A METHOD OF ESTIMATING GROUND-WATER SUPPLIES BASED ON DISCHARGE BY PLANTS AND EVAPORATION FROM SOIL

RESULTS OF INVESTIGATIONS IN ESCALANTE VALLEY, UTAH

By Walter N. White

ABSTRACT

Fluctuations of water levels in wells, if critically studied, may give much information as to the occurrence, movement, and quantity of available ground water. In some localities the ground-water level has been observed to decline during the day and to rise at night, the decline beginning at about the same hour every morning and the rise at about the same hour every night. This daily decline is due to the withdrawal of ground water from the zone of saturation by plants, and the rise at night is due to upward movement of water under slight artesian pressure from permeable beds of sand and gravel at some depth beneath the water table.

In practically every region a part of the water that is discharged by evaporation from the soil and by transpiration of plants is derived from ground water in the zone of saturation. In humid regions much ground water is discharged by evaporation and transpiration, but the recharge is generally so great that despite these losses the underground reservoirs overflow into the streams and maintain the stream discharge during much of the year. In arid regions the losses from evaporation and transpiration are high in comparison with the recharge, the ground water reservoirs seldom overflow into the streams, and the streams are dry most of the time. Throughout the western part of the United States there are many intermountain valleys that occupy closed rock basins or basins from which comparatively little water can escape either on the surface or underground. In such valleys under natural conditions the average annual ground-water recharge from precipitation on the valley and tributary mountains is about balanced by the average annual discharge by evaporation and transpiration from the areas of shallow ground water, usually located in the lowest parts of the valley, and a measurement of the quantity of ground water withdrawn by these processes may give a close approximation of the quantity of water that annually enters the underground reservoir. The water is largely lost so far as any benefit to man is concerned, but it can be in part reclaimed by means of wells. The amount that can be reclaimed represents the safe yield of the underground reservoir. This can be estimated if the natural discharge is known.

The climate of these valleys usually is arid or semiarid. The stream discharge is intermittent or ephemeral and very difficult to measure, and it is practically impossible to compute ground-water recharge therefrom. The discharge of ground water, consisting for the most part of evaporation and transpiration,

however, can be computed. This can be done from tank experiments such as were carried out by Lee [1] in Owens Valley—a method which may be fairly satisfactory as a basis for computing the discharge by evaporation but is slow where the transpiration of plants is under study. Moreover there are many varieties of ground-water plants, some of which it is difficult if not impossible to raise in tanks—large trees, for example.

A method of measuring discharge by transpiration that is directly applicable in fields of all kinds of plants using ground water is needed. Experiments to determine the feasibility of measuring the discharge by a method based on daily fluctuations of the water table were carried out by the writer in Escalante Valley, in southwestern Utah. This valley has an area of about 1,000 square miles, a length of about 90 miles, and a width ranging from 5 to 25 miles. It lies between two series of roughly parallel mountains and hills 6,000 to 10,000 feet high; the valley floor ranges in altitude from 4,800 to 5,500 feet. Ground-water recharge in this valley is derived chiefly from stream seepage on the outwash slopes at the mouths of mountain canyons. Nearly all the streams are intermittent or ephemeral. Under natural conditions the average annual recharge is balanced by an equal average annual discharge, most of which occurs by evaporation and transpiration within an area of about 200 square miles forming a strip of irregular width in the lowlands along the trough of the valley. The lands in some parts of this area are bare, but most of the area supports a growth of varying density of ground-water plants such as salt grass, tussock grass, rabbit brush, greasewood, shad scale, pickleweed, seep weed, sedges, and willows. Some sagebrush is also found. Cultivated crops, chiefly alfalfa, are raised on about 3,500 acres of the area, of which a part is irrigated from wells and a part is supplied by natural subirrigation with ground water from the zone of saturation.

Altogether about 75 shallow test wells were put down in this area of ground-water discharge in fields of all kinds of native ground-water plants and in fields of naturally subirrigated alfalfa. The area chiefly studied comprises about 32,000 acres in the vicinity of Milford. Fluctuations of water levels in these wells were measured regularly with a steel tape, and on most of them automatic water-stage recorders were maintained for varying lengths of time. As a check, test wells were put down and equipped with recorders in areas outside the valley, including Beaver Valley in the neighborhood of Beaver, Utah, and Snake Valley and Lake Valley, Nev. The records obtained from these observation wells show that during the growing season there is a marked daily fluctuation of the water table nearly everywhere in fields of ground-water plants. Usually the water starts down at 9 to 11 a. m. and reaches its lowest stage at 6 to 7 p. m. At 7 to 9 p. m. the water begins to rise and continues to rise until 7 to 9 a. m. the following morning. The maximum daily drawdown observed during the investigation amounted to about 1½ inches in greasewood and shad scale, 2½ inches in alfalfa, 3¾ inches in salt grass, and 4½ inches in sedges and associated marsh grasses. The fluctuations do not occur in plowed fields, cleared lands, tracts of sagebrush, and tracts where the water table is far below the surface. In general they begin with the appearance of foliage in the spring and cease after killing frosts. They cease or are materially reduced after the plants are cut. The water table rises sharply almost immediately after a rain in fields of ground-water plants during the growing season, even though the rain is light and affords no ground-water recharge. There is little or no rise of

[1] Lee, C. H., An intensive study of the water resources of a part of Owens Valley, Calif.: U. S. Geol. Survey Water-Supply Paper 294, pp. 51–60, 1912.

the water table after rains in cleared lands at any time or in fields of ground-water plants when plant life is dormant.

The problem of interpreting the fluctuations of the water table in terms of water used by the plants was approached in three ways. Cylinders were driven near observation wells so as to inclose columns of undisturbed soil in the zone in which the fluctuations take place, and the rise and fall of the water table in the inclosed columns after the addition or subtraction of measured amounts of water were carefully noted. From these experiments the specific yield of the soils was determined. The amount of ground water discharged daily by the plants was then computed by the formula $q=y(24r\pm s)$, in which q is the depth of ground water withdrawn, in inches, y is the specific yield of the soil in which the daily fluctuation of the water table takes place, r is the hourly rate of rise of the water table, in inches, from midnight to 4 a. m., and s is the net fall or rise of the water during the 24-hour period in inches. In field experiments the quantities on the right-hand side of the formula except the specific yield can be readily determined from the automatic records of water-table fluctuations.

Ground-water plants were raised in four tanks filled with soils of the types to which the plants are partial, provided with an automatic measured water supply, and otherwise equipped so as to duplicate as closely as possible conditions that exist in the field. A companion tank was provided for the vegetation tank to determine the discharge of ground water by evaporation alone; this tank was filled with bare soil of the same type as that in the corresponding vegetation tank, and the water table in it was maintained at similar depths. In this way the attempt was made to differentiate transpiration losses from evaporation losses. Daily fluctuations of the water table similar to those that occur in the field were obtained in the vegetation tanks. These fluctuations were correlated with the daily ground-water discharge as indicated by the measured water supply delivered to the tank. The amount of water required to produce a unit weight of dry vegetable matter in the tanks was computed, and the coefficient of ground-water discharge thereby obtained was applied to the field on the basis of dry weight of vegetable matter produced per unit area. Four water-surface evaporation pans were kept in operation in order to have a common basis for comparison, a determination being made of the ratio between all ground-water discharge disclosed by the tank experiments and water-surface evaporation for corresponding periods.

By means of these studies the amount of ground water discharged in fields of different kinds of ground-water plants was computed. As a final step the districts in the valley in which conditions are favorable for salvage of ground water by means of wells were mapped, and the areas of different kinds of ground-water plants were outlined. The computed coefficients of discharge were then applied to the different areas, and thereby estimates were reached as to the safe pumping yield in these districts.

INTRODUCTION

In most wells the water level fluctuates almost constantly. These fluctuations are due to many different causes, and if they are accurately recorded and critically studied they may give much definite information as to the occurrence, movement, and quantity of the ground water.

Seasonal fluctuations take place almost everywhere. These are due chiefly to the periodic character of the evaporation, including transpiration from plants. Heavy showers sometimes raise the water level by addition of rain to the ground water. The water level may be lowered as a result of pumping or the discharge of ground water by artesian wells. Some fluctuations are clearly due to variations in barometric pressure. In areas where the water table is within 2 or 3 feet of the surface minor changes in water level result from changes in temperature. Along seacoasts the water level in some wells rises and falls with the tides. It has been observed that passing railroad trains cause distinct fluctuations in certain wells near the tracks. Earthquakes may produce fluctuations of greater or lesser magnitude, which may result directly from the earth's tremors or indirectly from changes in pressure due to deformation in the earth's crust. Conditions sometimes exist underground that produce either periodic or irregular fluctuations of the water level by what is commonly known as geyser action. Fluctuations are produced by changes in stage or level in rivers or lakes. A large part of the fluctuations is a manifestation of a change in the ratio between the rate of ground-water supply or recharge and the rate of loss or discharge.

In some localities the ground-water level has been observed to decline during the day and to rise at night with clocklike regularity, the decline beginning at about the same hour every morning and the rise at about the same hour every night. In 1888 King [2] noted such fluctuations in certain shallow wells on low land adjoining the campus of Wisconsin University, which he attributed to changes in temperature. Daily fluctuations of the same character were noted by Prof. G. E. P. Smith, of the University of Arizona, in two wells in San Pedro Valley, Ariz., one in a forest of mesquite, the other in a grove of cottonwoods. Beginning in 1916 Professor Smith conducted a series of observations on these wells which demonstrated that the daily decline of the water table was due to withdrawal of ground water from the zone of saturation by the trees.[3]

There is some confusion in the mind of the average person as to the meaning of certain terms that appear repeatedly in the following pages. For the convenience of the reader who may not be familiar with these terms the definitions and explanations given by Meinzer [4] are abstracted below.

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[2] King, F. H., Observations and experiments on the fluctuations in the level and rate of movement of ground water on the Wisconsin Agricultural Experiment Station farm: U. S. Weather Bureau Bull. 5, 1892; Wisconsin Agr. Exper. Sta. Ann. Repts., 1889–1893.

[3] Described in an unpublished paper given before the Geological Society of Washington November 22, 1922.

[4] Meinzer, O. E., Occurrence of ground water in the United States, with a discussion of principles: U. S. Geol. Survey Water-Supply Paper 489, 1923.

The permeable rock materials that lie below a certain level are generally saturated with water. These saturated rocks are said to be in the zone of saturation, the upper surface of which is called the water table. The water in the zone of saturation is called ground water. If a well is sunk, it remains empty until it enters a saturated permeable bed—that is, until it enters the zone of saturation—then water flows into the well. If the rock through which the well passes is all permeable, the first water that is struck will stand in the well at about the level of the water table. If the rock overlying the bed in which the first water is struck is impermeable the water is generally under pressure that will raise it in the well to some point above the level at which it was struck. Such water is called artesian water, and the geologic structural feature in which it is confined is called an artesian basin.

In fine-grained material the earth is invariably moist for a distance of several feet above the water table. This condition is due to capillarity. The moist belt above the water table may be called the capillary fringe. The fringe is relatively thick in rock or soil that has small interstices, such as silt or clay loam, and relatively thin in substances that have larger interstices, such as coarse sand. Water in the capillary fringe may be called capillary water. A rock formation or stratum that will yield water in sufficient quantity to be of consequence as a source of supply is called an aquifer.

Evaporation is the principal process by which surface or subsurface water is converted to atmospheric water. Vegetal discharge of ground water is discharge through the physiologic functioning of plants. The water may be taken into the roots of the plants directly from the zone of saturation or from the capillary fringe, which in turn is supplied by the zone of saturation. It is discharged from the plants by the process of transpiration and becomes atmospheric water by evaporation from the surface of the leaves.

The specific yield of a rock or soil with respect to water is the ratio of (1) the volume of water which after being saturated it will yield by gravity to (2) its own volume.

Trees and other plants are lavish users of water. Experiments by the United States Department of Agriculture show that for various kinds of cultivated crops 500 to 1,000 pounds of water is required to produce a pound of dry matter. Observations by the United States Weather Bureau in an area of mountain slope near Wagonwheel Gap, Colo.,[5] show that the rate of run-off was materially higher after the timber was cut from the area than it was before. The rate of

[5] Bates, C. G., and Henry, A. J., Forest and stream-flow experiment at Wagonwheel Gap-Colo.: Monthly Weather Review Suppl. 30 (W. B. 946), pp. 62–66, 1928.

soil evaporation must have increased greatly with the exposure of the soils of the mountain slope to sunshine and wind, but this increase was less than the former losses from the forest by transpiration and by interception of precipitation.

Practically everywhere a part of the water that is discharged by evaporation from the soil and by transpiration of plants is derived from the zone of saturation. In humid regions much ground water is discharged by evaporation and transpiration, but the recharge is generally so great that, despite these losses, the underground reservoirs overflow into the streams and maintain the stream discharge during much of the year. In a report by Meinzer and Stearns [6] it is computed that the average annual recharge in the Pomperaug Basin, Conn., during a period of three years amounted to 15.58 inches, of which 6.21 inches evaporated either directly or through the agency of plants, 8.76 inches seeped into Pomperaug River and its tributaries, and 0.61 inch remained in storage in the zone of saturation.

Throughout the western part of the United States there are many intermountain valleys that occupy closed rock basins or basins from which comparatively little ground water can escape. In such valleys under natural conditions the average annual ground-water recharge from precipitation on the valley and tributary mountains is about balanced by the average annual discharge by evaporation and transpiration from the areas of shallow ground water, usually located in the lowest parts of the valley, and a measurement of the quantity of ground water withdrawn by these processes may give a close approximation of the quantity of water that annually enters the underground reservoir. The annual recharge of the ground water reservoirs in the aggregate is very great. The water is largely lost so far as any benefit to man is concerned, but it can in part be reclaimed by means of wells. It is improbable that all the water now lost by natural discharge in any of the ground-water reservoirs can be salvaged. The amount that can be reclaimed represents the safe yield of the reservoir.

Lee [7] seems to have been the first investigator to conclude that evaporation is not only measurable but is an accurate index of the available ground-water supply in valleys of the closed-basin type or those that are nearly closed so far as ground water is concerned.

A considerable part of the discharge of the Owens River and tributaries, on which Los Angeles in recent years has chiefly depended for its water supply, sinks into the gravel of Owens Valley

[6] Meinzer, O. E., and Stearns, N. D., A study of ground water in the Pomperaug Basin, Conn., with special reference to intake and discharge: U. S. Geol. Survey Water-Supply Paper 597, p. 142, 1929.

[7] Lee, C. H., An intensive study of the water resources of a part of Owens Valley, Calif.: U. S. Geol. Survey Water-Supply Paper 294, pp. 83–86, 1912.

and is dissipated by evaporation and transpiration from the shallow ground-water areas of the central valley flat. A small part of the discharge area consists of bare alkali flats, but the greater part of it supports a vigorous growth of salt grass.

Reduced to its simplest terms Lee's problem was to determine how many people in the city of Los Angeles could be supplied with water for each acre of salt grass and of bare alkali land in Owens Valley, it being assumed that the water lost from such land by transpiration and evaporation could be salvaged by putting in pumps and lowering the water table to a level below the zone of evaporation and the reach of the plant roots. He attacked his problem in two ways. First, measurements were made of the inflow of streams to the valley, and computations were made of the discharge of Owens River from the valley and the losses of water from the irrigated fields in the valley. The sum of the computed discharge and losses was subtracted from the measured inflow. The amount remaining was assumed to show the discharge by transpiration and evaporation from the salt-grass meadows and bare alkaline lands. Second, salt grass was grown in tanks in which the water table was maintained at different levels. The water supplied the tanks was carefully measured, and the coefficients of ground-water discharge thus obtained were applied to the entire area. The results obtained by the two methods were in close agreement and indicated total evaporation and transpiration losses between 68,000 and 83,000 acre-feet. This would be sufficient to supply more than 200,000 people with 300 gallons a day each.

There are not many valleys where ground water now lost by transpiration and evaporation has so high a potential value as in Owens Valley, but practically everywhere water has value for agricultural development. Just as in Owens Valley every acre of salt grass consumes water that would supply the domestic needs of several people in Los Angeles, so in many other valleys every acre of salt grass or other relatively worthless plants that use ground water consumes enough water to irrigate a fraction of an acre of valuable crops.

Lee's work in Owens Valley was a valuable contribution to ground-water hydrology. The tank method of determining the amount of ground water discharged by plants, however, is slow. Moreover, there are a great many varieties of plants that use ground water, and some of them—trees, for example—it is impracticable to raise in tanks. For these and other reasons a method that is directly applicable in fields of all kinds of ground-water plants is needed. The discovery of daily water-table fluctuations by Smith (p. 4) was made several years after the conclusion of the Owens Valley investigation. Smith had realized the need for a direct method of measuring plant discharge and was impressed with the possibility that such a method might be developed from the daily fluctuations in the water table. He had demonstrated that the fluctuations resulted from the withdrawal of ground water by the mesquite and cottonwood, and his findings seemed to show that the amount of the fluctuations was proportional to the amount of water withdrawn. However, it was clear that the fluctuations were the function of more than one variable and that the physical properties of the soil in which they took place had much to do with the amount of the daily rise and fall. He conceived the idea that the rise of the water table during the middle of the night, when the trees are transpiring little or no water, might give the key to the solution of a part of the problem.

Professor Smith's talk in Washington created considerable interest among geologists and engineers. There was nothing new in the idea that cottonwood and mesquite use ground water, but it was interesting indeed to learn that the water table responded unmistakably to the draft which they imposed on the underground reservoirs. Later he continued his investigations in fields of other kinds of ground-water plants.

Meanwhile O. E. Meinzer, geologist in charge of the ground-water division of the United States Geological Survey, devised methods of investigation for evaluating the daily fluctuations in terms of quantity of water. During the summer of 1923 Depue Falck and the writer made a soil and ground-water survey of Escalante Valley, in southwestern Utah, for the purpose of classifying public lands under the enlarged and stock-raising homestead acts. The investigation disclosed the fact that in a part of this valley near Milford alfalfa seed was being successfully produced without artificial irrigation, the plants being supplied with moisture from the zone of saturation by natural subirrigation. Mr. Meinzer saw the possibility of obtaining here a clue to daily water-table fluctuations based on known data as to the amount of water transpired by alfalfa. Largely on this account the valley was selected as a field for study.

