inches, and mean, 19.53 inches; from sand—minimum, 1.43 inches; maximum, 9.10 inches, and mean, 4.65 inches; from water—minimum, 17.33 inches; maximum, 26.93 inches, and mean, 22.2 inches.[3] The climatic conditions of arid America are so unlike those of England that the above results do not in the least apply. They show, however, that, other conditions being equal, the amount of evaporation from ground surfaces is somewhat less than from water surfaces.

Dr. E. Wollny of Munich confirms this view when, in summarizing the work of three years on evaporation from land surfaces, he concludes:[4]

> (1) That the quantity of moisture evaporated from the soil into the atmosphere is considerably smaller than that evaporated from a free surface of water.

[1] Bulletin No. 32, Minnesota Agricultural Experiment Station.

[2] Trans. Inst. Civ. Eng., Vol. XLV, pp. 3-29.

[3] A Treatise on Hydraulic and Water-Supply Engineering, by J. T. Fanning, 1889, p. 93.

[4] Prof. E. Wollny, Forschungen, Vol. XVIII, p. 486. Abstracted in the Monthly Weather Review, Department of Agriculture, November, 1895, p. 422.

(2) That the evaporation is smallest from naked sand, and largest from naked clay, whereas naked turf and humus or vegetable mold have a medium value.

(3) That the evaporation is increased to a considerable extent by covering the ground with living plants.

(4) Evaporation is a process that depends upon both the meteorological conditions and on the quantity of moisture contained by the substratum of soil.

(5) Among the external circumstances, temperature is of the greatest importance, inasmuch as, in general, evaporation increases and diminishes with it; but this effect is modified according as the remaining factors come into play and in proportion to the quantity of water supplied by the substratum.

(6) The influence of higher temperature is diminished more or less by higher relative humidity, greater cloudiness, feebler motion of the wind, and a diminished quantity of moisture within the soil, whereas its influence increases under opposite conditions.

On the other hand, low temperatures can bring about greater effects than high temperatures, if the air is dry, or the cloudiness small, or the wind very strong, or if a greater quantity of water is present within the evaporating substance.

(7) For the evaporation of a free surface of water, or for earth that is completely saturated with water, the important elements are, first, the temperature; next, the relative humidity of the air, and then the cloudiness and the direction and velocity of the wind; whereas, for the ordinary moist earth, no matter whether the surface is naked or covered with living plants, it is the quantity of rain upon which the soil depends for its moisture that is the important additional consideration. The effects of the external elements on evaporation become less important, as explained in paragraph 5, in proportion as the precipitation is less and as the soil is more completely dried out by the previous favorable weather, and vice versa. For these reasons the rate of evaporation from a free surface of water not infrequently differs largely from that from the respective kinds of soil.

(8) Free surfaces of water and soils that are continuously saturated evaporate into the atmosphere on the average more water under otherwise similar circumstances than soils whether naked or covered with plants and whether watered artificially or naturally. Only at special times, viz, when the influence of the factors that favor evaporation is most intense, when the plants are in the most active period of growth, and when the soil contains a large percentage of water, can the land that is covered with plants show larger evaporating power than the free water surface.

(9) When a soil that is not irrigated is covered with plants, it evaporates a far greater quantity of moisture than when the surface is bare. In the former case the evaporation can not exceed the quantity received by the soil from the atmosphere before or during the period of growth. Swampy lands and those that are well irrigated, as also free surfaces of water, can, under circumstances favorable to evaporation, sometimes give to the atmosphere a greater quantity of water than corresponds to the precipitation that occurs during the same time.

(10) The evaporating power of the soil is, in itself, dependent upon its own physical properties; the less its permeability for water, or the larger its capacity for water and the easier it is able to restore by capillarity the moisture that has been lost, by so much the more intensive is the evaporation. For this reason the quantity evaporated increases with the percentage of clay and humus in the soil, whereas it diminishes in proportion as the soil is richer in sandy and coarse-grained materials.

(11) Soil that is covered with plants loses by evaporation so much more water in proportion as the plants are better developed, or stand thicker together, or have a longer period of vegetation, and vice versa.

In the above summary Dr. Wollny touches upon various phases of evaporation which have an important bearing on Western irrigation. At present there is little data to enable us to compare intelligently the results obtained in Germany with those in this country. However, some of the Agricultural Experiment Stations are taking up this work, and in a few years we may hope to know much more of the behavior of soil moisture and ground waters and their relation to plant life. The main object to be attained in the artificial application of water to soil is to develop plant life, and as this can be accomplished only by creating a moist soil and subsoil, it is necessary that we endeavor to ascertain the greatest possible percentage of the total precipitation that can be used for this purpose. In this State evaporation from both water and land surfaces must be regarded as one of the chief sources of waste, and as such deserving of careful study.

TRANSPIRATION.

In arid America agricultural products are almost entirely dependent upon the water supply. As a rule, the soil is fertile, containing in abundance the elements necessary for the development of plants; but if the water supply be either deficient or applied at the wrong time, a partial growth will result. The portions of a wheat field that are missed at the first irrigation seldom yield one-third of a crop. These dry places may be irrigated subsequently, but the second watering can not restore the shrunken cellular tissues nor the lost vigor. The skilled horticulturist has learned by experience and observation how and when to irrigate his fruit trees. When the trees are young, water is conveyed in two furrows only, one on each side the row of trees and at some little distance beyond the farthest roots. As the tree grows, the roots thrust themselves farther into the soil, but chiefly in the direction of the water supply, and in the following season the two furrows may be increased to four, until finally, in well-matured trees, all the space of 20 feet or more between the rows is thoroughly watered. By such a method water is not only provided for the soil, but is applied in such a way as to lead out the roots in quest of moisture and food.

Much has been written recently on subirrigation, and many agricultural experiment stations have gone so far as to pronounce this method superior to all others. By it water is conveyed through pipes buried in the ground and is discharged through a large number of small holes located opposite each tree. This mode of irrigation has not been successful. In the first place, it is an impossibility to cause water to discharge equally through so many orifices; and in the second place, the water is deposited at particular points in the soil, around which the roots of plants are sooner or later massed. The few advantages to be gained by applying the water beneath the surface can not be compared to the disadvantages due to the difficulties in the way of its distribution and to the concentration of the roots at particular places.

The injurious effects upon vegetation caused by either too little water or too much are clearly illustrated by the results of experiments made by Dr. E. Wollny[1] on summer rape, as given in the following table. In this, the first column gives the per cent of water in the soil as compared to the total water-holding capacity. The second column gives the number of pods produced, and the following columns give the weight of the various parts:

Effect of excess and deficiency of moisture.

Per cent of water in the soil.	Number of pods.	Weight of plants air-dried.			
		Seed, in grams.	Straw, in grams.	Chaff, in grams.	Total, in grams.
10	43	1.4	2.8	1.4	5.6
20	61	2.4	4.4	2.6	9.7
40	142	6.9	10.4	6.7	24.0
60	97	4.3	8.1	4.4	16.8
80	95	3.9	7.3	3.9	15.1
100	19	0.3	2.0	0.6	2.9

In growing plants in pots it is possible to apply just the right amount of moisture, but on the irrigated field it is somewhat different. At each watering the ground is for a time nearly saturated. Part of this excess water is soon evaporated, either from the ground or indirectly through the foliage. Another part sinks into the subsoil, and the remainder keeps the soil moist. If this soil moisture can be maintained in the right proportion, or, in other words, if the amount drawn from the subsoil by capillarity equals the loss by evaporation until the next watering, the crop will grow under the most favorable conditions as regards moisture. If too little water is applied to the surface and the subsoil water for some cause is inaccessible, the crop will suffer and become more or less dwarfed. On the other hand, too much water may keep the soil near the extreme of complete saturation and produce upon vegetation as harmful effects as too dry a soil. A cubic foot of average soil when thoroughly saturated will contain from 25 to 30 pounds of water. According to Wollny's experiment, the best results were obtained on summer rape when about 40 per cent of the empty space in the soil was filled, which would be equivalent to from 10 to 12 pounds of water in every cubic foot of soil.