The production of alfalfa by natural subirrigation is of particular interest in connection with the present discussion, and a description of it may not be out of place at this point. It was found that in certain localities in Escalante Valley where the mean depth to ground water during the growing season is not less than 5 feet or more than 15 feet and the soil down to the water table is a sandy loam or a clay loam, alfalfa will produce profitable crops of seed without irrigation or at the most with one watering early in the season. (See pl. 3, *A*.) The fact that the plant is able to develop its own water supply in shallow ground-water areas was discovered accidentally under circumstances described by the writer[8] in 1927, as follows:

The fact that ground water is capable of maintaining deep-rooted plants in areas of deficient rainfall is illustrated by agricultural operations in Escalante Valley, near Milford, Utah. There the production of alfalfa seed with moisture derived from ground water has apparently passed the experimental stage and reached one where a reasonable degree of financial success is assured. The industry has been developed as the result of the experience of one rancher, and the story is rather romantic. The rancher was poor, having lost practically all he had in a vain attempt at dry farming on a ranch about 5 miles south of Milford. A few head of mortgaged cattle remained, and in the spring of 1919 he was pasturing this stock on lands near his homestead, all of which had been abandoned and most of which had previously been settled by dry farmers. One of the tracts, the S. ½ sec. 31, T. 28 S., R. 10 W., owned by the Beaver County Irrigation Co., had been irrigated and planted to alfalfa during the season of 1917 and then abandoned as a result of loss by the company of its water right in Beaver River by an adverse court decision promulgated in the winter of 1917–18. The rancher noticed to his surprise that a scattering growth of alfalfa among the greasewood and weeds, with which this half section was now covered, was increasing in thickness and vigor, although not a drop of water had been applied to the land in nearly two years. He decided that the alfalfa would provide considerable pasturage for his stock, and accordingly in the spring of 1919 he leased the tract from the company for two years, the consideration being that he was to keep the fence in repair. During the summer of 1919 he partly removed the greasewood and weeds from the land and grazed it sparingly, and in the fall he cut the alfalfa and obtained a crop of seed which sold for $3,000. In the following year the seed crop brought about $5,000. All this was accomplished with comparatively little cash outlay or labor, and in the brief period of two years the rancher rose from poverty to a state of comparative prosperity. This experience created considerable excitement, and the reputation of section 31 was established throughout southwestern Utah, thereby creating a considerable boom for the Milford district. The prospect of obtaining a highly profitable crop without artificial irrigation or at least without irrigation after the crop was started was an attractive one. It was clear to all that the alfalfa in section 31 owed its life to the fact that the roots penetrated to the water table. However, it was also clear that if agricultural operations of this kind were to be extended, the alfalfa must be irrigated during the period while it was getting its start and its roots were penetrating to ground water. No surface water was available, and accordingly pumping from wells was resorted to.

During 1919 and 1920 six pumping plants were installed in the locality, and there has been a slow but steady pumping-plant development ever since. In 1923 there were 20 pumping plants in operation and about 900 acres in alfalfa which had been started by irrigation from these plants. In that year about 600 acres was irrigated from these plants, but the remaining 300 acres was not irrigated because the alfalfa had reached ground water and was able to subsist without artificial irrigation. This subirrigated acreage does not include the 240 acres of alfalfa-seed land in section 31, in which the alfalfa got its start from one season of surface irrigation in 1917.

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[8] White, W. N., in Meinzer, O. E., Plants as indicators of ground water: U. S. Geol. Survey Water-Supply Paper 577, pp. 89–91, 1927.

The reported yields of alfalfa seed from the S. ½ sec. 31 in the period 1920 to 1923 are 272 bushels from 240 acres in 1920, 600 bushels from 240 acres in 1921, 701 bushels from 160 acres in 1922, and 700 bushels (estimated) from 160 acres in 1923. Comparable yields were reported from other nonirrigated alfalfa-seed lands in the vicinity.

In 1923 the lands devoted to this industry were located within an area about 3 miles long and 1 mile wide, the center of which is about 4 miles south of Milford, near the township corner common to Tps. 28 and 29 S., Rs. 10 and 11 W. The area lies on the lowermost slopes of the Beaver River delta, slightly to the east of the trough of Escalante Valley and 10 to 15 feet above the lowest lands in the valley. It ranges from 4,970 to 5,010 feet above sea level and slopes to the northwest with gradients ranging from 10 to 15 feet to the mile. Measurements of about 15 fairly evenly spaced wells in this area in the fall of 1923 showed depths to water ranging from 9 to 15 feet. The water table rises 1½ to 2½ feet in the late winter and early spring. On lands where natural subirrigation has proved feasible the soil and subsoil down to the water table is a dark-gray clay loam or sandy loam and a black loam derived largely from decomposed peat. Attempts to extend the cultivation of subirrigated alfalfa to adjoining areas where the subsoil is gravelly have not proved successful, although the depths to ground water in these areas are no greater than in the area where success has been attained.

Sagebrush forms the dominant vegetation, but unused lands cleared of sagebrush several years ago now carry a fairly vigorous growth of greasewood. A series of tests with the electrolytic bridge in the area shows that the soil does not contain excessive amounts of alkali, though the alkali content is near the danger line for young alfalfa, the average for 10 tests of soil to a depth of 5 feet being 0.39 per cent.

Figure 15 [not here reproduced] shows the root system of an alfalfa plant in a field near Milford that is naturally subirrigated. The soil penetrated by this root system to a depth of 8½ feet is a gray clay loam and black peaty loam. Below this depth it consists of coarse sand and gravel. During a part of the growing season a considerable portion of the root system is below the water table. In the spring and early part of the summer, when the water table is at depths less than 8½ feet, the growth of alfalfa plants in the immediate vicinity is rapid and vigorous. Later in the season, however, the water table drops into the gravel, and then the plants assume a withered appearance and do not make much more growth.

The Escalante Valley studies had a threefold purpose—(1) the investigation of daily fluctuations of the water table in fields of many kinds of plants that used ground water, (2) the interpretation of the fluctuations in terms of quantity of water used by the plants, (3) the use of the information as a basis for estimating the amount of the available ground-water supplies. About 75 test wells were put down in the valley and were equipped for a time with automatic water-stage recorders. As a check a few test wells were put down and studied in several near-by valleys in Utah and Nevada. An experiment station was established in the valley near Milford and equipped with a maximum and minimum thermometer, a rain gage, an anemometer, evaporation pans, and soil and vegetation tanks. The investigation occupied the fall and about half of the summer of

1925 and the whole of the seasons of plant growth in 1926 and 1927. Some work also was done during the winter of 1925–26. A summary of the results of the investigation in 1925 and 1926 was mimeographed and released during the summer of 1927. The present report was released in manuscript form in 1930.

The writer is indebted to O. E. Meinzer, under whose direction the work was planned and carried out, for unfailing good advice and counsel, to Herman Stabler, also of the Geological Survey, whose interest and suggestions contributed materially, and to Richard Ela, who helped with the field work in 1925 and 1926. Thanks are due to the citizens of Milford for their friendly support of the work, particularly to Mr. W. H. Hendrickson, Mr. Henry Bowman, Dr. C. R. Parrish, and others who cordially gave free use of their lands for the experiments.

GENERAL FEATURES OF ESCALANTE VALLEY

TOPOGRAPHY

Escalante Valley, which was chosen as the field for this investigation, covers an area of about 1,000 square miles. It has a length of about 90 miles in a northeast-southwest direction and a width ranging from 5 to 25 miles. (See fig. 1.) It lies in a trough between two series of roughly parallel mountain ranges and hills. The Mineral Mountains, which form a part of the east boundary, are the highest of these ranges and reach altitudes of about 10,000 feet. The Iron Mountains, along the east boundary, probably have a mean altitude of about 6,500 feet. The ranges on the west side of the valley include the San Francisco Mountains, with one peak reaching 9,725 feet, but for the most part are comparatively low. The valley floor has an altitude ranging from about 4,800 to about 5,500 feet. It slopes gently to the northeast, and the average gradient along the valley trough is only about 4½ feet to the mile. The potential drainage basin of the valley comprises an area of nearly 3,000 square miles, including about 1,000 square miles of valley land and nearly 2,000 square miles of tributary mountainous country. The valley is the most southerly of a series of valleys extending from the basin of Great Salt Lake into western and southwestern Utah that during Pleistocene time were covered by a great inland sea, now referred to as Lake Bonneville. The shore line of this ancient lake followed closely the 5,200-foot contour, and the lake covered about 800 square miles in the Escalante Valley. During the period of inundation the valley trough was partly filled by water-borne débris. Since the lake subsided the surface of the valley has scarcely changed except for minor modifications produced by wind action and stream erosion and some encroachment by fans of modern streams. The central valley floor is flat except for a few sand dunes.

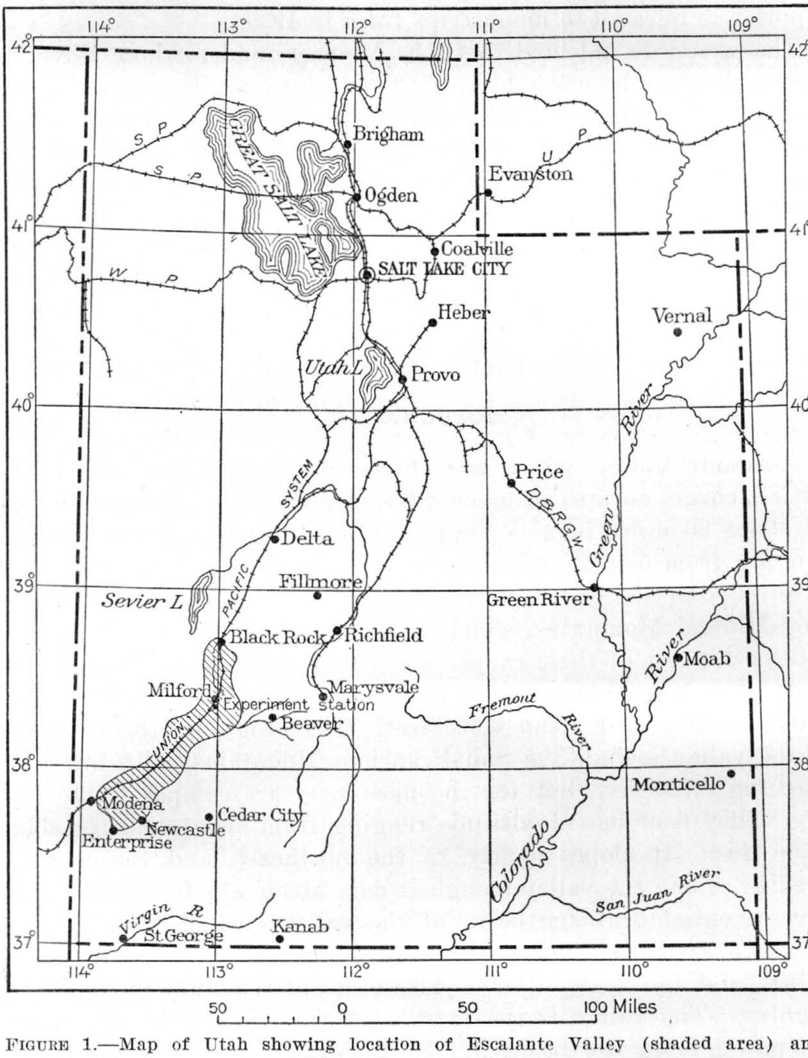

FIGURE 1.—Map of Utah showing location of Escalante Valley (shaded area) and Milford experiment station

The depth of the valley fill has not been determined, although several wells have been drilled to depths of 400 to 500 feet and one well near Milford is said to have attained a depth of 1,000 feet without reaching bedrock. The logs of these wells show the materials of the fill to be unconsolidated sediments consisting of clay, sand, and gravel. The records show that in some places the gravel is coarse, ranging from the size of a pea up to that of a cobblestone. These materials apparently were deposited during a period when the rainfall was much heavier than now and torrential streams of considerable magnitude entered the valley from both sides and dropped their suspended loads beneath the water of Lake Bonneville. In some localities fossil deltas of these streams reach far out into the valley.

PRECIPITATION

The climate of Escalante Valley is arid. According to records of the United States Weather Bureau (Table 1) the average precipitation during 19 years at Milford was 9.18 inches; at Black Rock, near the north end of the valley, the average for 23 years was 9.25 inches; at Modena, at the south end, the average for 26 years was 11.50 inches; at Nada, near the center of the valley, the average for 9 years was 12.08 inches; at Minersville, at the base of the hills, 11 miles southeast of Milford, the average for 24 years was 11.04 inches; at Frisco, on the lower slopes of the San Francisco Mountains, 1,000 feet higher than Milford, the average for 13 years was 8.26 inches; at Enterprise, at the foot of the Iron Mountains, the average for 14 years was 16.95 inches; and at Pinto, in the Iron Mountains about 10 miles back from the valley, the average for 26 years was 15.44 inches.

Rain gages were maintained for periods of several months each in 1925 and 1926 at various points in the adjacent mountains 800 to 1,200 feet above the valley floor. The records of precipitation thereby obtained cover too short a period to have much value. They tend to show, however, that the greater part of the mountain area receives very little more rain than the valley itself. Exception to this rule was found at altitudes above 6,500 feet in the Iron Mountains, adjoining the southeast extremity of the valley, where the average depth of rainfall from about a dozen spring, summer, and fall showers was 25 per cent higher than the average recorded for the same showers on the valley floor at Enterprise and 70 per cent above the average at Modena. Apparently there is a total area of about 50 square miles in the Iron Mountains that has the higher rate of precipitation. Other mountain areas bordering the valley at altitudes above 7,500 feet probably receive considerably more rainfall than the valley, but the total of such areas probably does not exceed 25 or 30 square miles. The testimony of residents of the valley indicates that the snowfall is heavy in parts of the Iron Mountains and at the crests of a few of the higher mountains in other ranges but that elsewhere it is little if any heavier than that on the floor of the valley.

From this rather meager information it is estimated that the average annual precipitation on the mountain areas encircling the valley is less than 15 inches and may not exceed 12 or 13 inches. This estimate is borne out by the appearance of most of the mountain slopes, which either are bare or support only a growth of sagebrush, piñon, and juniper, the characteristic mountain vegetation of desert regions, whereas in the relatively small area of higher rainfall in the Iron Mountains and adjacent ranges and on the higher peaks and ridges in the Mineral and San Francisco Mountains yellow pine, spruce, fir, and scrub oak are found.

The above conclusions as to the amount of precipitation on the mountain areas relates only to the mountains that are more or less closely adjacent to the valley. The Escalante drainage basin includes the west slopes of the Tushar Mountains, lying from 30 to 50 miles east of the valley. These mountains reach altitudes of more than 12,000 feet and receive much more moisture than the ranges bordering the valley. The run-off from that region reaches the valley through the Beaver River.

STREAM DISCHARGE

Only four perennial streams enter the valley. These are the Beaver River, Shoal Creek, Pinto Creek, and Meadow Creek. The Beaver River, which is by far the largest stream, drains the west slopes of the Tushar Mountains and formerly carried a large amount of water into the valley. The normal flow of the stream is now diverted and used for irrigation in the upper part of Beaver Valley, and the winter flow, the flood discharge, and the return water from irrigation in Beaver Valley are stored in a reservoir in Minersville Canyon, where the river has cut through the Mineral Mountains to reach the Escalante Valley. The water thereby conserved is used for irrigation at Minersville and on valley lands east and southeast of Milford.

Shoal, Meadow, and Pinto Creeks drain the area of more than average precipitation in the Iron Mountains and associated ranges.

Three gaging stations are maintained on the Beaver River by the United States Geological Survey in cooperation with the State of Utah. One is just below the Minersville Reservoir, and the records obtained there show that the average annual discharge of the river amounted to 33,000 acre-feet during the 14-year period 1913 to 1926. No gaging stations have been maintained on the three other perennial streams mentioned. A few current-meter measurements were made by the Geological Survey on Pinto Creek and Shoal Creek during the decade preceding the investigation, and several measurements of these streams and of Meadow Creek were made in 1925 and 1926 by the writer. Some information was obtained on the ratio of run-off to rainfall in the mountains at the headwaters of Shoal Creek, a part of the area mentioned as receiving exceptionally heavy precipitation. Two reservoirs with bedrock dams have been constructed on Shoal Creek to impound the run-off from about 30 square miles of this area. During a period of about two months in 1925 and five months in 1926 measurements of the rainfall were made at two points in the mountains above the reservoirs, and the inflow to the reservoirs resulting from these rains was recorded. These observations indicate that the ratio of run-off to rainfall above the reservoirs ranges from 0 to 3 per cent in the summer and fall, when the weather is warm and the soils dry, and from 15 to 25 per cent in the spring, when the weather is cool and the soils moist. According to figures on reservoir storage furnished by the owners the average annual run-off from the drainage area above the reservoirs amounts to about 2 inches in depth, or about 10 per cent of the precipitation.

From the fragmentary data available it appears that the normal combined flow of Pinto, Meadow, and Shoal Creeks ranges from 5 to 10 second-feet. In addition to this amount is the flood discharge that may follow torrential summer rains and melting of the snows in spring. The amount of the flood discharge varies within wide limits. In some years there are a dozen or more floods of varying magnitude and length. In other years there are only a few runs of storm water, and in exceptionally dry years the discharge of flood water is practically negligible. From measurements of inflow to the Shoal Creek reservoirs and information as to the magnitude and length of floods on Pinto and Meadow Creeks, it is estimated that the total combined flow of the three streams amounted to about 6,000 acre-feet in 1926. The run-off that year was about average, according to owners of the Shoal Creek reservoirs, one of which has been in operation for 30 years.

All other streams entering Escalante Valley are intermittent or ephemeral. There are hundreds of them, and they drain areas ranging from a few acres to 100 square miles or more. Many have no discharge for periods of months or even years. When a flow occurs it usually is brief, often lasting for only an hour or two or even for only a few minutes, although the discharge may be violent while it lasts. Under such conditions it is difficult to measure the run-off and practically impossible to compute the resulting ground-water recharge.

GROUND-WATER CONDITIONS

A preliminary investigation by the Los Angeles & Salt Lake Railroad Co. prior to constructing its road through the Escalante Valley about 1903 disclosed only two permanent sources of water suitable for engine use within a reasonable distance from its right of way, one a spring having a flow of about 1 second-foot issuing from the lavas near Black Rock, at the north extremity of the valley, and the other Desert Spring, with a flow of a few miner's inches, in the hills near Modena, at the south end.

Black Rock and Modena are about 90 miles apart. The railway company needed a water supply at several intermediate points in this stretch and in order to obtain it resorted to well drilling. In the period 1903 to 1906 the company drilled 6 deep wells along its right of way—3 at Milford, 310 to 400 feet deep, 1 at Thermo, 400 feet deep, 1 at Lund, 585 feet deep, and 1 at Beryl, 208 feet deep. The wells at Milford had a small artesian flow when they were not pumped. The depth to water at Lund was 6 feet, at Thermo, 18 feet, and at Beryl, 19 feet. All these wells yield fair supplies of water suitable for boiler use. During the period 1903 to 1910 about a dozen artesian wells 300 to 400 feet deep and one 700 feet deep were sunk by the town of Milford and by private interests in and around Milford, and about 20 small domestic artesian wells were put down in the trough of the valley between Milford and Black Rock. Besides the railway wells at Lund and Beryl one other deep well was put down in the southern part of the valley. This is the Webster well, just east of the base of the Table Buttes and about 10 miles south of Lund, in a barren waste of sand dunes and alkali flats many miles from any habitation. Statements concerning it disagree, the reported depth ranging from 160 to 300 feet.[9] The well has a flow of a few quarts a minute.

During a period extending from 1909 to 1915 a large number of settlers entered the valley and established homes with the intention of developing dry farms. Their efforts at farming were fruitless, but the well drilling they undertook has produced much information concerning the occurrence of ground water in the valley. Several hundred domestic wells were put down in the area. From the records of well drillers and measurements of water levels in about 200 of these wells the position of the water table was determined. (See pl. 1.)