We may thus classify productive soils under three heads in relation

[1] Experiment Station Record, Vol. IV, p. 532.

to the percentage of moisture which each contains, viz, as dry soils, moist soils, and wet soils. It may also be said that in each of these classes the amount of water drawn up by the roots and transpired by the leaves differs. The magnitude of this transpiration of vapor through the foliage of plants has been investigated by Messrs. King, Wollny, Hellriegel, and others, the results of whose labors are briefly summarized in the following tables:

Amount of water required for a pound of dry matter in Wisconsin.[1]

Crop.	Year.	Water per pound of dry matter.	Yield per acre, pounds.	Water per acre, inches.
Barley	1891	402	7,441	13
Do	1892	375	14,196	23
Oats	1891	501	8,861	20
Do	1892	525	8,189	19
Corn	1891	301	19,845	26
Do	1892	316	19,184	25
Clover	1892	564	12,486	30
Pease	1892	477	8,017	17

Ratio of water evaporated to weight of crop harvested, as shown by experiments of Hellriegel and Wollny.[2]

Crop (Hellriegel).	Water evaporated.	Crop (Wollny).	Water evaporated.
Horse beans	262	Maize	233
Pease	292	Millet	416
Barley	310	Pease	447
Clover	330	Sunflower	490
Spring wheat	359	Buckwheat	646
Buckwheat	371	Oats	665
Lupine	373	Barley	774
Spring rye	377	Mustard	843
Oats	402	Rape	912

According to Hellriegel, as shown by the above table, 330 tons of water would be absorbed by the roots of clover, drawn up through the stems, and evaporated from the breathing pores of the leaves, for each ton of clover harvested. If the yield be estimated at 3 tons per acre, the quantity of water per acre is 990 tons, or a volume sufficient to cover the surface to a depth of nearly 9 inches. So far as has been ascertained, no tests have been made in the Rocky Mountain region

[1] F. H. King, Agricultural Experiment Station, University of Wisconsin, Ninth Annual Report, 1892, p. 94.

[2] Department of Agriculture, Experiment Station Record, Vol. IV, p. 532.

of the amount of water actually consumed by the various agricultural crops between the time of germination and the harvest, but observed facts seem to indicate that this amount varies with the conditions of soil moisture.

In sections of northern Utah, where water can not be readily or cheaply conveyed to irrigate the land, the fields are usually sown in wheat and cultivated "dry," the annual yield being from 12 to 25 bushels per acre. During the period of growth the rainfall is occasionally less than 1 inch, and the soil and subsoil apparently are very dry. If the quantity of water consumed by the wheat was even one-third of that given by Prof. F. H. King for barley and oats, which averaged a depth of nearly 19 inches over the entire surface cultivated, it is difficult to conjecture where the supply could come from.

On irrigated lands the case is quite different. The proper amount of moisture is maintained in the soil, the plant is kept in a healthy, vigorous condition, and the normal amount of water passes through its tissues, bearing the necessary mineral food furnished by the soil. It is not unusual to irrigate alfalfa every other week, and to spread an amount of water over the surface during its period of growth sufficient to cover the ground to a depth of 6 feet. A part of the water used in irrigating usually sinks into the subsoil and flows off as seepage water, a second part is evaporated, and the third part, possibly one-third of the whole supply, passes through the tissues of the plant and is mostly transformed into vapor at the leaves.

The sagebrush and grasses indigenous to the uncultivated lands of the Rocky Mountain region require but little moisture to maintain their slow growth. In the vicinity of Corinne, Boxelder County, Utah, the average annual rainfall for the past twenty-five years has been less than 12 (11.73) inches. Little snow remains for any length of time on the ground; the evaporation in summer is excessive on all moist ground and water surfaces; and yet sagebrush flourishes, growing to a height of from 3 to 5 feet. If we deduct from the total yearly precipitation the probable amount of moisture evaporated, very little will remain for the use of the plants. It is possible that the total quantity of water absorbed by the roots of the plants that grow on uncultivated lands and transpired by their foliage does not exceed one-tenth of the annual precipitation, which in this State would be about $1\frac{1}{4}$ inches over the surface of unreclaimed arable lands. On the preceding estimates, based on observed facts, we may therefore conclude that in this State the amount of water evaporated from the foliage of plants ranges from a surface depth of 1 inch for buffalo grass and sagebrush to a surface depth of 20 inches for well-irrigated alfalfa.

CACHE VALLEY.

This beautiful valley is nearly surrounded by mountains. A spur of the Wasatch Range forms the elevated divide between it and Bear Lake Valley, in Rich County, to the east, and another spur of the same range forms the lower divide between it and Great Salt Lake and Malad River valleys to the west. The average elevation of the cultivated portion of the valley is about 4,500 feet. Its length from north to south varies from 40 to 50 miles, and its width from east to west from 10 to 15 miles.

The first white men who wintered in the valley were the Garr brothers. They were engaged by the authorities of the Mormon Church during the winter of 1855–56 to look after the range cattle owned by that church, and they built a rude log hut in the vicinity of what is now the church farm. In the summer of 1858 several families from Brigham reached the valley through Boxelder Canyon and made a permanent settlement in what is now Wellsville.

According to the latest report of the Utah statistician, the population of Cache County in March of 1895 was 18,286. The principal towns and cities in the order of population are: Hyde Park, 647 inhabitants; Providence, 944; Lewiston, 969; Richmond, 1,295; Wellsville, 1,390; Smithfield, 1,448; Logan, 5,756; total, 14,249.

Cache County contains an area of 697,600 acres, of which 30,923[1] acres were irrigated in 1889, and 38,430[2] acres in 1894. From information collected during the past season, supplemented by the records obtained by C. D. W. Fullmer, county statistician, the following table has been prepared, giving the approximate number of acres irrigated for each kind of crop in 1896.

Approximate area irrigated in 1896.

	Acres.
Cereals	20,000
Lucern, hay, etc	15,000
Potatoes, beets, etc	1,500
Fruit trees	1,200
Small fruits	25
Other products	900
Total	38,625

The water utilized in irrigating the southern end of the valley is diverted chiefly from New Canyon, Little Bear, and Blacksmith Fork streams. Logan River, with Summit, High, and Clarkson creeks, furnish the supply for the middle portion. Cub and Weston creeks are the chief sources of supply for the northern portion. Surveys for irrigating canals have been made to divert water from Bear River, in Cache Valley, but owing to the lengths of the proposed canals and the cost of construction, none has yet been built.

The soil in the cultivated portions of the southern end of the valley, and particularly in the vicinity of the towns of Paradise, Hyrum, and Millville, consists for the most part of a rich, black, clayey loam. In the western part clay, with occasional patches of alkali, predominates.

[1] Eleventh Census, Agriculture by Irrigation, F. H. Newell.
[2] First Triennial Report of the Bureau of Statistics of Utah.

The soil in the northern and northwestern portion of the valley varies from coarse gravel to fine sand and clay. On the whole, it may be designated as a soil well adapted for the production of wheat.

LOGAN RIVER.

The greater part of the drainage basin of Logan River lies in the mountain range east of Cache Valley. The main source of the stream is quite small, and heads high on the range about 40 miles within the mountains; but as it flows down a steep channel toward the west its

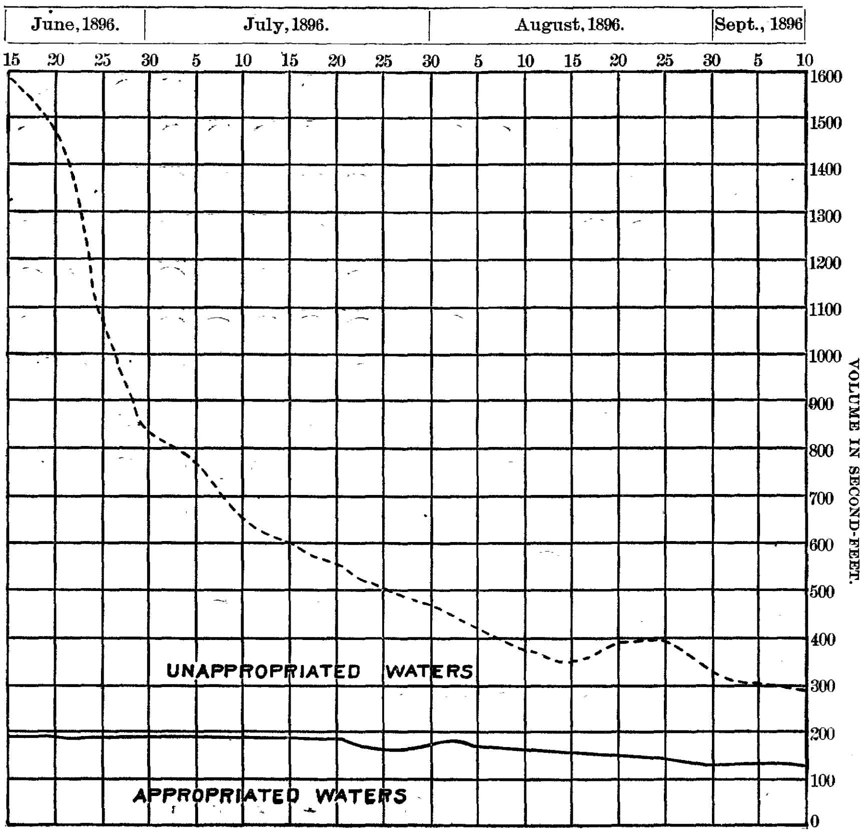


FIG. 4.—Diagram showing appropriated and unappropriated waters of Logan River.

waters mingle with those from Temple Fork, Boss Canyon Creek, Spring Creek, Ricks Spring, and Right Hand Fork Creek, which, when united, form one of the most important rivers in the State. From its head waters to where it unites with Bear River is some 50 miles, only 10 of which lie outside rugged canyons.

About the 1st of June, 1896, a permanent gaging station was established on this river a short distance below the mouth of the canyon and above all the canals save one, the Logan, Hyde Park and Smithfield. From daily river-height observations and several current meter measurements the flow has been accurately determined throughout the season. The waters used for beneficial purposes have also been determined by a series of measurements of each canal, and both results are represented graphically in fig. 4. The aggregate volume of all the canals is nearly 200 second-feet; and as the discharge of the river at the mouth of Logan Canyon during a dry season may be less than that amount, the apparent large surplus of last summer, which averaged during the month of August, 1896, 222 second-feet, is not to be depended upon.

Irrigating canals diverting water from Logan River.

Name of canal or ditch.	June.		July.		August.		September.	
	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.
Logan, Hyde Park, and Smithfield Canal	12	34.5	21	47.5	31	30.1	----	----------
Logan and Richmond Canal	12	60.4	21	69.1	31	50.1	----	----------
Providence Canal	12	5.4	21	8.2	----	----------	1	5.2
Logan, Hyde Park, and Thatcher Canal	12	*a* 48.9	21	*27.0	31	27.5	----	----------
Nursery Canal	----	----------	21	2.4	----	----------	1	0.7
Logan and Benson Ward Canal	12	*a* 25.0	21	23.9	----	----------	1	19.3
West Field or Little Ditch	----	----------	21	11.6	----	----------	1	7.5

a Estimated.

The Logan, Hyde Park, and Smithfield Canal was completed in June, 1882. Its head gate is located about 1½ miles above the mouth of the canyon, and at an elevation of 326 feet above the business center of Logan City. In July, 1892, the writer, as the consulting engineer of the city corporation, advised the abandonment of the old source of supply, and recommended that the future source be the Logan, Hyde Park, and Smithfield Canal, until funds were available to extend the conduit to the river. Logan City now gets its domestic water supply from that canal, and owns 26⅔ per cent of its paid-up capital stock. The canyon portion of the canal was never properly constructed, and the loss through leakage is very great. On August 31, 1893, the discharge at the head gates, as measured by the writer, was 48 second-feet. At a point 7,000 feet lower down the volume had been decreased, on account of waste, to 26.7 second-feet, a loss of 21.3 second-feet, or 44 per cent of the volume diverted. The area irrigated since 1892 has not varied to any appreciable extent, and the following table gives the figures for the three preceding years:

Area irrigated by Logan, Hyde Park, and Smithfield Canal.

Year.	Farm lands.	City lots.	Total.
	Acres.	*Number.*	*Acres.*
1890	2,184	[a] 63	2,310
1891	2,409	163	2,735
1892	2,785	169	3,123

[a] A city lot is equivalent to 2 acres of farm land.

The Logan and Richmond Irrigating Company was organized in November, 1864, and the canal was built in 1865–1867. The records of the company show that the land irrigated by this canal in 1878 was 1,400 acres of farm lands and 195 city lots, but the capacity of the canal was considerably increased in 1881, and more land was reclaimed at its lower terminus in the vicinity of the town of Smithfield. The areas irrigated by this canal in 1895 are as given below:

Area irrigated by Logan and Richmond Canal.

Precinct.	Farm lands.	City lots.	Total.
	Acres.	*Number.*	*Acres.*
Logan	897	214	1,325
Hyde Park	610	50	711
Smithfield	1,240	0	1,239
Total	2,747	264	3,275

Providence Canal is the only irrigating system of any considerable size which diverts water from the south or left bank of Logan River. It was begun in 1866, but owing to the fact that the locating engineer set pegs on an ascending grade from the proposed place of diversion, and the water would not flow uphill, the enterprise was abandoned until 1883, when the necessary changes in the elevations were made and the canal completed. The cost of maintenance has always been high, owing to faulty location and steep hillsides, averaging about $250 per annum, and the area irrigated since 1883 has not varied far from 300 acres.

Logan, Hyde Park, and Thatcher Canal was begun in the spring of 1860. It is the oldest in Cache Valley, and was the first to divert water from Bear River or its tributaries. The primary object held in view by the original projectors was to irrigate wheat lands, but several mill owners obtained permission to widen the canal sufficiently to furnish them with a supply for power purposes. A portion of the flow has been so employed ever since, but the tail water from the mills is nearly all subsequently used in irrigation. The canal branches at Sixth street, the upper branch extending to Hyde Park, the lower to a portion of Logan City. The acreage irrigated in 1860 was about 700 acres, and there has been a nearly uniform increase from that time to the present. Of late years the total number of acres irrigated by both branches of the canal has averaged about 2,115, of which 1,215 acres are located in Hyde Park and the remainder in Logan.

Logan and Benson Ward Canal has its headgates near the business center of Logan. The date of its water appropriation extends back to 1861. The extent of land at present irrigated by this canal includes 856 acres in Benson Ward and 2,150 acres in Logan precinct.

West Field, or Little Ditch, takes its supply from the tailraces of the mills and from Logan River at the city park. The first branch was made in the spring of 1860. The ditch flows into Spring Creek pond and receives a portion of its supply from this last source. The area irrigated in late years is 1,100 acres.

The average combined capacity of the 6 canals enumerated above was, for June, 1896, 188.8 second-feet; for July, 183.3 second-feet; for August, 157.6 second-feet; and for September, 131.5 second-feet. Comparing this with the aggregate area irrigated—12,920 acres—it appears that the duty of water per second-foot in June was 68.4 acres; in July, 70.4 acres; in August, 81.9 acres; and in September, 98.3 acres.

BLACKSMITH FORK RIVER.

This stream rises in a range of the Wasatch Mountains which separates Cache Valley from Rich County, flows in a northwesterly direction, and empties into Logan River. Its total length is about 35 miles. The average depth of compacted snow near the sources of this stream in February and March is about 4½ feet, and as the greater part of this snow melts during the month of May and the early part of June, the spring floods are excessive in proportion to the comparatively small area drained.

The discharge of this stream at a point a short distance below the mouth of Blacksmith Fork Canyon from June 15 to September 15, 1896, and the combined flow of all the irrigating canals diverting water therefrom are represented graphically in fig 5. The maximum volume of water appropriated and utilized is therein shown to be 180 second-feet, while the discharge of the stream may be said, if we except a few days in September, not to fall below that amount during the irrigating period.

As shown by the following table, six canals divert water from this source and vary in carrying capacity from 4 to 70 second-feet. The Hyrum Canal is the largest and is divided near its head gates, the upper branch supplying water to a portion of Hyrum City, and the lower being used on the fields adjacent to Millville. Solveson & Co.'s ditch is one of small capacity, and waters the lands on the river bottoms. The remaining four canals extend to the town of Millville and its vicinity, two being taken out on the east side of the river and two on the west.

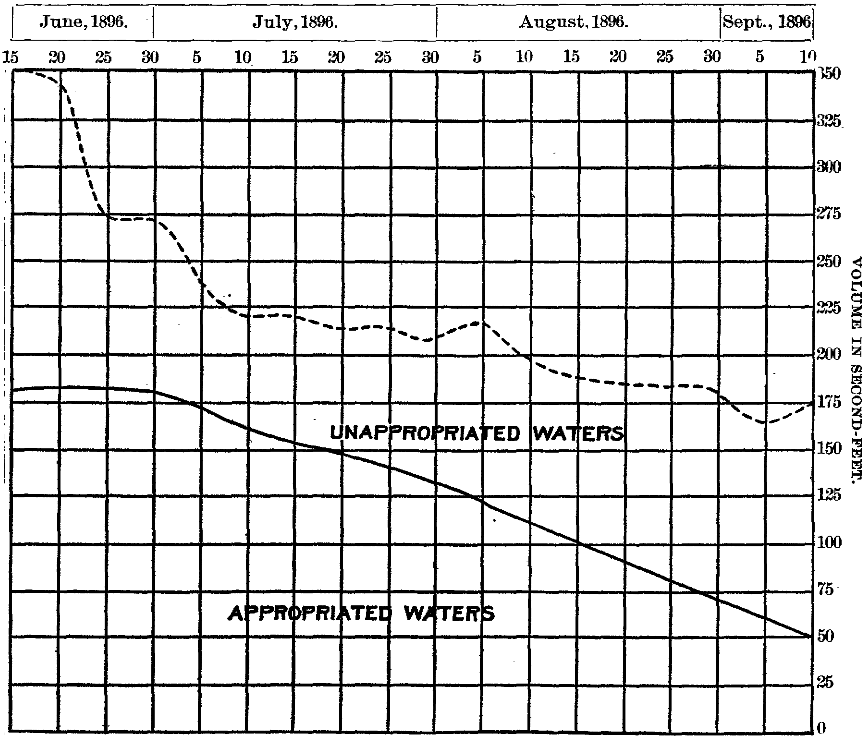


FIG. 5.—Diagram showing appropriated and unappropriated waters of Blacksmith Fork River.

Irrigating canals diverting water from Blacksmith Fork River.