Irrigation from wells was begun about 1919 and down to 1927 about 75 wells were put down and equipped with pumping plants, of which about three-fourths are in the Milford district. (See pl. 1.) Most of the irrigation wells are less than 100 feet deep, and a few are less than 50 feet deep. One group of six wells in the Beryl district in secs. 3 and 10, T. 35 S., R. 15 W., are around 400 feet deep.

[9] Meinzer, O. E., Ground water in Juab, Millard, and Iron Counties, Utah: U. S. Geol. Survey Water-Supply Paper 277, p. 153, 1911.

An area of about 560 square miles extending the full length of the valley is underlain by ground water at depths less than 50 feet. In about 380 square miles of this area the ground water is at depths less than 30 feet, and in 200 square miles it is at depths less than 15 feet. In an area of about 30 square miles at the north end of the valley artesian water occurs under sufficient head to rise to the surface, and in an area immediately west of Table Buttes near the south end of the valley thus far undeveloped except for the Webster well, already mentioned, there is some promise of obtaining flowing wells.

VEGETATION

On the foothills and low mountain slopes there is a growth of junipers and scattered piñon, together with small black sage, little rabbit brush, and shad scale. The upper parts of the valley slopes have a vegetation not greatly different except that there are no trees. On the lower parts of the valley slopes the vegetation is largely sagebrush (*Artemisia tridentata*) reaching a height of 3 or 4 feet. The lands in the area of ground-water discharge along the valley trough, comprising altogether about 200 square miles, are covered by alkali-resistant plants, such as greasewood (*Sarcobatus vermiculatus*), shad scale (two species), salt grass (*Distichlis spicata*), tussock grass (*Sporobolus airoides*), pickleweed (*Allenrolfea occidentalis*), and seep weed (*Dondia moquinii*).

Five types of lands are shown on the map (pl. 1) from a somewhat rough classification made in the course of a reconnaissance investigation by Depue Falck, of the Geological Survey, with some assistance by the writer. This classification is based in part on the alkali content and physical characteristics of the soil but principally on the vegetative cover. It is therefore a vegetation map as well as a land-classification map. Class B land is found on the higher parts of the valley slopes where the dominant growth is small black sage, little rabbit brush, and shad scale. This is a loam soil free from alkali. Class E land includes the sand hills and other sandy lands in the southern part of the valley. In some places these sandy lands are practically bare of vegetation, but in others they support a growth of sagebrush or rabbit brush, the latter usually larger than the rabbit brush on the class B lands. Class A land is characterized by a dominant growth of medium to large sagebrush. Its soil has a texture similar to that of class B land, but in places it contains considerably more humus. This difference is particularly noticeable in the Milford district, where the class A land has a gray to black loam soil that contains a high percentage of organic matter and is materially richer than the near-by class B land. Class C land, which lies in the low parts of the valley, has a soil consisting of heavy clay or clay loam and a dominant vegetation of greasewood or shad scale. Class D land, which lies in the lowest parts of the valley, is in general highly alkaline. In places these lowlands support a growth of greasewood and shad scale not greatly different from that on class C land, but the greasewood is usually less vigorous. The type nearly everywhere can be distinguished from class C land either by the dwarfed character of the greasewood or by the occurrence of salt grass, tussock grass, seep weed, or pickleweed associated with the greasewood and shad scale. In the Milford area a part of the class D land consists of salt-grass meadows carrying a light to heavy growth of salt grass or of salt grass associated with tussock grass.

PLANTS AS INDICATORS OF ALKALI

In order to determine the relation between the alkali content of the soils and the vegetation cover about 50 tests were made by Mr. Falck in the field with the Wheatstone bridge, and a few samples of soil were analyzed in the laboratory to determine the nature of the salts. From these data the following table showing the relation between vegetation and the alkali in the soil has been compiled:

Relation of vegetation to alkali in the soil in Escalante Valley, Utah

Dominant vegetation	Total alkali in soil (per cent by weight)			
	First foot	Second foot	Third foot	Fourth foot
Sagebrush	0.07	0.14	0.12	0.22
Greasewood	.54	.70	.90	.78
Shad scale	.26	.46	.91	.71
Pickleweed, seep weed, or salt grass	1.33	1.30	1.62	1.62

This table indicates that under average conditions in the valley sagebrush grows where the soil is practically free from alkali. Where shad scale predominates with greasewood secondary in shallow ground-water areas the upper foot or two is for the most part relatively free from harmful amounts of alkali, but heavier concentrations are found at greater depths. On the higher slopes shad scale is not an indicator of heavy alkali content. Greasewood indicates generally the occurrence of harmful amounts of alkali at all depths. Pickleweed and seep weed indicate heavily alkaline land. The range covered by salt grass is somewhat greater, but its presence is a sign of considerable alkali.

AGRICULTURAL UTILITY

The aridity of the Escalante Valley prevents the successful production of crops by dry farming—a fact which has been thoroughly demonstrated by the failure of several hundred homesteaders who settled there with the hope of making a livelihood in that way—but crops can be raised in the valley by irrigation if water can be made available.

About 1914 to 1916 the United States Department of Agriculture and the Utah Agricultural Experiment Station undertook a cooperative investigation to determine the possibilities of producing crops in the valley by irrigation. This investigation demonstrated that on lands of the type designated class B on the accompanying map alfalfa, potatoes, wheat, oats, barley, corn, sorghum maize, feterita, and garden truck could be successfully produced by irrigation with water from wells. Crops planted on class C land were a failure, the seeds for some reason failing to germinate. The ability of class A land to yield good crops by irrigation or natural subirrigation has been conclusively demonstrated in the Milford district (p. 10). Class D land contains too much alkali for any crops and therefore is worthless for farming. Class E land because of its sandy character may properly be classed as waste land. The total areas of the different types of land are as follows: Class A, 72,500 acres; class B, 27,700 acres; class C, 70,100 acres; class D, 25,500 acres; class E, 18,200 acres.

MILFORD DISTRICT

The Beaver River breaks through the Mineral Mountains from the east and enters the Escalante Valley at Minersville, about 11 miles southeast of Milford. It is the valley's only noteworthy stream and is by far its largest single source of ground-water supply. The area of ground-water discharge chiefly studied is that occupying the trough of the valley in a section which is believed to derive most of its ground water from this source. (See fig. 2.) It comprises a relatively narrow strip ranging in width from 1 to 4 miles and embracing about 32,000 acres. In this report the area is referred to as the Milford district. Cultivated crops consisting chiefly of alfalfa are raised on about 3,500 acres, of which a part is irrigated with water from wells and a part has not been irrigated for several years, being supplied by natural subirrigation with water from the zone of saturation. Most of the area of ground-water discharge is not cultivated and supports a growth of varying density of native plants, nearly all of which are habitual ground-water users. In the lower lands these plants include salt grass, alkali sacaton, sedges, and associated flat-bladed marsh grasses, seep weed, and ink weed. On the higher lands they include greasewood, rabbit brush, shad scale, and some sagebrush.

INVESTIGATION OF FLUCTUATIONS OF THE WATER TABLE

METHOD OF INVESTIGATION

OBSERVATION WELLS

As the initial step in the investigation, early in July, 1925, four wells were dug to the water table near Milford. One was sunk at the

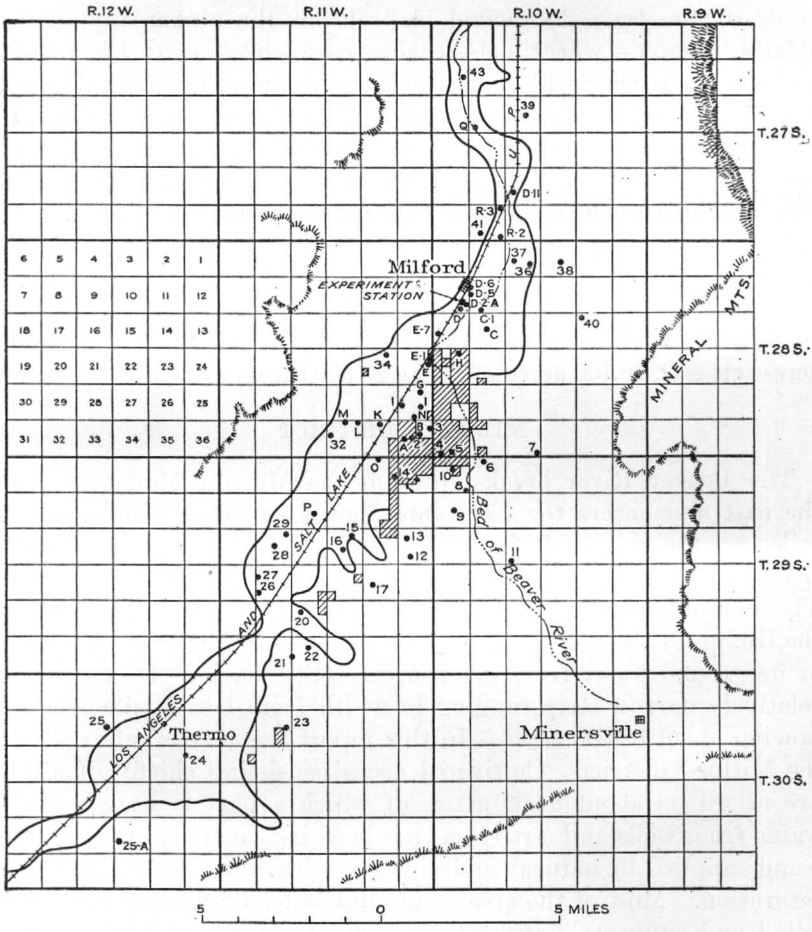

FIGURE 2.—Map of the vicinity of Milford, Utah, showing outline of area of ground-water discharge, part of the observation wells, and cultivated lands (cross hatched) that are irrigated or naturally subirrigated

center of a 40-acre field of vigorously growing alfalfa that had not been irrigated for three years and obviously was drawing water from the zone of saturation. A second was put down in cleared land adjoining the alfalfa field, where there was no vegetation except a scattering growth of Russian thistle and other shallow-rooted weeds.

A third was placed in the midst of a growth of greasewood mixed with some rabbit brush and shad scale. The fourth was put down in a field carrying an association of shad scale and greasewood. These wells and a privately owned shallow well in a salt-grass meadow were measured daily in the early morning and late evening with a steel tape, and it was at once found that all the wells except the one on the cleared land showed a decline during the day and a rise at night. The well in the cleared field displayed a slowly declining water table, with no rise either day or night. These first few measurements were encouraging, for they seemed to indicate that the investigation was on the right track. A little later three automatic water-stage recorders were placed over the wells, and continuous records of water-table fluctuation were obtained that disclosed many interesting features.

A program was accordingly laid out for putting down a large number of observation wells in fields of all types of vegetation and in cleared fields in the area of shallow ground water in the Milford district, together with a considerable number in shallow-water areas in other parts of the Escalante Valley and a few in valleys of similar character in Utah and Nevada. This plan was carried out during the fall of 1925 and the summers of 1926 and 1927. Altogether about 90 test wells were put down, and most of them were equipped for a time with automatic water-stage recorders.

With the exception of the dug wells above mentioned the observation wells were all put down with a hand auger, the Cabusco auger being used for most of them. This auger is equipped with a pan that fits closely over the top of the cutting blades and effectually brings up all loose sand and earth. The auger used had a diameter of 8½ inches and was provided with an adjustable handle capable of being extended to a length of 25 feet. Most of the holes were sunk to a level 2 to 4 feet below the water table. The holes were not cased, the material nearly everywhere being sufficiently consolidated to stand without support.

Quicksand was encountered in a few of the borings and flowed into the hole as fast as it could be removed by the auger. Such holes had to be abandoned. In some localities beds of dry gravel of considerable thickness stopped the auger before the water table was reached. When this happened, however, it was usually possible to penetrate to water by shifting the bore hole a few feet. The auger-hole explorations disclosed the fact that lands occupied by greasewood are usually underlain by caliche or cemented clay ranging in thickness from a few inches to 2 or 3 feet. This hard material, usually found just above the water table, stopped the auger and prevented the successful completion of a considerable number of holes. Nearly all the wells were put down in areas where the mean depth to water during the growing season is less than 10 feet.

Fluctuations of water level in these wells were measured regularly with a steel tape, and on most of the wells automatic water-stage recorders constructed to register to natural scale were maintained for varying periods. The location of most of the wells in the Milford district on which recorders were installed and maintained for periods of considerable length during the investigation is shown on Figure 2.

AUTOMATIC WATER-STAGE RECORDERS

The use of automatic water-stage recorders for registering fluctuations in ground-water levels was an outstanding feature of the Escalante Valley work. The results show that the instrument is as well adapted for use on wells as it is for gaging streams, canals, and reservoirs. The 7-day drum-type recorder (pl. 2, *A*) was used for most of the work. The essential parts of this instrument are an 8-day clock, a pen, pen carriage, and carriage track, a spiral drive shaft, a metal drum around which a record sheet is tightly wrapped, a sprocket wheel, a perforated metal tape, a float, and a counterweight. The clock, drum, and sprocket wheel together with the pen carriage and its accessories are mounted on a rigid base; the drum and sprocket wheel are supported on horizontal axes so as to turn with very little friction and are provided with an arrangement whereby the two can be readily engaged or disengaged. The pen carriage, drive shaft, and carriage track are mounted in a horizontal position parallel to the drum. The instrument is placed over the well, and the float is lowered to the water. The perforated tape is then looped over the sprocket wheel, the float is connected with one end of it, and a counterweight is attached to the opposite end. A very small fluctuation in the water level causes the float to rise or fall, and the movement, being communicated by the tape and sprocket wheel, causes the drum to revolve. Meanwhile, the pen is propelled by the clock horizontally across the face of the drum and the encircling record sheet. The graph thus recorded is the product of the up-and-down movement of the water level and the horizontal movement of the pen. The instruments that were used are constructed to record to natural scale—that is, the sprocket wheel is on the same shaft and has the same diameter as the drum, and therefore the rise or fall displayed by the graph is equal to the rise or fall of the float. The horizontal scale is 1 inch in 24 hours. A grid of horizontal and vertical lines subdivides the record sheet into vertical spaces representing 0.01 foot and horizontal spaces representing 2 hours each.

The floats used in the work were made of copper or galvanized metal and ranged from 5 to 24 inches in diameter. The instruments installed over the dug wells were equipped with 24-inch floats, the area of water surface in these wells being large. Many of the auger-hole wells (original diameter 8.5 inches) were reamed out until they had a diameter of about a foot, and on these wells 7 and 8 inch floats were used. Floats 5 and 6 inches in diameter were used on the unchanged auger holes, care being taken to place the recorder so that the float would not be in contact with the sides of the hole. When used with the 24-inch floats the instruments were found to be exceedingly sensitive to every movement of the water table. They were not quite so sensitive when the 7 and 8 inch floats were used, but the difference was so small that it could scarcely be detected. Some records obtained with the 6-inch floats were good, and others were rather poor, the graph having in places a stair-step appearance, indicating that the movement of the drum was spasmodic and lagged behind the movement of the water table. The 5-inch floats were found to be unsatisfactory, the graphs obtained with them generally having a stair-step shape.

Three of the automatic recorders were put in operation near Milford in 1925. In 1926 four were used, and in 1927 the number was increased to six. Plate 2, *B*, shows a typical installation over a well in a field of greasewood, with the instrument housed in a small wooden box.

DAILY FLUCTUATIONS

GENERAL CHARACTER

The records obtained from the observation wells with these recorders show that during the growing season there is a marked daily fluctuation of the water table nearly everywhere in fields of ground-water plants. The water table generally goes down during the daytime, when transpiration is rapid. Usually the water starts down at 9 to 11 a. m. and reaches its lowest stage at 6 to 7 p. m. At 7 to 9 p. m. the water begins to rise, and it continues to rise until 7 to 9 the next morning. As a rule the daily drawdown is somewhat greater than the nightly recovery, the deficiency in recovery indicating the rate of seasonal decline of the water table. In general the daily fluctuations begin in the spring with the appearance of foliage and cease in the fall after killing frosts. They do not occur in plowed fields, cleared lands, tracts of sagebrush, and areas where the water table is far below the surface. Generally the daily fluctuations vary directly with the temperature, wind movement, and intensity of sunlight and inversely with the humidity, and they follow more or less closely the daily fluctuations in evaporation from a free water surface. They are also affected somewhat by changes in barometric pressure. Usually the greatest drawdown occurs on hot windy days. The water table remains constant or rises on cloudy days accompanied by rain and falls on cloudy days with no rain but not so much as on sunny days. The amount of the daily fluctuation varies with the stage and vigor of plant growth. The maximum daily drawdown observed during the investigation amounted to about 1½ inches on a tract of greasewood and shad scale, 2½ inches in a field of alfalfa, 3¾ inches in a salt-grass meadow, and 4¼ inches in a meadow of sedges and associated marsh grasses. When the water table is in a stratum of sand or gravel the daytime drawdown usually is small and the level remains practically constant at night. Occasionally wells in soil of finer texture also failed to show a rise at night.

FLUCTUATIONS PRODUCED BY DIFFERENT TYPES OF VEGETAL COVER

ALFALFA

The longest and in some respects the most interesting record of water-table fluctuations compiled during the investigation was obtained 4½ miles south of Milford in a 40-acre alfalfa field belonging to W. H. Hendrickson. The field supported a good stand of vigorously growing alfalfa, which had not been irrigated for several years and was drawing its water supply from the zone of saturation. (See pl. 3, *A*.)

Two wells were put down near the middle of the field, a dug well 11 feet deep (well A) and an 8-inch auger hole 13 feet deep (well A–1). An automatic water-stage recorder was maintained on one or the other of these wells during the greater part of the period August 22, 1925, to November 4, 1926, and during a part of the growing season of 1927. The record thereby obtained and assembled shows that the daily fluctuations start in April, when the plants begin to sprout, and end in late October or early November, after heavy frosts have stopped all growth for the season. The amplitude of the daily fluctuation varies with the rate of plant growth; in fact, the graph reflects with fidelity every change in the stage of growth. For example, the cutting of the crop is followed by a flattening of the daily curve and a pronounced rise of the water table. The records reproduced in Figures 3 and 4 illustrate the gradual flattening in the daily curve in 1925 with the progress of the season and the approach and final arrival of cold weather in the fall, also the evolution of the graph in 1926 from an almost straight line about the middle of March to a curve having a daily amplitude of 1½ to 1¾ inches the second week in May.

Graph A (fig. 3) was obtained from well A during the week September 26 to October 3, 1925. At this time the field was being grazed by sheep, and the plants were clipped close to the ground but apparently were growing well. September 27 and 28 were fair and warm, and the drawdown on each day amounted to 1.2 inches. On September 29, after a light frost, the drawdown was only 0.96 inch, and on September 30, after a heavy frost, it was only 0.5 inch. October 1 and 2 were fair and warm. On these days the alfalfa seemingly had recovered from the effects of the frosts, and the daily fluctuations were materially increased. Graph B, obtained during the week October 10 to 17, shows comparatively small daily drawdown, particularly on the 11th and 13th, both of which were cloudy and were preceded by night showers, which wetted the soil to a depth of about 1 foot and may have contributed sufficient moisture to the upper plant roots to help serve the needs of the plants for several days. Graph C shows that the daily fluctuations again became large during the period October 24 to 31. The alfalfa was still green and apparently doing fairly well, although the amount of its growth could not be estimated owing to the fact that the field was being closely cropped by stock. Frosts occurred nearly every night, but the days were warm and sunny. Graph D shows a week of rain and cold weather. A rain amounting to 0.59 inch occurred on the night of November 1. On November 3 the weather suddenly turned cold, plant growth apparently ceased, and the graph flattened into a practically straight line. Graph E was obtained early in December, when the weather was cold and the plants dormant. In graph F (fig. 4) and graph G (fig. 4) minor fluctuations appear during the weeks March 12 to 18 and March 27 to April 3, but these are believed to have been due to variations in atmospheric pressure. At the end of the first week in April (graph H) the plants began to sprout. About April 13 the growth became rapid, and daily fluctuations of considerable amplitude developed. By the beginning of the second week in May (graph I) the alfalfa had reached a height of 6 inches and was growing very fast. In the week May 8 to 15 the daily fluctuations averaged about 1½ inches. Daily fluctuations continued through May and the first few days in June, ranging from 1¼ to 2 inches and averaging about 1½ inches, and the water table declined at the average rate of about 3½ inches per week. On June 8 (graph J) the first crop was cut. This halted the growth but did not stop it altogether, for the second growth was already sprouting vigorously at the base of the older plants, and these young shoots were too short to be reached by the mower. Nevertheless, the amplitude of the curve was reduced about 50 per cent, and the daily drawdown became less than half an inch. Moreover, the seasonal decline

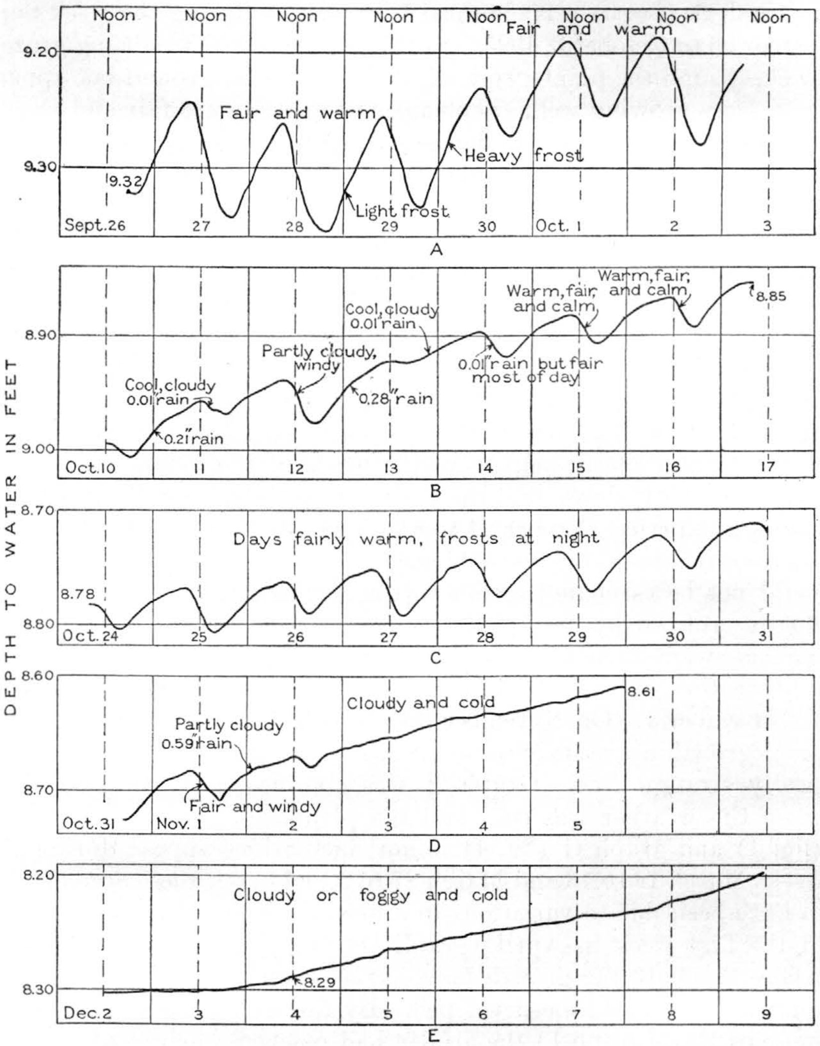

FIGURE 3.—Daily fluctuations of the water table in Hendrickson's naturally subirrigated alfalfa field, fall and early winter, 1925. A, Weather warm and alfalfa growing vigorously, but growth checked somewhat by heavy frost night of September 29. B, October 10 to 13 rainy and cool and cloudy or partly cloudy; October 14 to 17 fair. C, Days cool but sunny; light frosts at night. D, Heavy rain night of November 1, followed by cloudy and cold weather November 2 to 5. E, Cloudy or foggy and cold

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FIGURE 4.—Daily fluctuations of the water table in Hendrickson's naturally subirrigated alfalfa field, spring and summer, 1926. F, Days moderately warm, but heavy frosts at night; plants show no signs of growth. G, Cool and partly cloudy, frosts at night; no signs of growth. H, April 11 and 12 partly cloudy, with some rain night of April 11; April 13 to 16 fair and warm, no frosts, plants growing well. I, Warm and sunny; alfalfa growing vigorously. J, Alfalfa cut June 8; thereafter fluctuations declined about one-half. K, Hot and dry; plants parched and stunted; upward movement of ground water by capillary action reduced owing to decline of water table into gravel

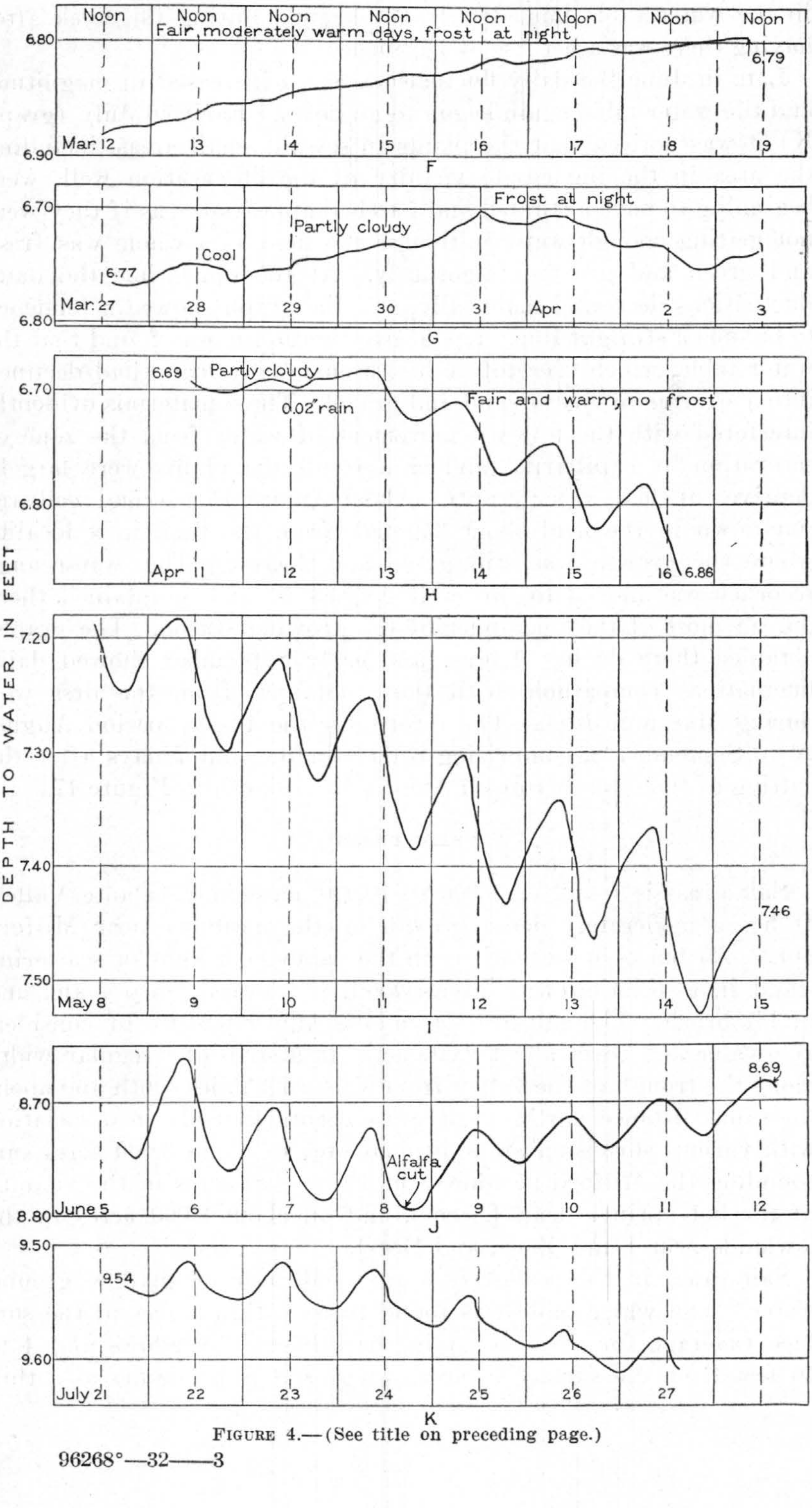

FIGURE 4.—(See title on preceding page.)

in the water table immediately ceased, and during the week after haying there was a net rise of 1¼ inches.

Late in June the daily fluctuations again increased in magnitude and the water table again began to go down. Early in July (graph K) it was noticed that the plants in several small areas, including the area in the immediate vicinity of the observation well, were beginning to have a stunted and parched appearance, as if they were not getting enough water, although the field as a whole was fresh and green and growing vigorously. At the same time the daily fluctuations decreased materially, and the graph showed a tendency to become a straight line. Upon investigation it was found that the water table, which theretofore had been in clay loam, had declined into a stratum of coarse sand and gravel. These materials evidently interfered with the upward movement of water from the zone of saturation by capillarity, and as a result the plants were largely deprived of their water supply. About August 15 a second well was put down in the field about 350 feet from the first, in a locality where the growth was still green and heavy. The water-stage recorder was moved to this well August 24 and maintained there during most of the remainder of the growing season. The graphs obtained there during August and early September showed daily fluctuations comparable with those obtained from the first well during May and June. The record for the 13-day period August 26 to September 8, comprising 6 days before and 7 days after the cutting of the second crop, on August 31, is shown in Figure 17.

SALT GRASS

Salt grass is found on 9,000 to 10,000 acres in Escalante Valley. It has a moderately dense growth on the meadows near Milford (pl. 3, *B*) but occurs elsewhere in the valley as a light or scattering stand in association with greasewood, pickleweed, shad scale, and rabbit brush. The salt-grass meadows afford pasture of considerable value and cover about 2,600 acres in a strip of irregular width along the trough of the valley from Milford 4 miles south and about the same distance north. Salt grass occurs sparsely in association with various shrubs on an additional area of about 3,000 acres surrounding the Milford meadows, on 300 or 400 acres in the vicinity of the hot springs near Thermo, and on about 3,000 acres in the lowlands near Lund, Zane, and Beryl.

Salt grass in this valley is a sure indicator of shallow ground water. The water table was found to be within 4 feet of the surface (average for the season) in the salt-grass meadows and 4 to 10 feet from the surface in areas where salt grass occurs as a thin growth associated with greasewood, shad scale, rabbit brush, or pickleweed. Where the depth to the water table is more than 15 feet the plant is absent.

Conditions apparently favorable for its growth, besides a shallow water table, are a deep soil with plenty of humus and a moderate but not excessive amount of alkali. If soil conditions are not right the plant is likely not to thrive. Near the south end of the valley, near Lund, Zane, and Beryl, where there is in the aggregate about 40,000 acres underlain by ground water at depths of less than 10 feet, salt grass grows on only about 3,000 acres, and even there the stand is thin. Its failure to maintain a foothold in these areas is apparently due in part to unfavorable ground-water conditions, the water table being nowhere less than 6½ feet deep at any time during the season, and in part to unfavorable soil conditions. In the shallow-water areas of the Lund district the soil contains much alkali. In the lowland south of Zane and Beryl the soils do not contain so much alkali but the top soil is comparatively thin and the subsoil consists largely of sand and gravel.

Salt grass, like greasewood, alfalfa, and other ground-water plants, has a large and extensive root system. Explorations with an auger disclosed that the salt-grass meadows are underlain by thousands of stemlike roots running for the most part in approximately horizontal directions and forming a mass from a few inches to 2 feet thick, below which small rootlets penetrate to greater depths. The total absence of the plant from all parts of the valley where the water table is deeper than 15 feet indicates that shallow ground water is necessary for its existence, and it follows that the roots must penetrate to the capillary fringe overlying the water table if not to the water table itself. Hairlike rootlets were brought up from a depth of 6 feet in a bore hole on land adjoining the Milford meadows, where there was a thin growth of salt grass and the water table was 7 feet below the surface. Roots of the plant doubtless could have been traced to greater depths in areas where the water table was deeper than 7 feet, but no attempt was made to do so.

Altogether 18 test wells were put down in salt-grass lands, of which 3 were sunk in sandy soil and 15 penetrated black or gray clay loam. In the sandy soil the water table fell during the day but remained practically at a standstill during the night. Records obtained from the wells in clay loam during the growing season all show some rise at night as well as a daytime decline. The amplitude of the daily curves varied in different wells and at different times during the growing season from a small fraction of an inch to 3½ inches. The greatest fluctuations occurred in meadows of the greatest density and at times when the grasses were growing most rapidly.

The graphs in Figures 5 and 6 were obtained from well 1, in a field supporting a light growth of salt grass associated with tussock grass and some pickleweed, and illustrate characteristic variations in the daily fluctuations that took place in this well with the progress of the season.

Graph A (fig. 5) represents the record for the period January 14 to 20, 1926. Midwinter conditions then prevailed, and plant life was dormant. The feature of the record of particular interest is the rise between noon and midnight and the fall between midnight and noon January 14 to 18, the top of the curve being reached near midnight each day and the bottom near noon. These fluctuations had directions practically opposite to those that occur during the season of plant growth and were probably due to slight diurnal changes in barometric pressure. For two months or so after the week of this record the graph either was a straight line or showed minor fluctuations due apparently to diurnal changes in atmospheric pressure. Late in March and early in April the water table here became very active. The record then obtained is particularly interesting, both because of the wide range in movements of the water table that it discloses and because the fluctuations took place when the plants were dormant. A part of the record for this period is reproduced in Figure 6. Marked rises occurred after light rains March 31 and April 3, 5, 6, 8, 11, and 12. As a matter of fact the gain in water level amounted to thirty or forty times the depth of the precipitation as measured by a rain gage at the well. A pronounced but less abrupt decline followed each rise. No evidence of growth could be detected in the plants surrounding the well. Nevertheless the record of April 1, 2, 4, and 14 to 17 displays the daytime drawdown and nighttime recovery ordinarily observed during the growing season.

The general character and wide amplitude of the fluctuations recorded in this graph were probably the result of a combination of causes. For two months prior to the period of record the water table had been within 18 inches of the surface of the meadow, and during the record period it ranged from 1 inch to 15 inches below the surface. The soils above the water table had become almost saturated with moisture contributed from above by rainfall and from below by capillary action—that is, they had about reached the limit of their capacity for holding water by capillary tension. From experiments with undisturbed soil columns in sealed cylinders (p. 75) it was found that clay loam soils of the type surrounding this well have specific yields averaging about 3 per cent—that is, when the soils are holding all the moisture they are capable of retaining by capillarity the water table will be raised 1 foot by the addition of a depth of water amounting to about 0.03 foot, or 0.36 inch.

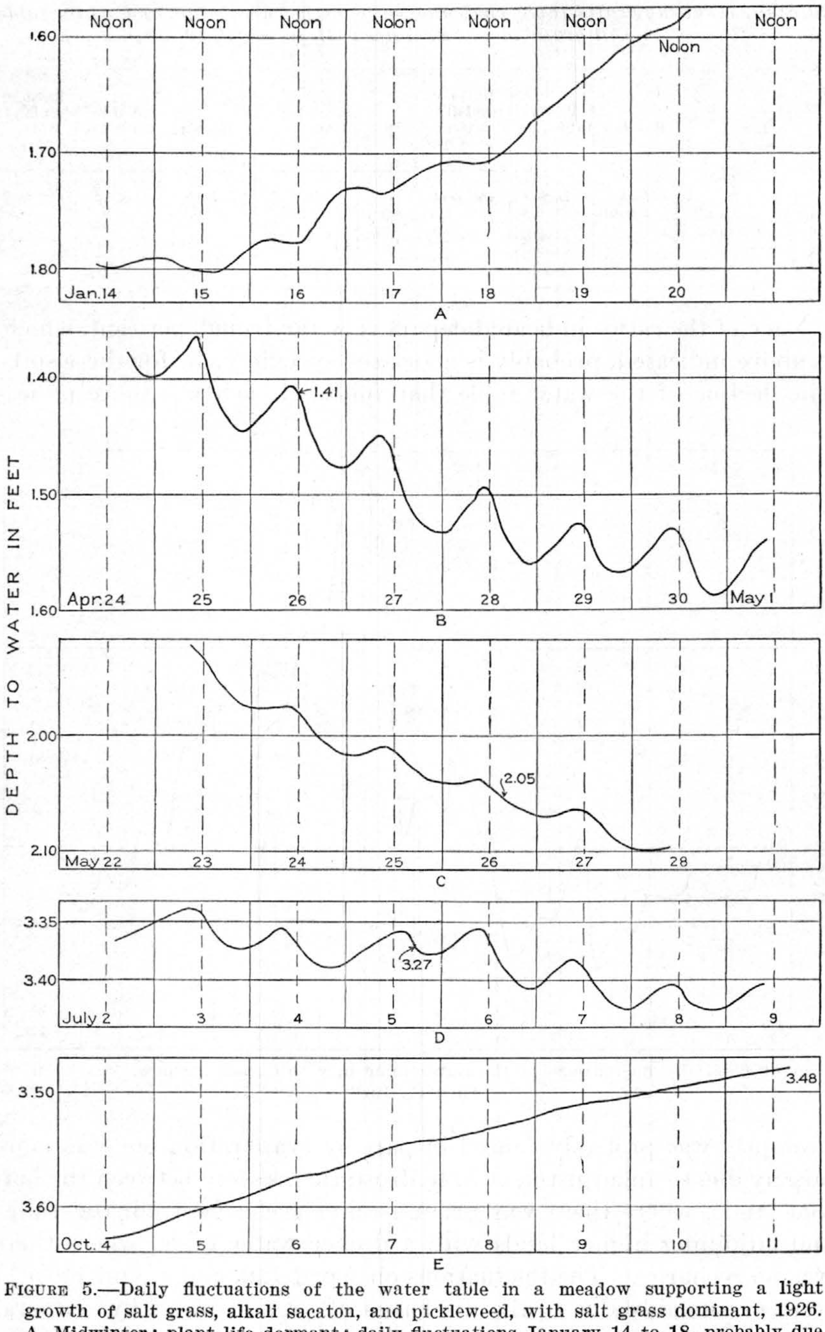

FIGURE 5.—Daily fluctuations of the water table in a meadow supporting a light growth of salt grass, alkali sacaton, and pickleweed, with salt grass dominant, 1926. A, Midwinter; plant life dormant; daily fluctuations January 14 to 18, probably due to diurnal changes in barometric pressure. B, Plants growing slowly; the graph shows the result of the combined draft by evaporation and transpiration. C, Plants still growing slowly; water table has lowered and evaporation decreased. D, Plants growing rapidly; water table 40 inches below surface and evaporation about stopped. E, Plants dormant