Name of canal or ditch.	June.		July.		August.		September.	
	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.
Solverson & Co.'s ditch	18	3.9	9	0.8	5	2.2	15	Dry.
No. 1 canal	{18 29	27.8 32.9	}10	17.4	4	22.8	15	4.3
Hyrum canal	18	48.7	10	63.6	4	65.9	15	22.8
No. 3 canal	18	70.6	10	51.7	4	26.1	15	11.2
No. 2 canal	----	----------	9	16.4	4	6.7	15	3.4
No. 4 canal	----	----------	9	13.5	4	1.1	15	Dry.

LITTLE BEAR RIVER.

Little Bear River, Little Muddy River, or Boxelder Creek, as it is variously termed, is a tributary of Logan River. It is formed by two main streams which unite near the town of Paradise, in the southern part of the valley. One of these tributaries is called the East Fork of Little Bear River, and has a total length from its head waters to its mouth in Logan River of 33 miles. The general trend of its course within the mountains is easterly, but after joining the South Fork the

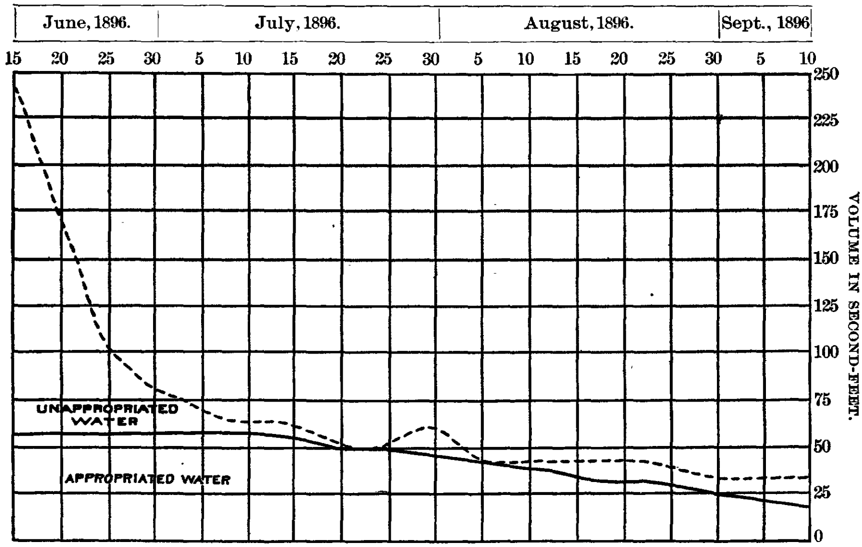


FIG. 6.—Diagram showing appropriated and unappropriated waters of South Fork of Little Bear River.

combined waters flow in a northerly direction to Logan River. The South Fork is fed by numerous springs and rivulets which flow from the south side of the divide lying between Cache Valley and Ogden Valley, and its greatest length from its source to its confluence with the East Fork is 10 miles. The following table gives the names and

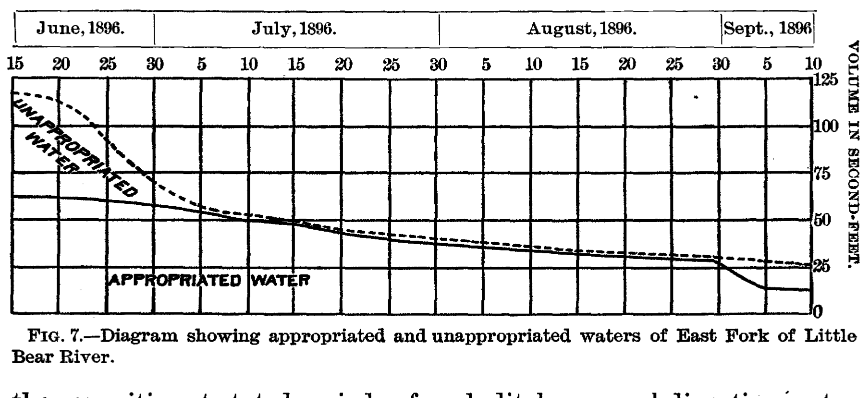


FIG. 7.—Diagram showing appropriated and unappropriated waters of East Fork of Little Bear River.

the capacities at stated periods of each ditch or canal diverting water from Little Bear River and its tributaries. A glance at figs. 6 and 7 shows that the waters of both forks were nearly all utilized during the past season.

In this portion of the valley the gain due to seepage waters from irrigated areas and from the adjacent bench lands is of considerable value to the inhabitants of Wellsville. On July 15, 1896, the flow in the South Fork was 61 second-feet. On the same date Hyrum Canal was diverting 55 second-feet, and a surplus of 24 second-feet remained in the river. These figures show a gain from seepage and deep-seated springs of 43 second-feet. Subsequently the springs were measured and aggregated nearly 20 second-feet, thus leaving a balance of 23 second-feet of seepage waters.

Irrigating canals diverting water from Little Bear River.

Name of canal or ditch.	June.		July.		August.		September.	
	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.
From East Fork.								
Jackson Surplus Ditch	19	3	10	2.3	6	Dry.		
Frank Law Ditch	19	1.6	10	Dry.				
Facer Ditch	19	6.8	10	1.1	6	Dry.		
Paradise Irrigation and Reservoir Company's Canal	19	50.2	10	47.2	6	35.1	15	22.5
From South Fork.								
Nichols Ditch			11	Dry.				
Davis & Co.'s Ditch			11	Dry.				
Hyrum Canal			11	57.4	6	40.1	15	12.8
From main stream.								
South Field Ditch			11	2.7	6	Dry.		
Paradise Hollow Ditch			14	2.5	7	2	15	Dry.
Miller Ditch			14	2.8	7	1.4	15	Dry.
Wellsville East Field Ditch			14	26.1	7	4.9	12	2.6

CUB RIVER.

Cub River, the main source of supply for the northern portion of Cache Valley, rises in Idaho, flows in a southwesterly direction for a distance of 28 miles, and empties into Bear River. The six ditches which head on this stream were each measured three times last summer, with results as stated in the following table. The highest is the Cub River and Worm Creek Irrigation Company's canal, which supplies with water the town of Preston, Idaho. It is taken out on the north side of the river, and conveyed through a pass in the ridge into Worm Creek channel, which is used to convey the canal water to a lower elevation, where it is again diverted into several ditches that distribute irrigating water to the various precincts of Preston. The next canal of any considerable importance is that of the Cub River and Middle Ditch Irrigation Company, which on June 25 carried 50.7 second-feet. By far the largest canal on this stream was begun in 1860, for the purpose of watering bench lands located north of Franklin, on the right bank of Cub River. Owing, however, to a grave error in the grade, the project was temporarily abandoned, and it was not until after the settlement of Lewiston that a resurvey was made and the canal completed. It is now known as the Lewiston Ditch, or canal. The lowest canal, but the first to divert water from Cub River, if one excepts the Perkins Ditch, which is now practically abandoned, is the Franklin City Ditch, which was built in 1864 by Messrs. Parkinson, Smart, Woodward, and others.

The accompanying diagram (fig. 8) showing the appropriated and unappropriated waters of Cub River, indicates a large surplus during the months of June, but after July 10 the flow is nearly all utilized by the various canals.

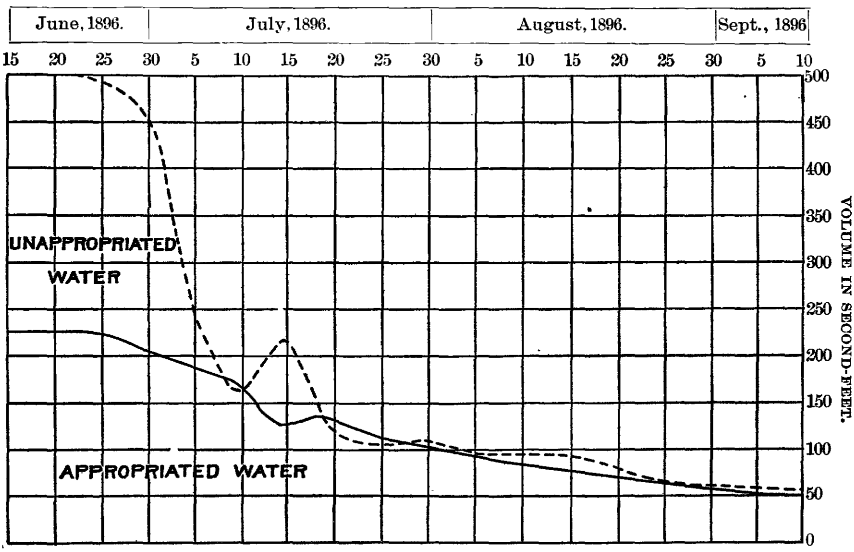


FIG. 8.—Diagram showing appropriated and unappropriated waters of Cub River.

Irrigating canals diverting water from Cub River in Oneida County, Idaho.

Name of canal or ditch.	June.		July.		August.		September.	
	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.
Cub River and Worm Creek Irrigation Company's canal	25	42.5	27	31.8	----	----------	7	8.4
Morehead, Taylor, and Kent Ditch	25	4.8	26	1.5	----	----------	7	Dry.
Cub River and Middle Ditch Irrigation Company's canal	25	50.7	27	15.9	----	----------	7	12.0
Taylor ditch	25	Dry.	27	2.1	----	----------	7	Dry.
Lewiston ditch	25	122.1	27	51.0	----	----------	7	30.2
Franklin City ditch	26	5.6	28	2.4	----	----------	7	Dry.

HIGH CREEK.

High Creek is a tributary of Cub River. It rises near the boundary line between Utah and Idaho and flows in a southwest course for a distance of about 9 miles. Numerous ditches, as may be seen by the following table, take water from this comparatively small stream, but, with the exception of the two Richmond canals, their discharges during July and August are small. The Richmond Irrigation Canal, increased by a portion of the flow from Cherry Creek, waters the sloping bench lands lying between High Creek and Richmond. This canal, when augmented by the flow from City Creek, also furnishes water for the upper portion of the town of Richmond. The lower portion of this town and the farm lands adjacent thereto are watered by the Richmond City Canal.

Irrigating canals diverting water from High Creek, in Cache County, Utah.

Name of canal or ditch.	June.		July.		August.		September.	
	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.
Williams and Derney Ditch	28	1.3	29	Dry.	----	----------	----	----------
Upper High Bair Ditch	28	2.9	29	Dry.	----	----------	----	----------
Upper Coveville Ditch	28	7.8	29	Dry.	----	----------	----	----------
Richmond Irrigation Company's Canal	28	43.2	29	2.5	----	----------	9	1.0
Williams Bros., Eckelson and Day Ditch	28	3.6	29	Dry.	----	----------	----	----------
Norman Day Ditch	28	0.7	29	Dry.	----	----------	----	----------
Richmond City or Irrigation Canal	28	25.5	29	16.4	----	----------	9	3.8
Two Eleventh Ditch	28	8.7	29	0.9	----	----------	9	1.0
Lower Coveville Ditch	28	6.8	29	1.2	----	----------	9	2.1
J. Bright Ditch	28	8.9	29	2.8	----	----------	9	0.6

SUMMIT CREEK.

Summit Creek has its source near the head waters of Logan River, and after flowing in a southwesterly course for a distance of 13 miles empties into Bear River. The summer flow of this creek is diverted through various canals, a list of which is given in the order of elevation in the following table, and is used to irrigate the town lots of Smithfield and the farm lands adjacent thereto. A portion of the flow is first used for mechanical purposes, but is subsequently diverted for irrigation purposes.

Irrigating canals diverting water from Summit and Birch creeks in Cache County, Utah.

Name of canal or ditch.	June.		July.		August.		September.	
	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.
Roskelly Ditch			3	Dry.				
Peterson Ditch			3	Dry.				
Surplus Ditch			3 31	13.0 3.9			10	2.8
Union Milling Company's Ditch			3 31	3.6 1.1			10	0.8
Mack's Old Mill Race Ditch			3 31	14.1 5.0			10	3.1
City Ditch			3 31	1.0 0.3			10	0.2
Morehead Ditch			3 31	0.7 0.2			10	0.1
Levy Ditch			3 31	11.9 3.6			10	1.6
Big Ditch			3 31	21.8 6.7			10	4.8

MISCELLANEOUS MEASUREMENTS.

The following table gives the results of measurements made of the flow of canals and ditches from other streams within Cache Valley other than those before described:

Results of measurements of irrigation canals and ditches.

Name of canal or ditch.	June.		July.		August.		September.	
	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.
From Clarkston Creek.								
Birch Creek ditch	----	----------	----	----------	12	3.6	3	3.0
Upper Dam ditch	----	----------	----	----------	12	1.9	3	1.4
Lower Dam ditch	----	----------	----	----------	12	1.5	3	2.0
From Sugar Creek, Oneida County, Idaho.								
Upper Wheeler ditch	----	----------	27	0.2	----	----------	7	Dry.
Taylor and Perkins ditch	----	----------	27	0.9	----	----------	7	0.4
Lower Wheeler ditch	----	----------	27	0.9	----	----------	7	Dry.
From Cherry Creek, in Cache County, Utah.								
Upper Cherry ditch	30	10.7	30	6.2	----	----------	9	1.1
Cherry Creek Water Section canal	30	7.5	30	0.9	----	----------	9	1.0
From Maple Creek and tributaries, Crooked Creek and Deep Canyon, in Oneida County, Idaho.								
Crooked Canyon Creek ditch	27	0.3	28	0.4	----	----------	8	Dry.
J. Chatterton and J. Lowe ditch	27	2.7	28	Dry.	----	----------	----	----------
J. Lowe ditch	27	0.4	28	1.0	----	----------	8	Dry.
Silver Point ditch	26	2.7	28	Dry.	----	----------	----	----------
Maple Creek or Franklin City ditch	26	11.6	28	5.0	----	----------	8	3.1
Stalker and Woodward ditch	27	1.7	28	2.9	----	----------	9	0.6
Woodward ditch	26	3.5	28	Dry.	----	----------	----	----------
Stalker and Flack ditch	26	4.6	28	1.7	----	----------	8	Dry.
From Spring Creek, at Providence, in Cache County, Utah.								
Bullock ditch	----	----------	8	0.7	3	1.3	14	0.4
Bear ditch	----	----------	8	2.2	3	3.9	14	Dry.
South Bench ditch	----	----------	8	10.6	3	11.7	14	4.2
Upper ditch	----	----------	8	9.5	3	3.5	14	6.8
Town ditch	----	----------	8	6.7	3	3.4	14	2.9
Accommodation ditch	----	----------	8	0.9	3	Dry.	14	0.2
From Weston Creek, in Oneida County, Idaho.								
Lapray and Norton and Coburn ditches	----	----------	18	2.6	11	1.4	4	0.8
No. 1 ditch	----	----------	18	3.6	11	1.5	3	1.6
Georgson ditch	----	----------	18	2.3	11	1.8	3	1.4
Weston Town ditch	----	----------	18	2.4	11	1.4	3	2.1
East ditch	----	----------	17	2.5	11	1.0	4	1.0
South Field ditch	----	----------	17	4.3	11	3.9	4	3.0

Smaller creeks and springs of Cache Valley from which water is diverted for irrigating purposes.

Name.	June.		July.		August.		September.		October.	
	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.
City Creek (Richmond)			1	2.6	1	Dry.				
City Creek (Clarkston)			17	0.9	12	0.8	3	0.7		
Deep Canyon Creek (Mendon)			16	1.4	12	1.5	11	1.2		
Dry Canyon Creek (Avon)					5	0.8	15	Dry.		
Dry Creek (Weston)			18	0.5			15	Dry.		
Flat Canyon Creek	27	0.9	28	Dry.						
Green Canyon Creek	13	5.9	31	Dry.						
Hyrum Dry Canyon Creek					6	0.4	15	Dry.		
Millville Creek			9	3.9	4	4.3	14	4.5		
Myler Creek			17	0.3	12	0.4	3	0.4		
New Canyon Creek			15	4.5	8	4.9	12	4.5		
Nebo Creek			1	0.6	30	Dry.				
Ox Killer Creek	27	0.4	28	Dry.						
Pole Canyon Creek					6	1.5				
Spring Creek (Richmond)	30	1.3	29	0.3			9	Dry.		
Three Mile Creek					12	0.1	11	Dry.		
Twin Creek			16	1.1	13	1.6	11	1.2		
Worm Creek	24	1.7	26	Dry.						
Coburn Spring							4	0.6		
Clayton Spring			15	1.8	8	1.9	12	1.6		
Done et al. springs									22	10.2
Gardner Spring			15	5.0	8	4.3	12	3.5		
Gibson et al. springs									22	6.5
Gitten Spring			16	0.4	13	0.5	12	0.4		
Garr Spring			9	3.6	5	3.2	14	3.1		
Graveyard Spring			16	0.6	13	0.5	11	0.4		
Hyrum Field Seepage springs					7	10.2				
Halverson Spring			30	0.5						
J. Stone and T. Lowe Spring	27	1.5					8	0.2		
Millville Creamery Spring							7	3.6		
Marks et al. springs									22	3.8
Michelson Spring							3	0.3		
Merrill et al. springs									22	5.8
New Dam Spring			15	4.0	8	4.3				
North Field Dam Spring No. 1			15	7.0	8	7.5				
North Field Dam Spring No. 2			15	4.0	8	3.6				
Pond Spring (Mendon)			16	1.1	12	0.9	11	1.1		
Pond Spring (Logan)							11	7.5		
Rocky Point Spring			16	1.6	12	0.5	11	0.3		
Wellsville City Spring			15	3.0						
Wm. Cunningham's Spring							12	0.15		
Wm. Hugh's Spring	26	0.17								
Newton Reservoir			17	8.6	12	4.9	2	1.9		
Hopkins's Slough									23	6.5

Sources of water supply in Cache Valley not used in irrigation in Cache County.