Rainfall, resulting water-table rise, and ratio between rainfall and water-table rise in salt-grass meadow, March 31 to April 12, 1926

Date	Rainfall	Water-table rise	Ratio of rainfall to water-table rise	Date	Rainfall	Water-table rise	Ratio of rainfall to water-table rise
	Inch	*Inches*	*Per cent*		*Inch*	*Inches*	*Per cent*
Mar. 31	0.01	0.6	1.7	Apr. 7	0.26	9.5	2.8
Apr. 3	.11	3.7	3.0	Apr. 8	.11	2.9	3.8
Apr. 5	.12	3.8	3.2	Apr. 12	.03	1.1	2.7
Apr. 6	.03	1.8	1.6				

None of the ratios indicated depart very far from 3 per cent, which, as above indicated, probably is about the specific yield for these soils. The decline of the water table that followed each rise more or less

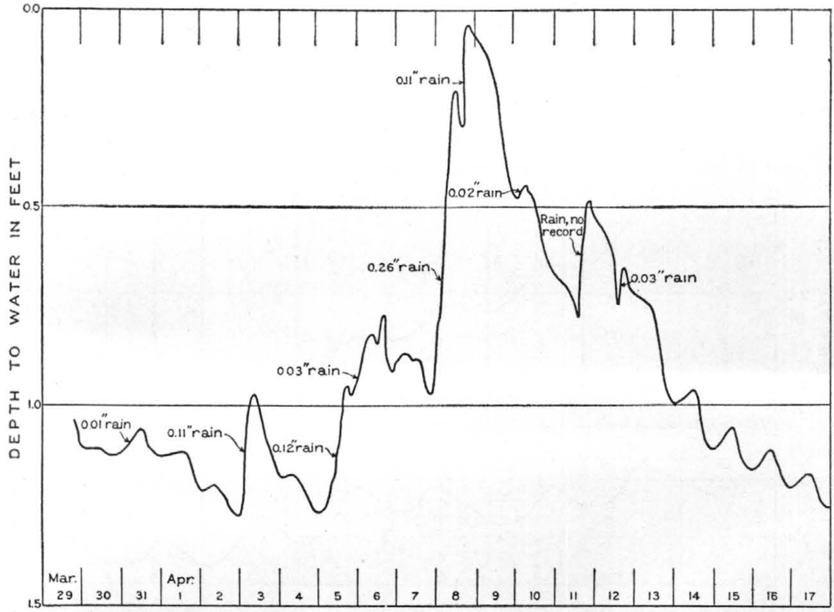

FIGURE 6.—Daily fluctuations of the water table in a salt-grass meadow, March 30 to April 17, 1926

promptly was probably caused in part by evaporation but was more largely due to an adjustment in hydrostatic pressure between the bottom lands, where there was ground-water recharge from the rains, and adjoining higher lands with a deeper water table, where there was no recharge. The fluctuations on April 1, 2, and 4, and 14 to 17 were presumably due to the discharge of ground water by evaporation, as the water table was only 12 to 15 inches from the surface and the weather was warm and fair.

By the week of April 24 to May 1 (graph B, fig. 5) the grasses and shrubs had begun to grow, and although the water table was declining, it was still less than 19 inches from the surface. The effect of the combined draft by transpiration and evaporation is shown by the large daily fluctuation. By the third week in May (graph C) the water table had declined to about 2 feet below the surface and evaporation of ground water had correspondingly decreased. Meanwhile the plants were growing slowly, and the daily fluctuations were small. By the first part of July (graph D) the water table was about 40 inches below the surface and evaporation losses were small, but the plants were growing rapidly and the curve had again increased in amplitude. By the first part of October (graph E) the plants had stopped growing, evaporation was negligible in amount, and the graph had become a nearly straight line.

In the meadows of denser salt grass in the Milford district the observed daily fluctuations during the season of plant growth were materially greater than those described above. Figure 18 shows typical conditions. This graph was obtained during the week August 20 to 27, 1926, from a field a quarter of a mile due east of the railway station at Milford, in which the density of growth was considerably above the average for the district. It shows a daily drawdown ranging from 1.2 to 3.25 inches.

GREASEWOOD

Greasewood has a widespread occurrence in the lower parts of the Escalante Valley, being found to some extent on about half of the area of natural ground-water discharge. Pure stands of greasewood ranging from a fraction of an acre to several acres in extent are occasionally seen, but it is usually associated with shad scale and rabbit brush and here and there with salt grass, alkali sacaton, or pickleweed. In some places it is the dominant growth; in others it is more or less scattered, with other plants dominant. The largest areas of greasewood land are found where the depth to the water table is less than 15 feet, but the plant does not seem to be able to exist if the water table is too close to the surface, the roots apparently requiring most of the time a depth of not less than 3 feet of aerated soil. Greasewood gives way to salt grass, alkali sacaton, and pickleweed in the lowest part of the valley in the Milford district, where in the spring the water table rises to the surface or comes within a foot or two of the surface.

The greasewood areas extend up the slopes to distances varying with the character of the soil and the depth to ground water. In some localities greasewood does not extend beyond the line of 15-foot depth to water, but in most of the valley the upper limit of the plant ranges between the lines of 25-foot and 40-foot depth to water. In four or five tracts of small extent where the lands are subject to a certain amount of wetting by storm waters greasewood is found where the depth to water is 50 feet or even 60 feet.

Almost everywhere in the valley the plants contain considerable dead wood and appear only moderately thrifty. The shrubs usually range from 2 to 3 feet in height and seldom reach 4 feet. The old plants grow slowly, an average plant putting on only a few ounces of new growth annually. However, in localities where greasewood fields are cleared and the clearing is not followed by cultivation, new growth quickly springs up from the roots, and according to the report of settlers the original density of stand is restored in four to six years.

In prospecting for ground water in the early days near Tonopah, Nev., greasewood roots were found to go to depths of more than 20 feet—according to some reports, as much as 40 feet—to get ground water, and near Grandview, Idaho, roots of greasewood were observed penetrating the roof of a tunnel 57 feet below the surface.[10]

In the course of the Escalante Valley investigation greasewood roots 12 feet long were traced to the water table from the tops of cut banks adjacent to the bed of the Beaver River. Small roots were brought up in borings on greasewood flats from depths of more than 10 feet, just above the water table. It was found that nearly everywhere beneath greasewood lands there is a thickness of caliche or cemented clay a few inches to 3 feet thick just above the water table. This material is so hard that it is penetrated with difficulty by a steel bar and hand auger. Nevertheless, examination with a microscope disclosed that tiny hairlike greasewood roots had tunneled through it to ground water.

In the Milford district 18 observation wells were put down in fields supporting greasewood in an unmixed stand, or only slightly mixed with other plants. In 11 of these wells typical daily fluctuations of the water table occurred, with a pronounced rise at night during the growing season. In six of them there was no rise at night. In the Thermo-Nada district four wells were put down in greasewood or in an association of greasewood, rabbit brush, and shad scale, with greasewood dominant. Three of these wells displayed the characteristic daytime drawdown and nighttime rise, but one did not. In the shallow water areas near Lund and Beryl 10 wells were sunk in fields of greasewood or in fields of mixed greasewood, rabbit brush, and shad scale. Only one of these showed any considerable daily fluctuation.

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[10] Meinzer, O. E., Plants as indicators of ground water: U. S. Geol. Survey Water-Supply Paper 577, p. 41, 1927.

The three graphs reproduced in Figure 7 show variations in fluctuations that took place with the progress of the season in well E–2–A, in a tract of greasewood about 1½ miles south of Milford. The plants in this field are 3 feet high (pl. 4, *A*), and the thickness of stand and vigor of growth are slightly above the average for the Milford district. During the period June 17 to 23 (graph A)

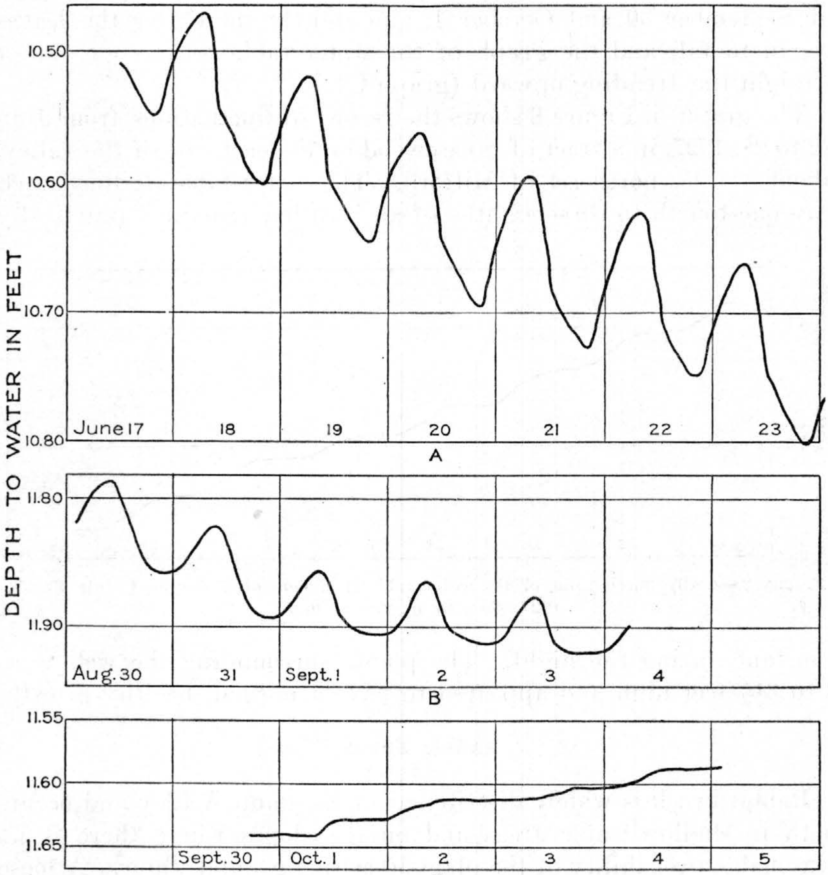


FIGURE 7.—Daily fluctuations of the water table in a field of greasewood, 1927, showing variations with the progress of the season

the plants were brilliantly green and apparently were putting on considerable foliage and some green stem growth. The average daytime drawdown during the six days amounted to 1.6 inches, the average nightly recovery was 1.1 inch, and the net water-table decline for the period was 3 inches.

By the later part of August the plants had assumed a slightly grayish look quite in contrast with their brilliant green coloring in

June, and they apparently had ceased to put on much, if any, new growth. On August 30 and 31 (graph B) the daytime drawdown amounted to 0.9 inch, and the nighttime rise was about 0.5 inch. In the period September 1 to 3, after the grubbing out of the greasewood within a radius of about 20 feet of the well (see p. 47), the daytime drawdown averaged only about 0.5 inch and the nighttime recovery also about 0.5 inch. Heavy frosts occurred on the nights of September 30 and October 1, and shortly thereafter the leaves began to fall and the graph of the water table became an almost straight line trending upward (graph C).

The graph in Figure 8 shows the record of fluctuations from July 22 to 28, 1927, in a tract of greasewood on the east side of the valley, about 3 miles northeast of Milford. The water table declined each day one-fourth to three-eighths of an inch but remained practically

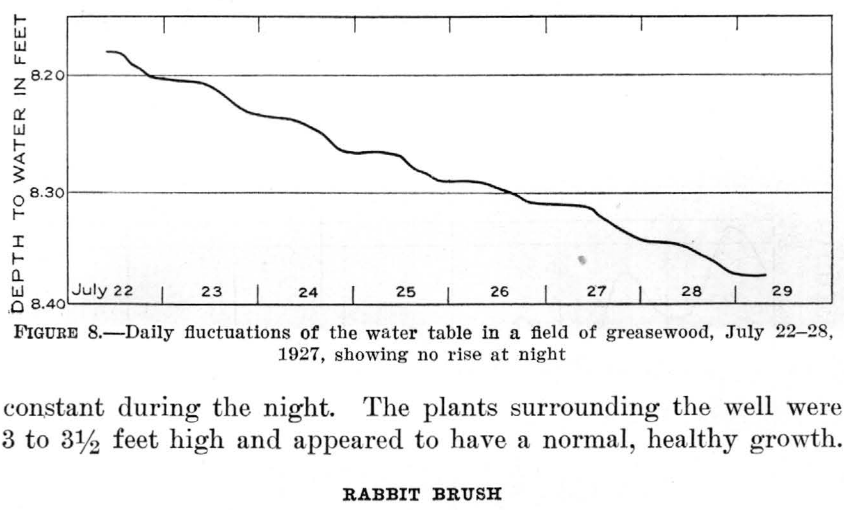


FIGURE 8.—Daily fluctuations of the water table in a field of greasewood, July 22–28, 1927, showing no rise at night

constant during the night. The plants surrounding the well were 3 to 3½ feet high and appeared to have a normal, healthy growth.

RABBIT BRUSH

Rabbit brush is widely distributed in Escalante Valley and occurs both in shallow-water areas and on the slopes where there is no reasonable probability of the plants reaching ground water. A loose sandy soil free from alkali and an abundant supply of fresh water apparently provide the best conditions for this shrub. Giant rabbit brush 4 to 8 feet high occurs in places on sandy loam soils along intermittent streams in the mountains bordering the valley, but on the valley floor the plants seldom exceed 3 feet in height. On the slopes out of the reach of ground water the plants usually have a decidedly stunted appearance and average little more than a foot high. Moreover on these high lands the period of growth is generally short, and by midsummer growth has nearly or quite ceased. Exception to this general rule is seen in a few small areas of sand dunes, of which one of a few hundred acres at the south end of the valley near Zane is an example. There rabbit brush 3 to 4 feet high partly covers the sand dunes and is growing vigorously, although the depth to the true water table is about 80 feet and it seems unlikely that there is a perched water table. Apparently in such areas the plant is able to obtain exceptionally large quantities of moisture from rainfall. The rains sink readily into the sands, and the light sandy surface serves as a mulch to prevent the loss of the moisture by evaporation. Elsewhere in the valley the size and character of the plants evidently depend on their ability to obtain ground water. Even in the shallow-water areas, however, the plants are not very vigorous, seldom exceeding 3 feet in height and often containing considerable dead brush. The plant dislikes alkali, which

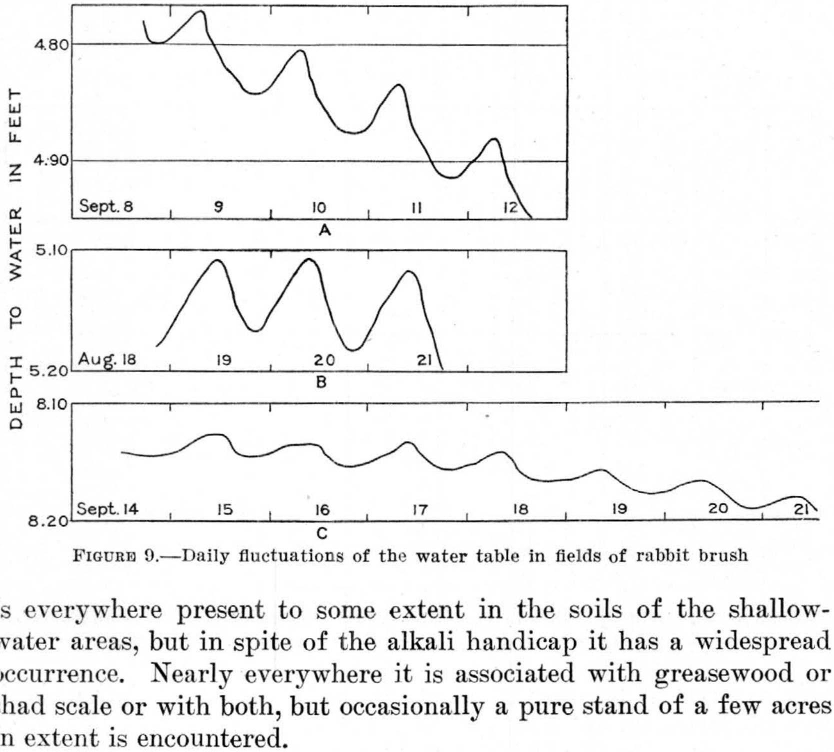


FIGURE 9.—Daily fluctuations of the water table in fields of rabbit brush

is everywhere present to some extent in the soils of the shallow-water areas, but in spite of the alkali handicap it has a widespread occurrence. Nearly everywhere it is associated with greasewood or shad scale or with both, but occasionally a pure stand of a few acres in extent is encountered.

The graphs in Figure 9 were obtained from wells in tracts of rabbit brush. Graph A represents a field carrying an exceptionally heavy stand of rabbit brush free from other plants. This field is near the dry bed of the Beaver River about 2 miles south of Milford. (See pl. 4, *B*.) Graph B was taken from a well in a field supporting a high stand of rabbit brush near the Beaver River, about 16 miles southeast of Milford, and graph C from a well in moderately heavy rabbit brush in Lake Valley, Nev.

SHAD SCALE

Shad scale has a wider distribution than any other shrub in the Escalante Valley with the possible exception of rabbit brush. It occurs alike in the shallow-water areas of the lowlands and on the slopes where the depth of water is 100 feet or more. It can grow in tight silt or clay-silt soils where other plants apparently are unable to maintain a foothold—in fact, it seems to favor such soils. The thickest stands of shad scale occur in areas that are subject to a cer-

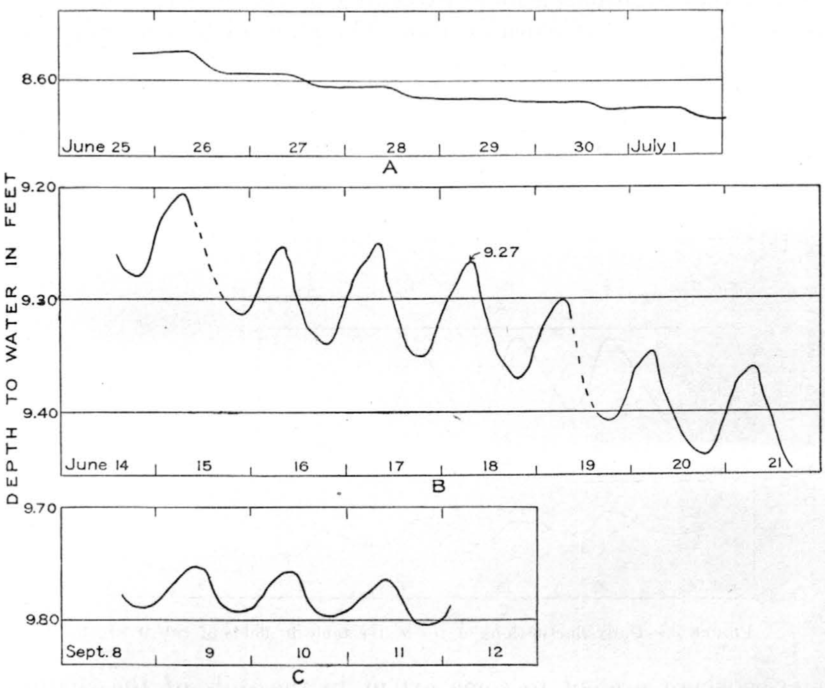


Figure 10.—Daily fluctuations of the water table in fields of shad scale and of shad scale associated with greasewood and rabbit brush

tain amount of flooding by silt-laden storm waters, but the plants in such localities are small, usually not exceeding a foot in height. The largest and most thrifty plants, reaching a height of 2 feet or more, are found in shallow-water areas on clay or clay-loam soils in association with rabbit brush or greasewood or both.