Name of source.	June.		July.		August.		September.		October.	
	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.
Bear River at Battle Creek	23	3,954.1	25	1,187.2			5	872.6		
Do			25	1,198.8			28	820.7		
Do			25	1,197.9						
Spring Creek (Mendon)									20	66.4
Spring Creek (Millville)									27	4.4
Spring Creek (Franklin)									23	1.4

RESULTS OF STREAM MEASUREMENTS.

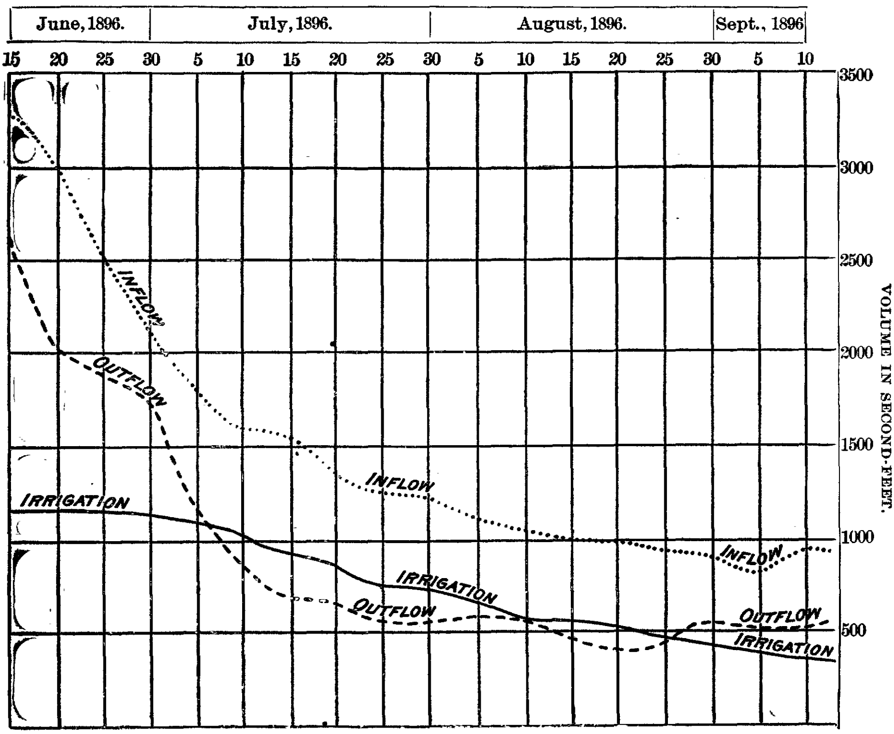


FIG. 9.—Diagram of water supply of Cache Valley, exclusive of Bear River.

For purposes of comparison some of the results of the stream and canal measurements made in Cache Valley during the summer of 1896 are summarized in the diagrams of figs. 9 and 10. Fig. 9 shows the inflow, outflow, and irrigating waters of the valley exclusive of Bear River, while fig. 10 includes both the inflow and outflow of Bear River. As has been stated, no water is diverted from this river in Cache Valley, all the water now utilized being obtained from the various tributaries. The aggregate discharge of all these tributaries, including wells and springs, is shown by the curved line termed "inflow" in fig. 9. This diagram also shows the total amount of the inflow which was used for irrigation purposes and the surplus which was discharged into Bear River.

It will be seen that the volume used for irrigation on any one day does not represent the difference between the inflow and the outflow on the same day. On every day from June 15 to September 15, 1896,

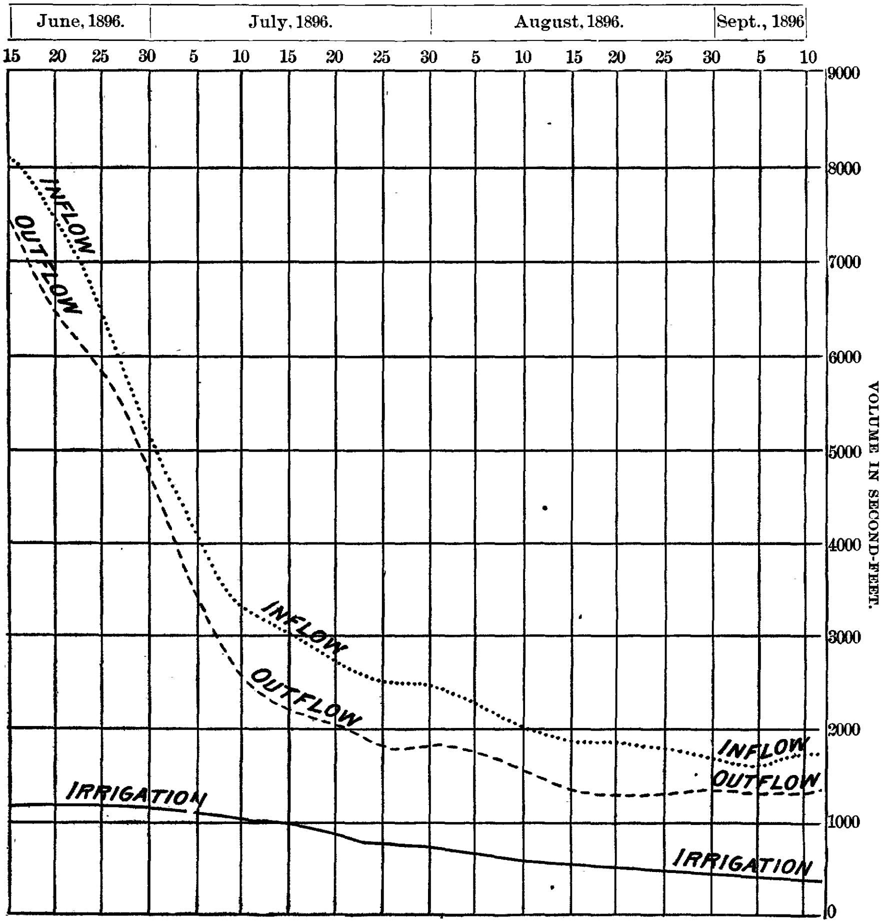


FIG. 10.—Diagram of water supply of Cache Valley, inclusive of Bear River.

excepting a few days in August, there was a gain due to seepage waters. This gain during the latter half of June averaged a continuous flow of 500 second-feet, or 18 per cent of the inflow, but it decreased rapidly until the 20th of August, when it began to increase gradually to September 15. In the following table are given, in cubic feet per second, the volume flowing into the valley, Bear River excepted,

the volume diverted for irrigation, and the outflow, besides the average monthly gain, resulting from seepage waters.

Water supply of Cache Valley, exclusive of Bear River, in second-feet.

Date.	Inflow.	Irrigation.	Outflow	Average monthly gain from seepage.
1896.				
June 15	3,275.8	1,163.1	2,659	500.4
June 20	3,006	1,162.9	2,029	
June 25	2,537.5	1,159 1	1,884	
June 30	2,107.6	1,136	1,739	
July 5	1,805.9	1,081.9	1,149	181.6
July 10	1,591.4	1,020.2	849	
July 15	1,552.5	925.5	684	
July 20	1,341.3	860	674	
July 25	1,244.2	755.6	554	
July 30	1,224 4	731.9	554	
August 5	1,108.2	632.2	557	34
August 10	1,036.9	573.4	562	
August 15	998.6	547 5	462	
August 20	997.7	512.3	417	
August 25	938.4	470.5	438	
August 30	905.2	442.8	553	
September 5	813.2	394.7	508	61.5
September 10	938.9	352.7	508	
September 15	864.6	334.7	603	

The rainfall from June 15 to September 15 on the 450 square miles lying within the area bounded by the locations of the stream measurements in Cache Valley was 3.58 inches, or an equivalent of 85,920 acre-feet of water. Assuming, for the present, that the amount of water evaporated from the surface of the irrigated area, together with that transpired by the leaves of cultivated plants, would aggregate a depth of 12 inches during the three months from June 15 to September 15, the loss due to evaporation over an irrigated area of 38,625 acres would equal 38,625 acre-feet. Again, if we assume that the water evaporated from the surface of the uncultivated portions of the valley was 4 inches during the same time, this loss over an area of 450 square miles, less 38,625 acres, or 249,375 acres, would equal 83,125 acre-feet. Comparing the losses due to evaporation with the gain from rainfall, the former is the greater by 35,830 acre-feet, which would maintain a stream of 200 second-feet for nearly three months.

If we assume that the rainfall just balances the evaporation, then the gain due to seepage would be so given in the above table. In this case the amount evaporated from the surface of the uncultivated portion of the valley in three months would be less than 2¼ inches, an amount apparently too small.

Irrigating duty of water in Cache Valley in 1896.

Month.	Duty of water in acres per sec. ft.
1896.	
June	52
July	67
August	113
September	166
Average	99.5

The figures given above include all the waste arising from absorption, seepage, and evaporation in the conveyance of the water as well as all waste caused by imperfect methods of irrigating.

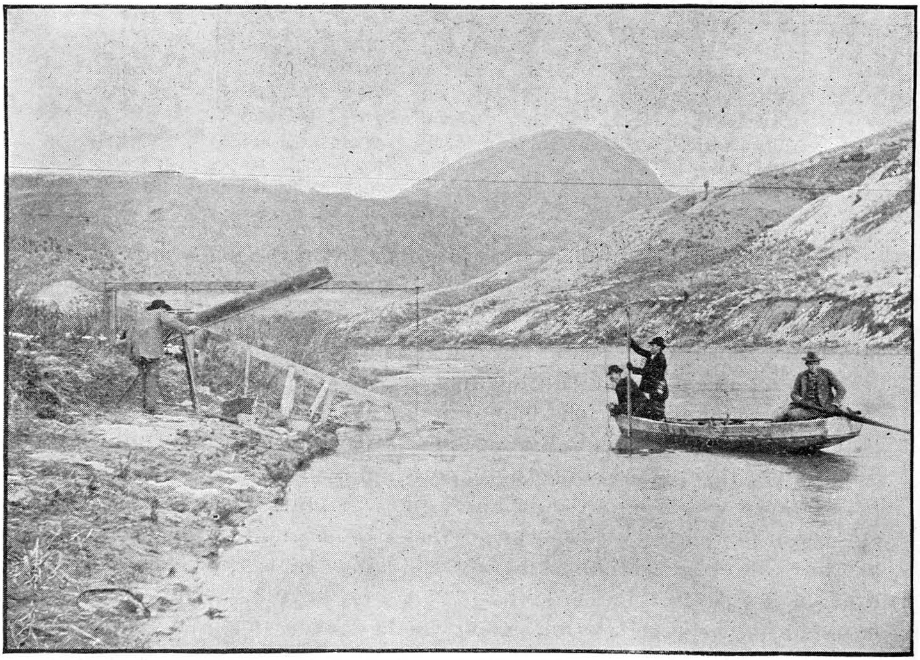


FIG. 11.—Bear River at Collinston Utah.

SEEPAGE WATERS IN OGDEN VALLEY.

This valley comprises the highest irrigated land in Weber County. It is separated from Great Salt Lake Valley by a narrow spur of the Wasatch Mountains and is watered by the South, Middle, and North forks of Ogden River and several small creeks. The three main tributaries meet near the lower part of the valley and form Ogden River, which traverses the mountain range through a canyon over 5 miles long, having an average fall in that distance of 80 feet to the mile. The torrential character of the river in this portion is illustrated in fig. 12. All of the water flowing from the upper valley must pass through this narrow gorge.

The irrigators of Ogden Valley supply annually 5,600 acres with water diverted from Ogden River and its tributaries, as shown by the small map, Pl. III. This diversion is, however, illegal during times

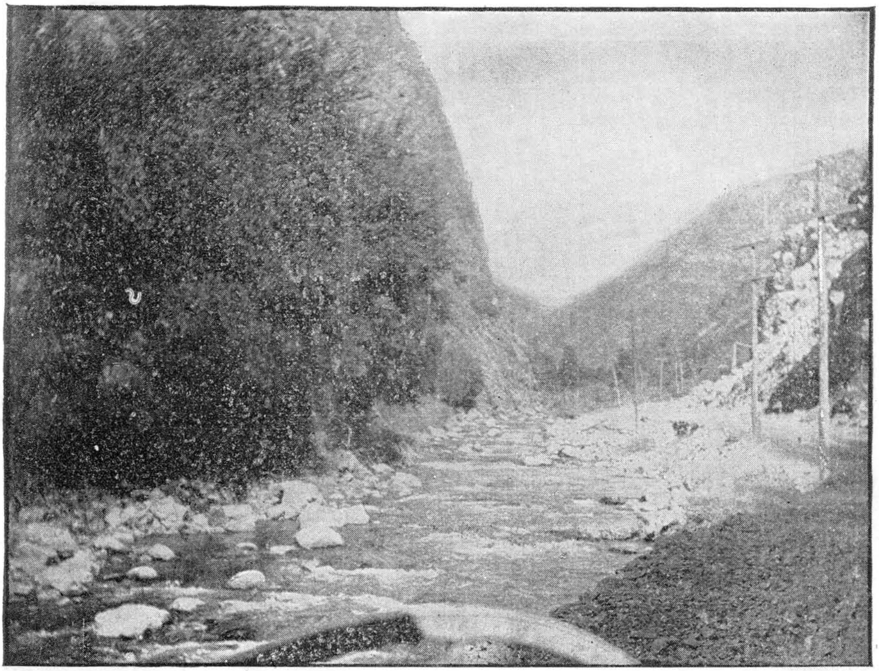


FIG. 12.—Narrows of Ogden River.

of scarcity, since all the summer flow belongs to prior appropriators whose canals are situated in the lower portions of the county, the relative location being shown on the left half of Pl. III. Many disputes have arisen between the irrigators of the two sections, and to prevent costly litigation, the writer sought to determine, if possible, whether water could be diverted and applied to the land in the upper valley without lessening materially the supply to the legal owners below.

The results of measurements made in 1894 are given in the following table:

Ogden Valley inflow and outflow in 1894.

Date.	Inflow, in second-feet.	Volume used in irrigation.	Outflow, in second-feet.	Seepage waters and private springs.
July 10	154.0	140.0	156.5	142.5
15	129.8	121.0	140.7	131.9
20	127.2	104.7	119.2	96.7
25	118.6	93.5	105.4	80.3
30	107.1	85.0	106.8	84.7
Aug. 5	96.0	77.5	99.7	81.2
10	88.5	74.0	106.8	92.3
15	81.2	71.4	100.5	90.7
20	76.5	66.0	106.8	96.3
25	75.0	56.5	110.4	91.9
30	73.1	44.0	113.0	83.9
Sept. 5	80.2	31.0	121.2	72.0
10	79.0	27.0	119.2	67.2

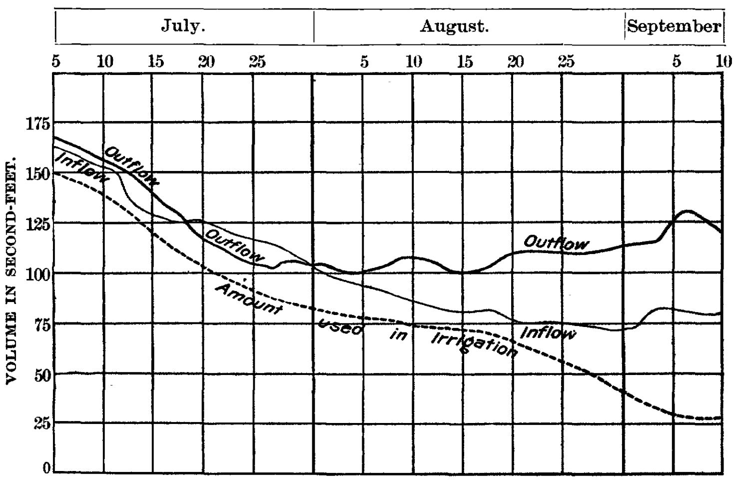
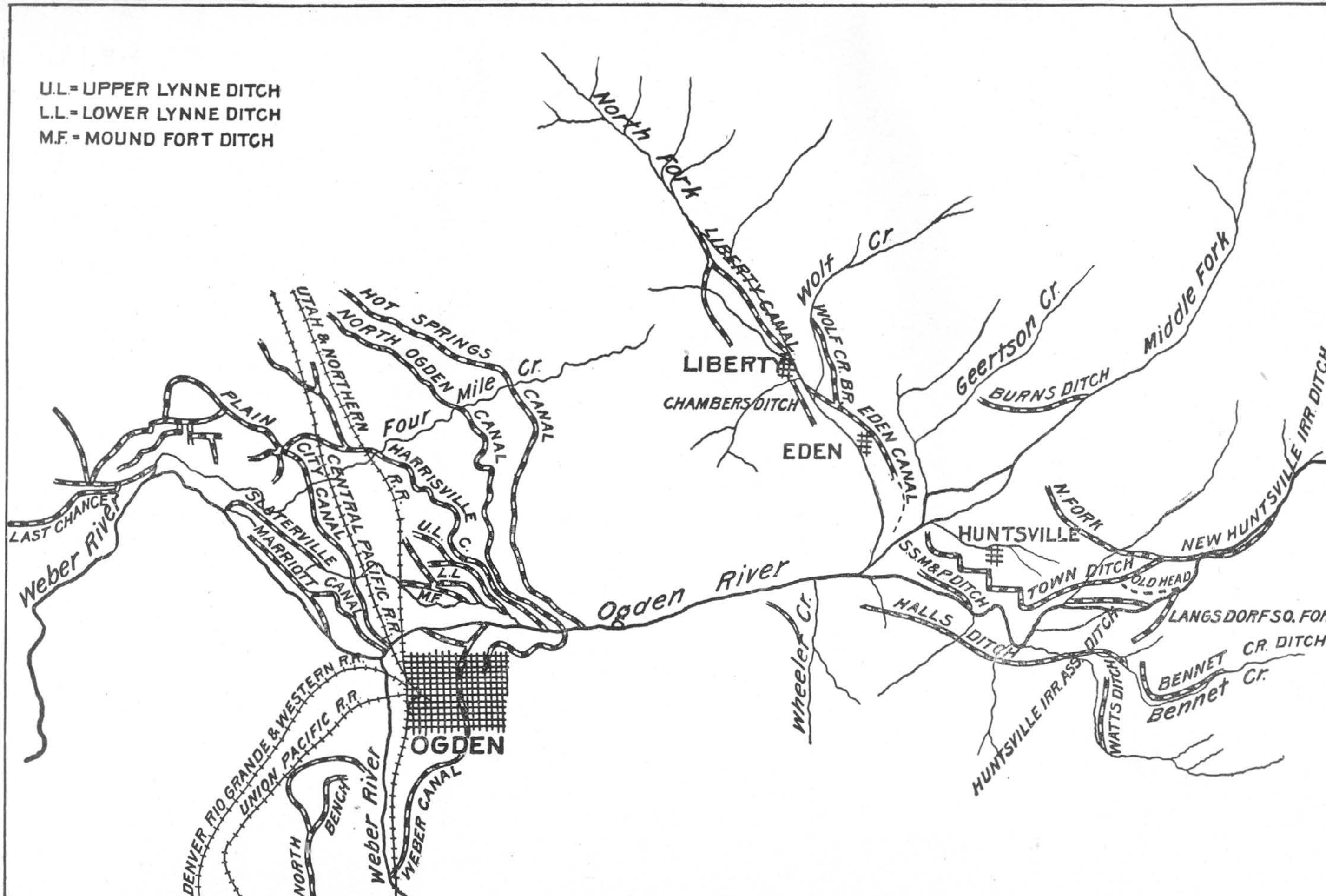