The graphs shown in Figure 10 were obtained from wells in areas occupied by shad scale, or by shad scale in association with greasewood or rabbit brush. Graph A came from well E–7, in a field carrying a heavy stand of dwarf shad scale. Graph B came from well D at the Milford experiment station, which was in a field of larger shad scale and greasewood, with shad scale dominant in the proportion of about 8 to 1. Plate 5, *A*, shows a view of this field with the experiment station in the left background. Graph C came from well E–12, in a field of moderately large shad scale with a scattering growth of rabbit brush.

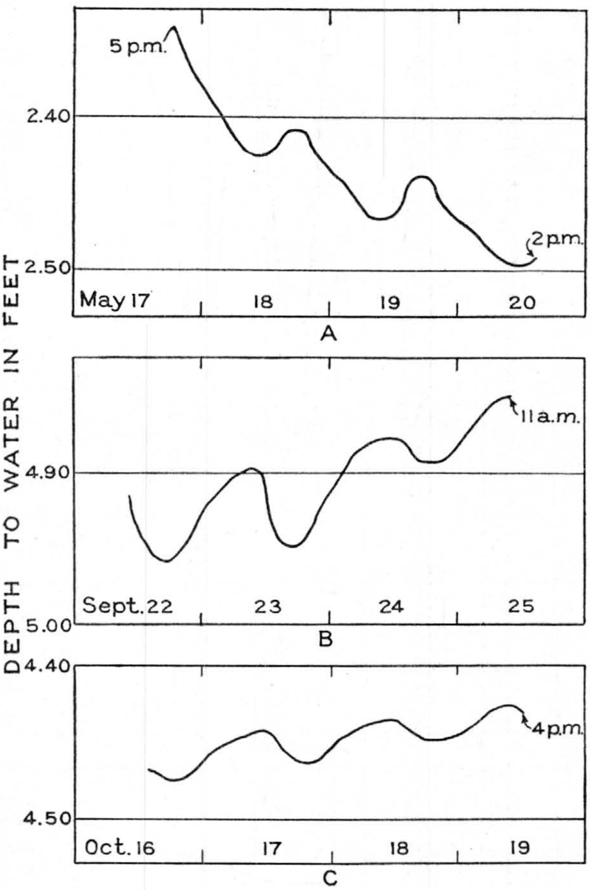


FIGURE 11.—Daily fluctuations of the water table in a field of pickleweed, 1926

PICKLEWEED

Pickleweed is common where the depth to water is 8 feet or less in parts of the Milford district and in the immediate vicinity of Lund. Its growth usually is comparatively thin and scattering, and its presence indicates a high percentage of alkali in the soil. It occurs as a pure stand on some lands that are otherwise bare, and in places it is associated with a thin growth of salt grass or scrubby greasewood or shad scale.

The three graphs in Figure 11, from well D–5, show fluctuations of the water table beneath a tract of alkali land near Milford where the only vegetation is pickleweed. Graph A was obtained May 17 to 20, 1926, at a time when the plants had an unhealthy appearance and the

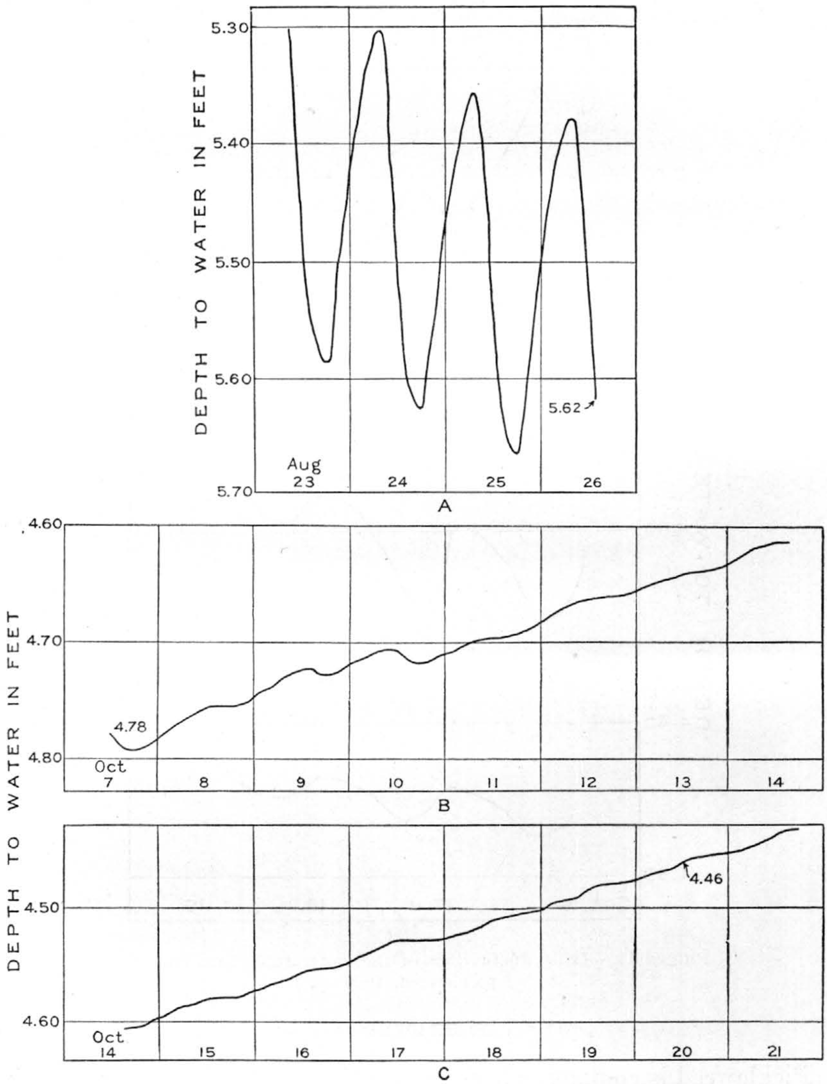


FIGURE 12.—Daily fluctuations of the water table in a thicket of willows, 1926

growth seemed to be at a standstill. The graph is remarkable in that it shows a rise of the water table during the day and a fall at night. It is one of a very few graphs obtained during the season of plant growth displaying this characteristic. Graph B was obtained somewhat later in the season, when the pickleweed had a fresh green appearance and apparently was growing vigorously. Graph C covers a 3-day period in October when the plants showed some damage from frost but were still alive and apparently growing slowly.

WILLOWS

The graphs in Figure 12 were obtained from well E–9, in a thicket of young willows in the dry bed of the Beaver River about 2 miles southwest of Milford. (See pl. 5, *B*.) The willows were from 8 to 12 feet high and close together and apparently were putting on an abundance of woody growth as well as foliage. Graph A was obtained during hot clear weather in late August. The leaves at that time were dense and green, and the plant growth was probably

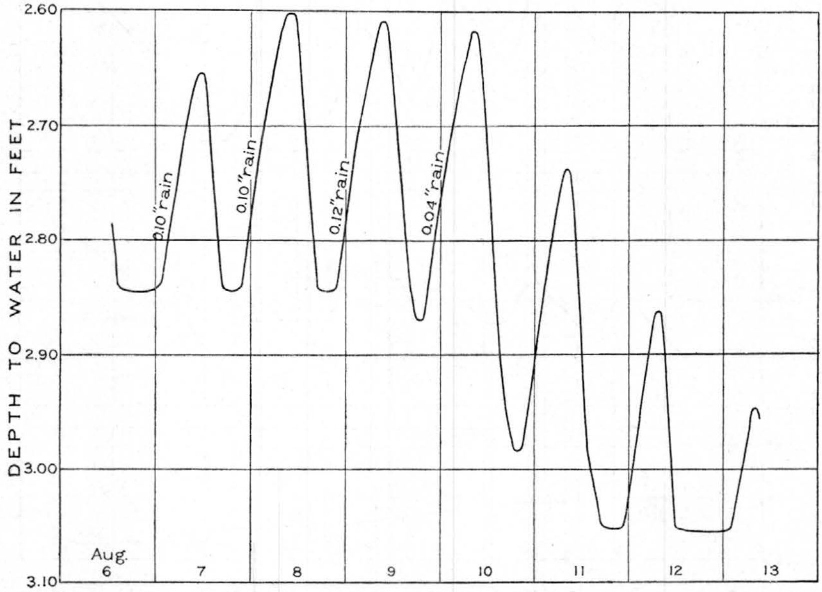


FIGURE 13.—Daily fluctuations of the water table in a meadow of assorted grasses, August 6–13, 1926

progressing as fast as at any other time during the season. The water table was between 5 and 6 feet from the surface, and the daily fluctuations averaged about 3¾ inches. Graphs B and C were obtained during the period October 7 to 21. The first severe frosts of the season had occurred September 30 and October 1, and as a result a few of the leaves had begun to turn yellow, but not all seemed damaged. A succession of heavy frosts on the nights of October 5, 6, 7, 8, and 9 apparently completed the destruction, and by the middle of October most of the leaves had fallen. Slight daily fluctuations persisted until October 10, and thereafter the record became nearly a straight line.

MEADOW GRASSES

In the Beaver River bottoms just north of Milford there is about 400 acres of pasture and hay land covered with an assortment of grasses, in which there are several species of sedges and flat-bladed grasses and comparatively little salt grass or alkali sacaton. These grass lands were once irrigated and are said to have yielded annually 2 tons of hay to the acre. They have not been watered for several years, but the grasses continue to grow fairly well, particularly in

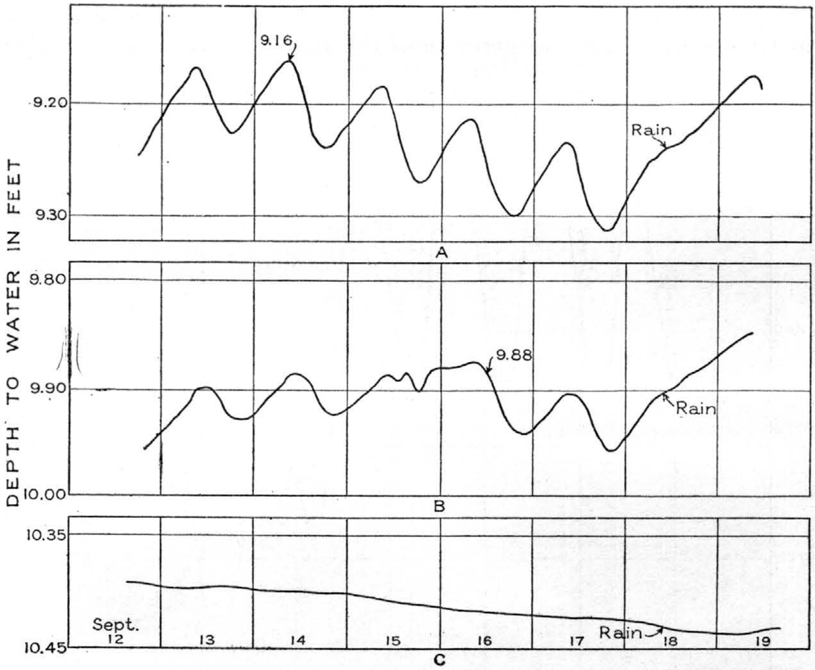


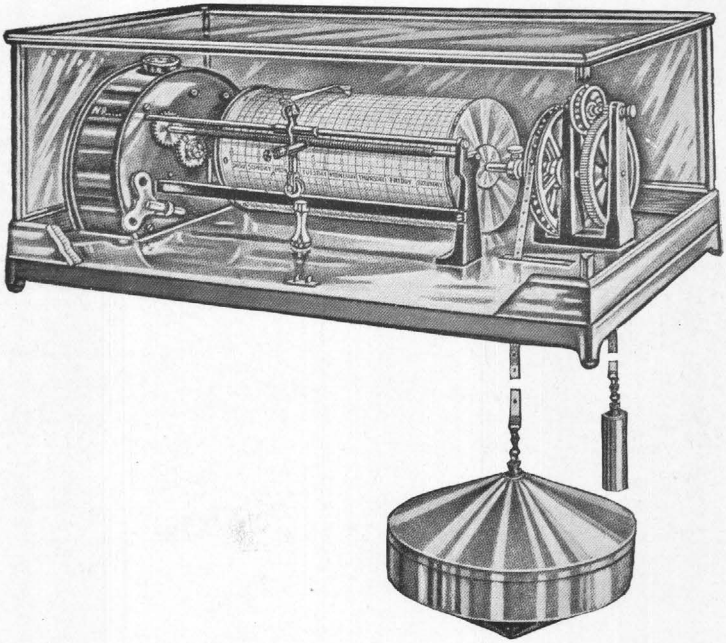
FIGURE 14.—Comparison of daily fluctuations of the water table in a field of alfalfa and in an adjoining bare field, September 12–19, 1925. Graph A, from well A, at center of alfalfa field; graph B, from well 2, near edge of alfalfa field; graph C, from well B, in cleared field adjoining alfalfa field, about 900 feet from well 2

the early part of the summer, and to afford valuable pasture for stock and some hay. A graph obtained from well R–3, in these meadows, during the week August 6–13, 1926, is shown in Figure 13.

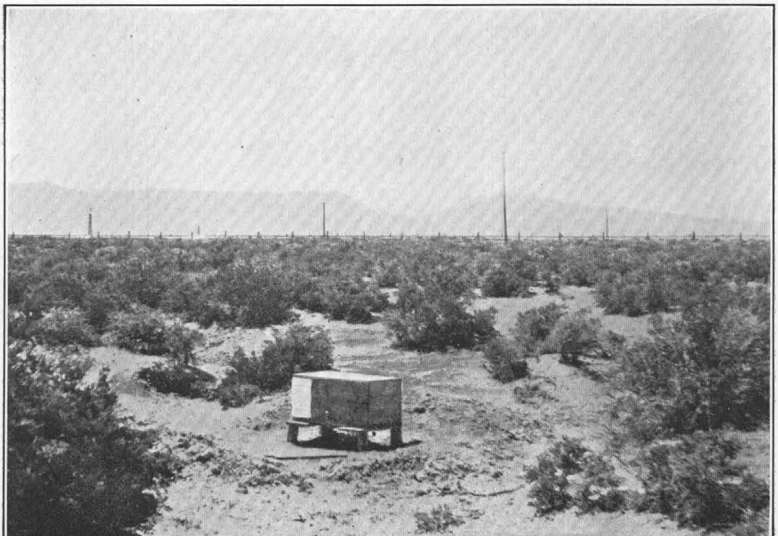
The daily fluctuations of the water table ranged during this period from 2¼ to 4¼ inches.

SAGEBRUSH

Four wells were put down in fields of sagebrush in different parts of the valley. All the graphs obtained from them consisted of



A. AUTOMATIC WATER-STAGE RECORDER

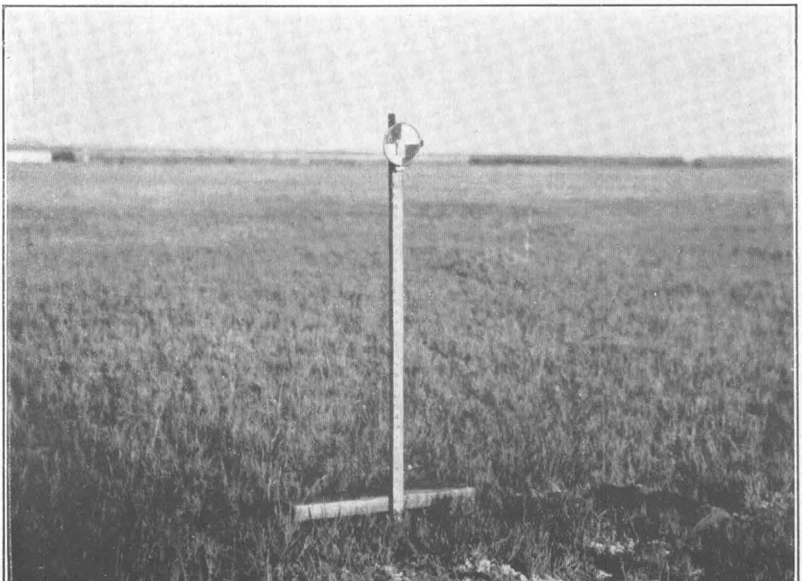


B. AUTOMATIC WATER-STAGE RECORDER INSTALLED OVER AN AUGER-HOLE WELL IN A FIELD OF GREASEWOOD

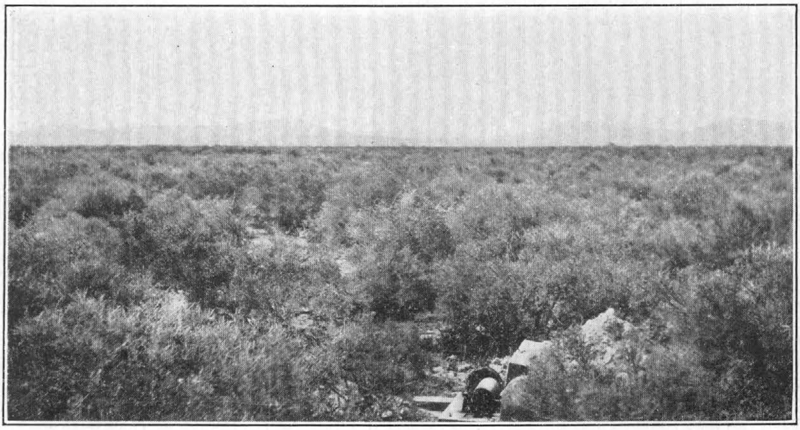
The recorder is housed in a small shelter that is locked.

A. FIELD OF NATURALLY SUBIRRIGATED ALFALFA NEAR MILFORD, UTAH

Test pit for determining specific yield in the foreground. This field had not been irrigated for four years prior to the time the picture was taken.

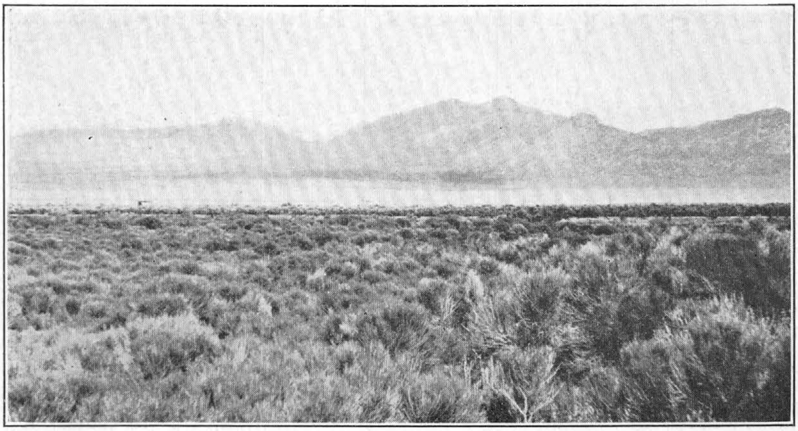


B. SALT-GRASS MEADOW NEAR MILFORD, UTAH



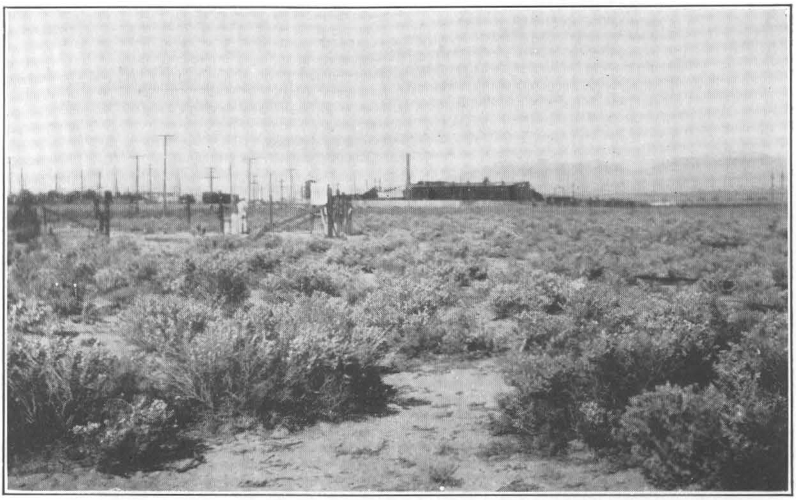
A. HEAVY STAND OF GREASEWOOD NEAR MILFORD, UTAH

Recorder is shown over auger-hole well in foreground.



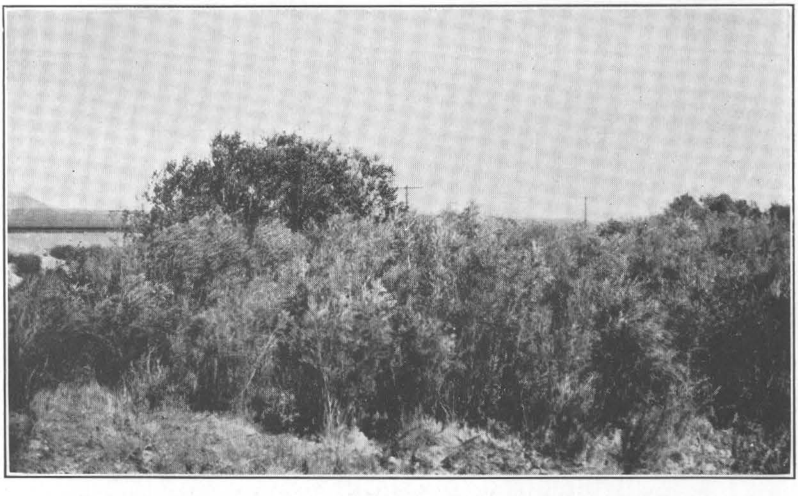
B. HEAVY STAND OF RABBIT BRUSH NEAR THE DRY BED OF THE BEAVER RIVER, IN THE ESCALANTE VALLEY, UTAH

Daily fluctuations of the water table in this field are shown in Figure 9, graph A.



A. FIELD OF SHAD SCALE AND GREASEWOOD, WITH SHAD SCALE DOMINANT

The Milford experiment station is shown at the left.



B. THICKET OF YOUNG WILLOWS IN THE FORMER BED OF THE BEAVER RIVER, NEAR MILFORD, UTAH

The graphs in Figure 12 were obtained from a well in this thicket.

straight or almost straight lines. None showed a rise in the water table during the night. On the basis of this evidence it is assumed that sagebrush in Escalante Valley uses little or no ground water.

CLEARED FIELDS

It was believed that the water table in cleared lands or in plowed fields would show little or no daily fluctuation, and this proved to be true. Several test wells were put down in such areas and equipped with water-stage recorders, and in each one the graph was found to

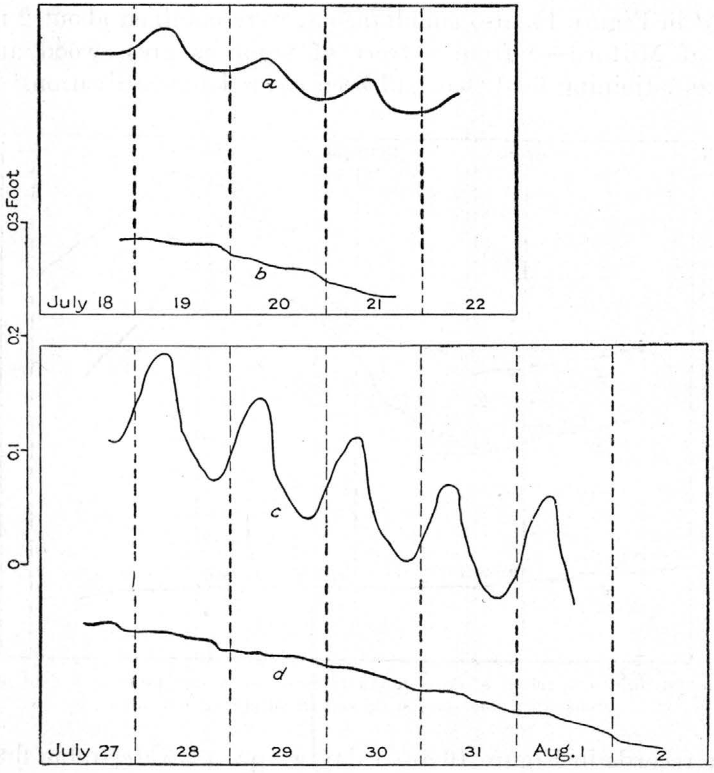


FIGURE 15.—Comparison of daily fluctuations of the water table in fields of greasewood and in cleared land, July 18–22 and July 27 to August 2, 1926

be a straight or nearly straight line. A comparison of fluctuations in fields of ground-water plants and in adjoining bare fields can be made by reference to the graphs in Figures 14, 15, and 16. The graphs shown in Figure 14 were obtained during the week September 12 to 19, 1925, from three wells—two in Hendrickson's naturally subirrigated alfalfa field and one in an adjoining tract of cleared land. At that time the alfalfa looked thrifty and apparently was enjoying normal early fall growth. The average daily drawdown in the well at the center of the alfalfa field (graph A) amounted to about 1 inch. The drawdown in the well at the border of the field (graph B) varied considerably from day to day but averaged much less than that in well A. The water level in the well in the cleared field (graph C) displayed almost no daily fluctuation.

Graphs *a* and *b* in Figure 15 are simultaneous records of water-table fluctuations near Milford—*a* from a well in a stand of greasewood covering about a quarter of an acre and *b* from a well in adjacent bare land that has been cleared of brush for building. Graphs *c* and *d* in Figure 15, also simultaneous, were obtained about 2 miles south of Milford—*c* from a tract of vigorous greasewood and *d* from an adjoining field that had been cleared for cultivation.

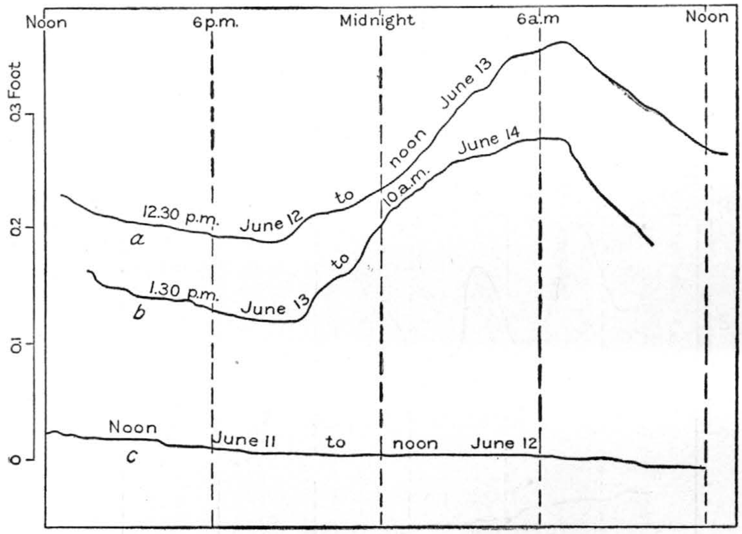


FIGURE 16.—Comparison of daily fluctuations of the water table in a field of greasewood and shad scale and in adjoining bare land

The records in Figure 16 are 1-day graphs of water-table fluctuation. *a* and *b* came from well D at the Milford experiment station, which was located in a field of shad scale and greasewood, and *c* from a well on a near-by flat on which the vegetation had been killed by flooding.

FLUCTUATIONS BEFORE AND AFTER PLANTS ARE CUT

If the daily water-table fluctuations described in the preceding pages are due to the discharge of ground water from the zone of saturation through the agency of plants, it follows that the fluctuations should cease or be materially reduced if the growth of the

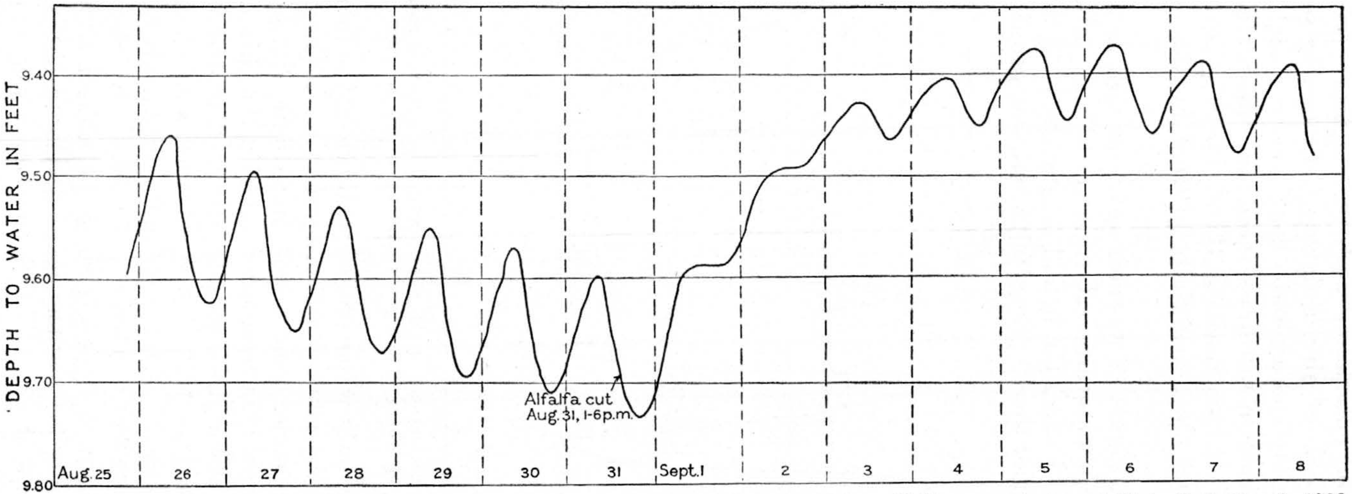


FIGURE 17.—Daily fluctuations of the water table in a field of alfalfa before and after alfalfa was cut, August 26 to September 8, 1926

plants is stopped or checked for a time. In order to obtain information on this point automatic water-stage recorders were maintained over wells in fields of alfalfa during the cropping season to cover periods both before and after the fields were cut, and similar observations were made in salt-grass meadows and in tracts of greasewood. The graphs obtained in these experiments show that the daily fluctuations were materially affected by the cutting of the plants.

The graph in Figure 17 was obtained from well A–1, at the center of Hendrickson's naturally subirrigated alfalfa field containing about 40 acres. During the period August 26 to 31, and in fact for several weeks prior thereto, the alfalfa had been growing vigorously,

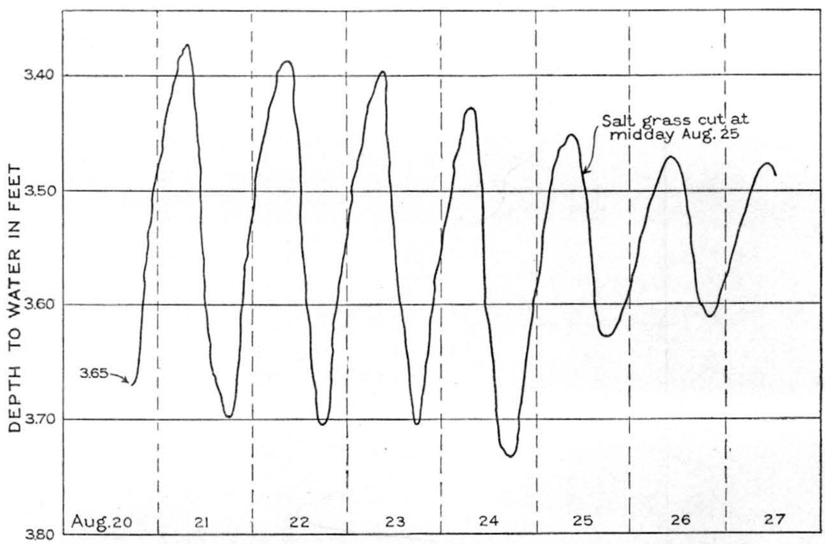


FIGURE 18.—Daily fluctuations of the water table in a salt-grass meadow before and after the salt grass was cut, August 20–27, 1927

and the average daily water-table drawdown had amounted to about 1½ inches. On the afternoon of August 31 the alfalfa was cut, and there was a pronounced and almost immediate change in the character of the graph. On September 1 and 2 the customary daytime drawdown was absent, the ground-water level remaining practically constant on both days. Meanwhile, however, a sharp rise took place at night, and in the 48 hours from midnight August 31 to midnight September 2 there was a net rise of 3 inches. By September 2 new growth had begun to appear among the alfalfa stubble, and the characteristic daily fluctuations again developed but with comparatively small amplitude. About September 9, ten days after the alfalfa was cut, the new stand was growing rapidly, and the fluctuations were nearly as large as they were before the crop was cut.

The graph in Figure 18 is the record of water-table fluctuations obtained from well D–6 in a field supporting a thick stand of salt grass, which apparently was growing vigorously. During the first five days of the period the drawdown averaged about 3¾ inches daily. About midday August 25 the grass was closely clipped in a space surrounding the record well having a radius from the well of about 8 feet, after which the amplitude of the daily fluctuation curve was reduced about 50 per cent. Moreover, the curve did not regain its former amplitude during the rest of the season. No rise in the water table is indicated by the graph, nor was one to be expected, the cut-over area being very small in comparison with the size of the uncut meadow surrounding it.

The record of water-table fluctuations in a well in a large field of greasewood during the period August 30 to September 3, 1927, is

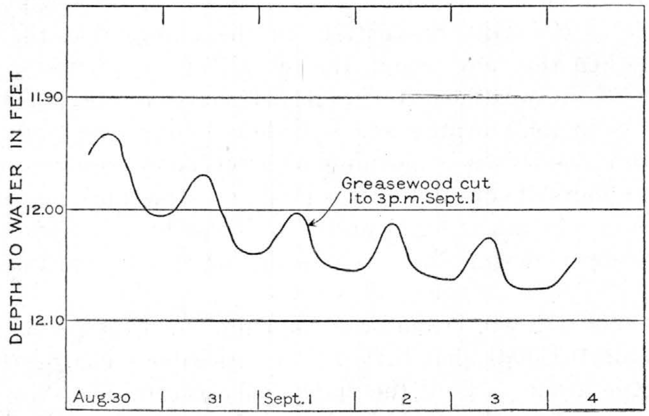


Figure 19.—Daily fluctuations of the water table in a field of greasewood before and after plants were cut, August 30 to September 3, 1927

shown in Figure 19. For a week prior to August 30 the average daily drawdown in this well amounted to 0.8 inch. Early on the afternoon of September 1 the greasewood was grubbed off for a distance of 20 feet on all sides of the well. (See pl. 6, *A*.) In the following week the daily drawdown was noticeably less than it was before the greasewood had been cut. As in the salt-grass experiment the area cleared of greasewood was small compared with the size of the surrounding tract, on which uncut shrubs continued to grow vigorously.

No rains occurred and there was no ground-water recharge while these experiments and others like them were carried out. Therefore the described effects on the water table that followed cutting of the plants must have been due to a sudden cessation or lessening of the draft by the plants on the zone of saturation.

EFFECT OF RAIN ON FLUCTUATIONS

An interesting demonstration of the fact that plants in Escalante Valley draw heavily on ground water in the zone of saturation is shown by the comparative effects of rains on the water table in fields of ground-water plants and elsewhere. During the growing season the rains are generally light, often amounting to only a few hundredths of an inch and hardly ever exceeding half an inch. They seldom penetrate the soil for more than a foot, and usually the moisture goes down only a few inches. It was found that rains at this season have little or no effect on the water table in plowed fields, in cleared lands, or in fields of sagebrush, but usually they are followed by an almost immediate rise of the water table in salt grass and marsh grass meadows, in willow thickets, and in fields of alfalfa, greasewood, and rabbit brush. The amount of the rise seems to depend less on the amount of the rainfall than on the prevailing amplitude of the daily fluctuations of the water table, the time of the day when the rain occurs, the length of the showers, and the character of the weather after them. The rise is greatest when the rain occurs in the morning and is followed by a cool cloudy afternoon. It is less when a morning or afternoon shower is followed by several hours of sunshine. It is least and sometimes inappreciable when the rain comes at night and is followed by a hot sunny morning, the rate of decline, however, being materially less than it had been.

In the late fall, winter, and early spring, when the plants are dormant, rainfall usually has little or no noticeable effect on the water table in the lower parts of the valley. An exception to this general rule was noted in the meadows near Milford, where in the early spring ground water is within a few inches of the surface and a certain amount of recharge follows even very small showers, resulting in a prompt and pronounced rise in the water table. (See p. 30 and fig. 6.)

Figure 20 shows two simultaneous records of water-table fluctuations obtained during the week August 29 to September 5, 1925. Graph A came from Hendrickson's field, in which there was a vigorous growth of alfalfa that had not been irrigated for three years. Graph B came from well B, 1,500 feet from well A, in a tract of cleared land adjoining the alfalfa field. Early in the morning August 31 there was a light shower, amounting to about 0.04 inch, followed all day by cool cloudy weather. The rain penetrated the soil to a depth of only about an inch, and there was no ground-water recharge. Nevertheless, the water table in the alfalfa field not only did not go down but rose and continued to rise until midday September 1, the total rise in 36 hours amounting to 2.4 inches. The water level in the adjoining cleared field showed a very slight rise and declined approximately 0.5 inch in the 36 hours during which the water level in the alfalfa field rose 2.4 inches, but the rate of decline was noticeably less than it had been before the shower. The slight rise may have been due to a change in barometric pressure. The lessening in the rate of decline was doubtless due to less discharge in the alfalfa field.