FIG. 13.—Diagram illustrating inflow and outflow of Ogden Valley.

A more detailed description of the measurements is to be found in a preliminary report on seepage water and the underflow of rivers,[1] published in 1895. The general facts are illustrated by the accompanying diagram, fig. 13, illustrating the inflow and outflow of Ogden

[1] Utah Agricultural Experiment Station Bulletin No. 38, by Samuel Fortier, hydraulic engineer, February, 1895.



MAP OF PRINCIPAL DITCHES FROM OGDEN RIVER.

Valley, and by the dotted line the amount used in irrigation. If no water returned by seepage or was added by percolation from the adjacent mountain lands, the outflow would be represented by the vertical distance between the dotted line representing the amount used in irrigation and the light line representing the inflow; but, as shown by the heavy line, the actual outflow is far greater than this, being larger at times than the inflow upon the corresponding dates.[1]

To be more certain that the ratio existing between the inflow and outflow of this valley was correctly determined in 1894, the writer sent Messrs. Rhead and Humphreys with a different current meter to make a similar test during 1896. The results obtained by them, given below, corroborate the records of 1894:

Results of measurements in Ogden Valley in 1896.

Date—1896.	Inflow in second-feet.	Volume used in irrigation.	Outflow in second-feet.	Seepage waters and private springs.
Aug. 20	91.6	106.5	101.1	116.0
25	86.0	99.2	99.5	112.7
30	78.7	89.4	97.4	108.1
Sept. 5	70.0	79.2	95.0	104.2
10	62.8	70.2	93.0	100.4
15	55.3	60.7	90.0	95.4
20	50.4	51.6	89.1	90.7

Some of the Ogden Valley canals, such as the Eden Canal, obtain a portion of their discharge from seepage waters, and this accounts for the fact that the aggregate volume used in irrigation exceeds the inflow.

[1] The public lands and their water supply, by F. H. Newell: Sixteenth Ann. Rept. U. S. Geol. Survey, Part II, 1895, p. 529.

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1895.

Sixteenth Annual Report of the United States Geological Survey, 1894–95, Part II, Papers of an economic character, 1895, octavo, 598 pp.

Contains a paper on the public lands and their water supply, by F. H. Newell, illustrated by a large map showing the relative extent and location of the vacant public lands; also a report on the water resources of a portion of the Great Plains, by Robert Ha

A geological reconnoissance of northwestern Wyoming, by George H. Eldridge, 1894, octavo, 72 pp. Bulletin No. 119 of the United States Geological Survey; price, 10 cents.

Contains a description of the geologic structure of portions of the Big Horn Range and Big Horn Basin, especially with reference to the coal fields, and remarks upon the water supply and agricultural possibilities.

Report of progress of the division of hydrography for the calendar year 1893–94, by F. H. Newell, 1895, octavo, 176 pp. Bulletin No. 131 of the United States Geological Survey; price, 15 cents.

Contains results of stream measurements at various points, mainly within the arid region, and records of wells in a number of counties in western Nebraska, western Kansas, and eastern Colorado.

1896.

Seventeenth Annual Report of the United States Geological Survey, 1895–96, Part II, Economic geology and hydrography, 1896, octavo, 864 pp.

Contains papers by G. K. Gilbert on the underground water of the Arkansas Valley in eastern Colorado; by Frank Leverett on the water resources of Illinois; and by N. H. Darton on a reconnoissance of the artesian areas of a portion of the Dakotas.

Artesian-well prospects in the Atlantic Coastal Plain region, by N. H. Darton, 1896, octavo, 230 pp., 19 plates. Bulletin No. 138 of the United States Geological Survey; price, 20 cents.

Gives a description of the geologic conditions of the coastal region from Long Island, N. Y., to Georgia, and contains data relating to many of the deep wells.

Report of progress of the division of hydrography for the calendar year 1895, by F. H. Newell, hydrographer in charge, 1896, octavo, 356 pp. Bulletin No. 140 of the United States Geological Survey; price, 25 cents.

Contains a description of the instruments and methods employed in measuring streams and the results of hydrographic investigations in various parts of the United States.

1897.

Eighteenth Annual Report of the United States Geological Survey, 1896–97, Part IV, Hydrography, 1897, octavo, — pp. (In preparation.)

Contains a progress report of stream measurements for the year 1896, by Arthur P. Davis, and four other papers relating to hydrography. The first of these is by Frank Leverett, and relates to the water resources of Ohio and Indiana, especially as obtained by wells; the next is by N. H. Darton, on the artesian waters of South Dakota, being supplementary to his paper in the Seventeenth Annual; following this is a fully illustrated paper, by James D. Schuyler, on water storage, mainly for irrigation and the construction of dams; the last paper, by Robert T. Hill, describes the artesian conditions of a portion of Texas in the vicinity of San Antonio.

Water Supply and Irrigation Papers.

This series of papers is designed to present in pamphlet form the results of stream measurements and of special investigations. A list of these, with other information, is given on the outside (or fourth) page of this cover.

Survey bulletins can be obtained only by prepayment of cost as noted above. Postage stamps, checks, and drafts can not be accepted. Money should be transmitted by postal money order or express order, made payable to the Director of the United States Geological Survey. Correspondence relating to the publications of the Survey should be addressed to **The Director, United States Geological Survey, Washington, D. C.**

WATER-SUPPLY AND IRRIGATION PAPERS.

1. Pumping water for irrigation, by Herbert M. Wilson, 1896.
2. Irrigation near Phœnix, Arizona, by Arthur P. Davis, 1897.
3. Sewage irrigation, by George W. Rafter, 1897.
4. A reconnoissance in southeastern Washington, by Israel C. Russell, 1897.
5. Irrigation practice on the Great Plains, by E. B. Cowgill, 1897.
6. Underground waters of southwestern Kansas, by Erasmus Haworth, 1897.
7. Seepage waters of northern Utah, by Samuel Fortier.
8. Windmills for irrigation, by E. C. Murphy.
9. Irrigation near Greeley, Colorado, by David Boyd.
10. Irrigation in Mesilla Valley, New Mexico, by F. C. Barker.
11. River heights for 1896, by Arthur P. Davis.
12. Water resources of southeastern Nebraska, by Nelson Horatio Darton.

In addition to the above, there are in various stages of preparation other papers relating to the measurement of streams, the storage of water, the amount available from underground sources, the efficiency of windmills, the cost of pumping, and other details relating to the methods of utilizing the water resources of the country. Provision has been made for printing these by the following clause in the sundry civil act making appropriations for the year 1896–97:

Provided, That hereafter the reports of the Geological Survey in relation to the gauging of streams and to the methods of utilizing the water resources may be printed in octavo form, not to exceed 100 pages in length and 5,000 copies in number; 1,000 copies of which shall be for the official use of the Geological Survey, 1,500 copies shall be delivered to the Senate, and 2,500 copies shall be delivered to the House of Representatives, for distribution. (Approved, June 11, 1896; Stat. L., vol. 29, p. 453.)

The maximum number of copies available for the use of the Geological Survey is 1,000. This quantity falls far short of the demand, so that it is impossible to supply all requests. Attempts are made to send these pamphlets to persons who have rendered assistance in their preparation through replies to schedules or donation of data. Requests specifying a certain paper and stating a reason for asking for it are attended to whenever practicable, but it is impossible to comply with general demands, such as to have all of the series sent indiscriminately.

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