Seven graphs are reproduced in Figure 21 showing the comparative effects of showers on the water table in the same alfalfa field at different times in the year. During the week of graph A the

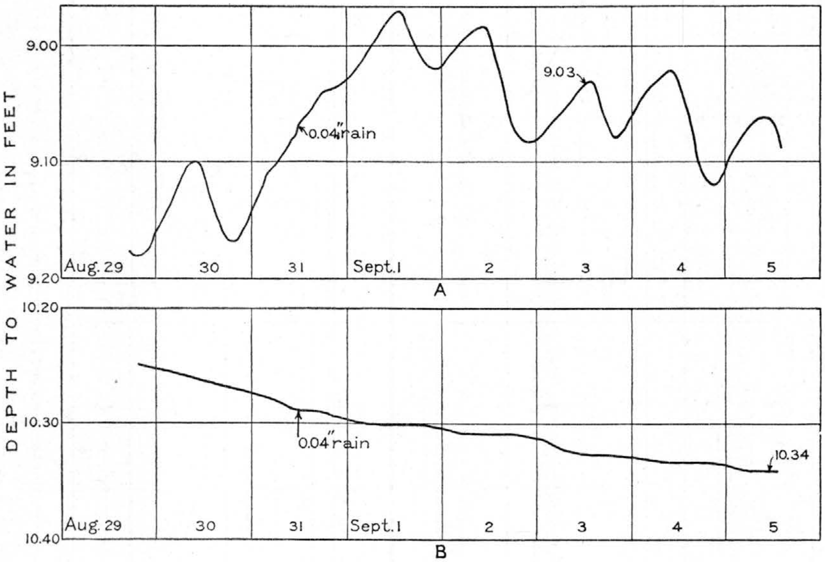


FIGURE 20.—Comparative effects of a light summer shower on daily fluctuations of the water table in an alfalfa field and in an adjoining cleared field. August 29 to September 5, 1925

weather was warm and the alfalfa was green and apparently growing vigorously. A fall of rain amounting to 0.28 inch in the hours between 1 a. m. and 5 p. m. September 18, 1925, checked the decline of the water table, which during the four days preceding had been a quarter of an inch a day, and caused a net rise of 1.2 inches during the 24 hours from midnight September 17 to midnight September 18. When graph B was made the alfalfa was being heavily grazed by sheep and cattle and was still growing fairly well. October 2 and 3 were fair and warm, and October 6, 7, and 8 were fair and cool, with light frosts at night. Rain on October 4 and 5 aggregating 0.97 inch raised the water table 2.2 inches in 48 hours. The weather continued cool during the week of October 9 to 15

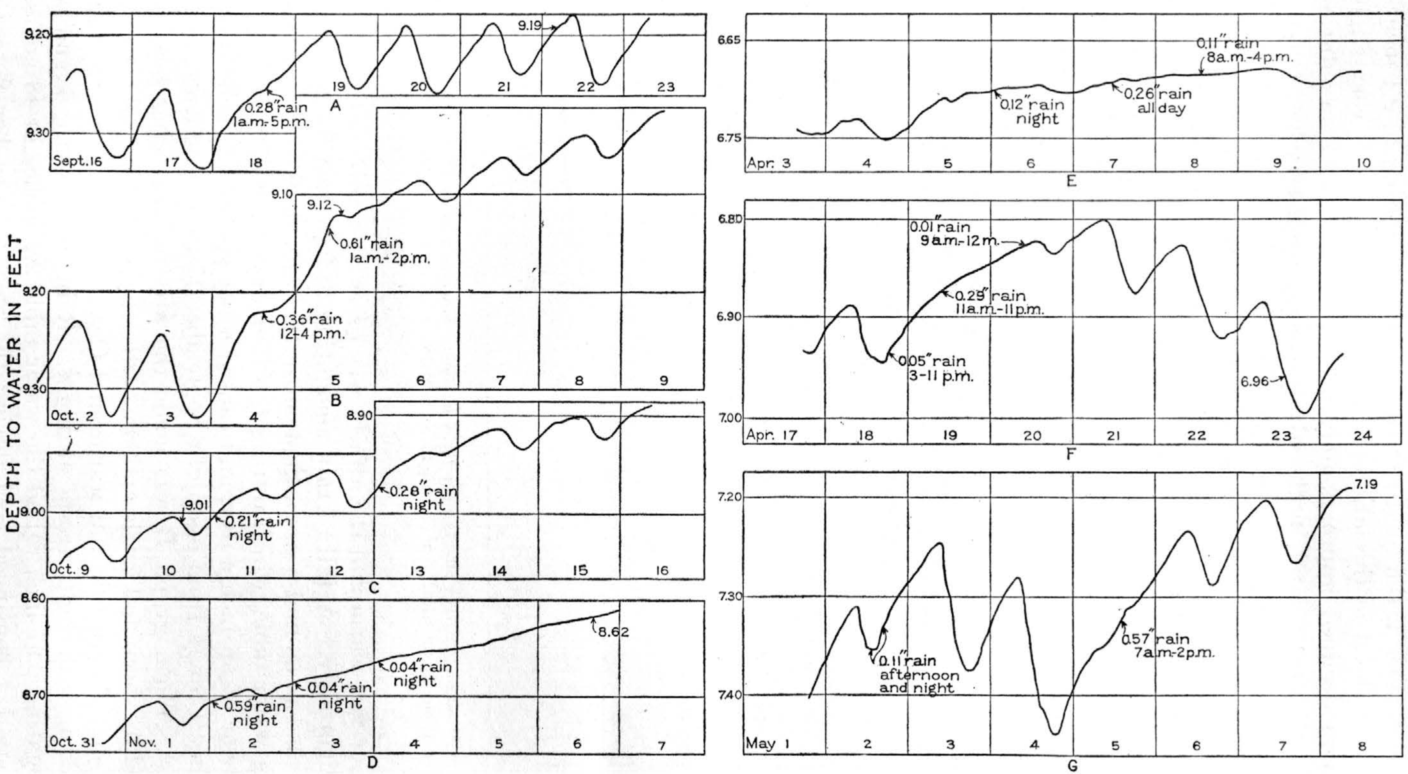


FIGURE 21.—Comparative effects of rain on daily fluctuations of the water table in an alfalfa field during different times of the year

(graph C), and the alfalfa began to turn brown. Obviously it had almost stopped growing. Rains amounting to 0.21 inch and 0.28 inch on the nights of October 10 and 12 had some effect on

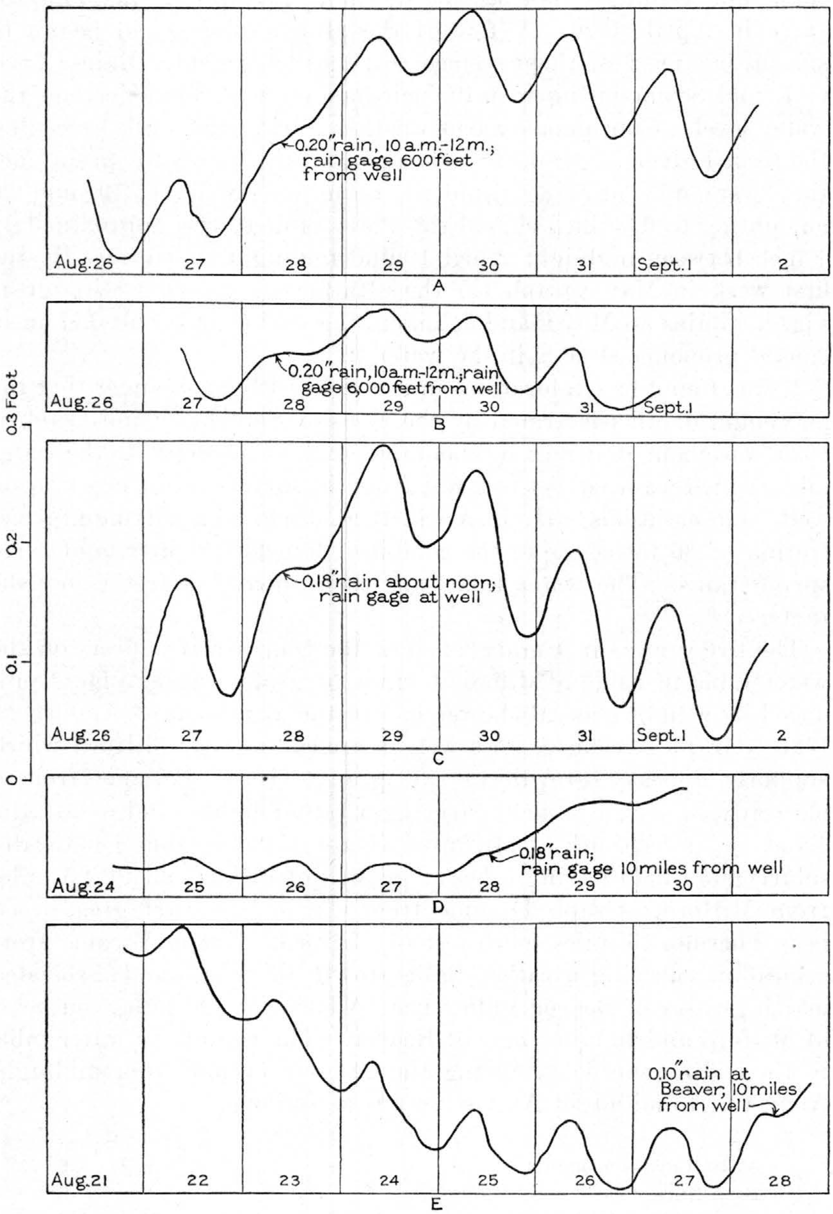


FIGURE 22.—Comparative effects of a shower, August 28, 1927, on daily fluctuations of the water table in fields of different kinds of ground-water plants

the water table, but this was small compared with the effects of the rains on September 18 and October 4 and 5, shown in graphs A and B. A heavy rain amounting to 0.59 inch on the night of November 1 (graph D) apparently had no effect on the ground-water level. By this time the plants had assumed a uniform brown color and seemingly had become dormant. Graph E was obtained early in April, 1926. A few of the alfalfa plants had begun to sprout, but most of them seemed to be still dormant. Rains April 6, 7, and 8 amounting to 0.49 inch had no apparent effect on the water level. Continuous warm weather during the week preceding the record given in graph F had caused all the plants to sprout, and they were now growing rapidly. Rains on April 18, 19, and 20 amounting to 0.35 inch caused the water table to rise approximately 1 inch between midnight April 18 and midnight April 20. By the first week in May (graph G) the alfalfa was growing with great vigor. Rains on May 2 and 5, amounting to 0.11 inch and 0.57 inch, caused pronounced rises in the water table.

It was found by explorations in this field with a soil auger that the maximum depth penetrated by the rains of September and October, 1925, was about 18 inches, or about one-sixth of the depth to the water table, which was then 8½ to 9 feet from the surface at the observation well. Observations early in April, 1926, disclosed a maximum penetration of 36 inches from the combined late fall, winter, and early spring rains. The water table was then about 7½ feet below the surface.

The five graphs in Figure 22 show the comparative effects on the water table in fields of different kinds of ground-water plants produced by a light general shower late in the afternoon of August 28, 1927. Graph A came from a well in a meadow near Milford which supports a heavy growth of salt grass. Graph B came from a naturally subirrigated field carrying a rather light stand of alfalfa, about 1½ miles south of Milford. Graph C came from a naturally subirrigated field having a heavy growth of alfalfa, about 4.5 miles from Milford. Graph D came from a field of dwarf greasewood near Thermo, 15 miles southwest of Milford. Graph E came from a meadow carrying a rather light growth of sedges and associated marsh grasses in Beaver Valley near Adamsville, 20 miles southeast of Milford and 10 miles west of Beaver. The rise of the water table in these different fields during the 24-hour period from midnight August 27 to midnight August 28 was as follows:

	Inches
A. Salt-grass meadow	1.6
B. Alfalfa field	.6
C. Alfalfa field	1.6
D. Greasewood	.5
E. Marsh-grass meadow	1.1

The amount of the rise was roughly proportional to the density of the vegetation, the greatest rise occurring in the salt-grass meadow and in one of the alfalfa fields, where the growth was heavy. The rain penetrated the soil to depths ranging only from 3 to 7 inches, and accordingly there was no ground-water recharge. Similar water-table rises almost immediately following small showers in summer have been observed in areas of ground-water plants in Snake Valley and Duck Valley, Nev.

These sudden rises after summer rains are clearly not due to ground-water recharge but are the result of a sudden cessation of the draft on the ground water by the plants. The rise is somewhat analogous to that which occurs in the vicinity of a pumped well when pumping ceases. The rise begins as soon as pumping stops. At first it is rapid, but after partial hydrostatic adjustment has taken place the rate of rise becomes slower. In a field of ground-water plants thousands of tiny pumps are operating, each drawing a small amount of water from the zone of saturation or the overlying capillary fringe. During showers and for some time thereafter the air is usually cool, the surfaces of the leaves are moist, and the weather is cloudy. Under these conditions the processes of transpiration are reduced to a low ebb, and the plant has little need for ground water. It therefore ceases pumping, and the water table immediately rises.

The sudden rise of the water table in fields of ground-water plants after showers throws considerable light on the effect of vegetation on stream flow. It apparently explains the sudden increases in stream discharge which sometimes occur after light showers. There is no surface run-off or ground-water recharge after these showers, but the demands of the vegetation in the area drained by the stream are greatly decreased. As a result the heavy draft on the ground water suddenly ceases, the water table rises rapidly, and almost immediately there is an increase of ground-water discharge to the streams and consequently an increase in stream flow.

The water table rises during the winter in the areas of ground-water discharge, but the beginning and progress of this rise seem entirely independent of rainfall. This is illustrated by the table below giving the average daily rise recorded at the well in the Hendrickson alfalfa field from October 6, 1925, to April 16, 1926, together with the precipitation during the 17 periods into which the record is divided. These figures show that the water table rose more rapidly from October 6 to January 14 than from January 15 to April 12, although the rainfall during the first period was considerably less than that during the second.

Rise of water table in well A, in Hendrickson's alfalfa field, during the winter of 1925–26 and rainfall during the same period

Period	Average rise per day	Rainfall	Remarks
	Inch	*Inches*	
Oct. 6 to 10	0.28	0	Alfalfa growing slowly.
Oct. 10 to 17	.25	.52	Do.
Oct. 17 to 25	.13	0	Alfalfa growing well.
Oct. 24 to 31	.12	0	Do.
Oct. 31 to Nov. 7	.22	.67	Alfalfa stopped growing.
Nov. 7 to 14	.18	.01	
Nov. 14–25	.21	.30	
Nov. 25 to Dec. 2	.20	.15	
Dec. 2 to 12	.19	0	
Dec. 12 to 17	.16	.08	
Dec. 17 to 24	.17	.04	
Dec. 17 to Jan. 14	.18	.02	
Jan. 14 to Mar. 12	.14	1.83	
Mar. 12 to 27	.07	.04	
Mar. 27 to Apr. 3	.04	.23	Alfalfa sprouting slowly.
Apr. 3 to 12	.07	.52	Do.
Apr. 12 to 16	[a] .41	.02	Alfalfa growing rapidly.

[a] Fall.

The conclusion is reached that comparatively little recharge occurs from rains on the floor of Escalante Valley. The rise of the water table during short periods after summer rains and during the long winter periods is caused by upward percolation from underlying water-bearing beds, whose water is under slight artesian pressure. These beds are supplied by intake high on the valley slopes, chiefly from the streams that issue from the mountain canyons.

FLUCTUATIONS DUE TO BAROMETRIC PRESSURE

In most regions the levels in artesian wells fluctuate to some extent with variations in atmospheric pressure, and in some localities such fluctuations have been noted in water-table wells. Several of the graphs obtained in Escalante Valley during the winter and spring when the ground was frozen or very wet disclose small fluctuations that apparently were due to changes in barometric pressure. This is seen in graphs F and G, Figure 4; graph A, Figure 5; and graph C, Figure 7. Only two of the graphs obtained during the summer show evidence of being affected by changes in barometric pressure, although careful search was made for such evidence during which special attention was given to graphs from wells in cleared fields. The exceptions are graph A, Figure 11, and graph B (for September 15, 1925), Figure 14.

SEASONAL FLUCTUATIONS

Most of the automatic records of the water-table fluctuations that were obtained during the late spring, summer, and early fall show a decided downward slope from day to day, but those that were obtained during the remainder of the year have an upward trend. These downward or upward trends indicate the rate of seasonal decline or rise of the water table. Observations were made several times a year on about 100 wells spaced at varying distances along the length of Escalante Valley, in order to study these periodic fluctuations. It was found that in all localities in the valley where ground-water plants are common the water table declines during the growing season and rises during the period when plant life is dormant. The decline usually begins with the first appearance of vegetation in the spring, and the rise begins when the plant growth is stopped or materially slowed up in the fall.

In parts of the Milford meadows evidences of the decline are seen late in March or early in April, before the grasses begin to sprout. (See fig. 6.) This occurs because the water table is at the surface or within a few inches of the surface, and considerable ground water is lost by evaporation from the soil, particularly on sunny and windy days. Also in localities close to pumping plants in the Milford district the march of water-table rise and fall is distributed somewhat by fluctuations due to pumping. In the greater part of this district, however, and elsewhere in the valley the fall and rise are very closely coincident with the beginning and end of the period of plant activity. The rise, as is explained on page 53, is independent of rainfall. The autumn of 1925 was rather wet and that of 1926 was unusually dry; nevertheless, in the same fields the annual rise began at almost exactly the same time in each of these years. In naturally subirrigated alfalfa fields the rise in 1925 began with heavy rains on October 4 and 5. (See fig. 3, graph B.) In 1926 the rise began the first week in October, although there had been no rains of consequence for weeks. It was noticed that in the meadows the seasonal rise begins, whether it rains or not, late in August or early in September, when the grasses are approaching maturity and the growth is slowing up. The rate of rise in the meadows, however, becomes more rapid after the occurrence of heavy frosts. The seasonal rise in fields of other ground-water plants follows closely the appearance of frosts severe enough to harm plant life seriously.

The average amount of the annual decline and rise of the water table is much greater in the Milford district than anywhere else in the valley. Also in that area the summer decline in each year of the investigation was somewhat greater than the winter recovery, and there was therefore a net loss in height of the water table. The average seasonal rise in 37 representative observation wells in the Milford district in 1925–26 and 1926–27 amounted to 1.88 feet. In the meadows and subirrigated alfalfa fields the average rise was 2.54 feet. In fields of greasewood, rabbit brush, and shad scale the rise averaged 0.86 foot. On the higher lands adjoining the areas occupied by ground-water plants the water level rose an average of 0.18 foot in 9 wells and declined an average of 0.34 foot in 8 wells. The data that were obtained as to the seasonal fluctuations are given in the following table. (See also figs. 2 and 23.) In all but 8 of the wells the lowest levels occur in the fall and the highest in the follow-

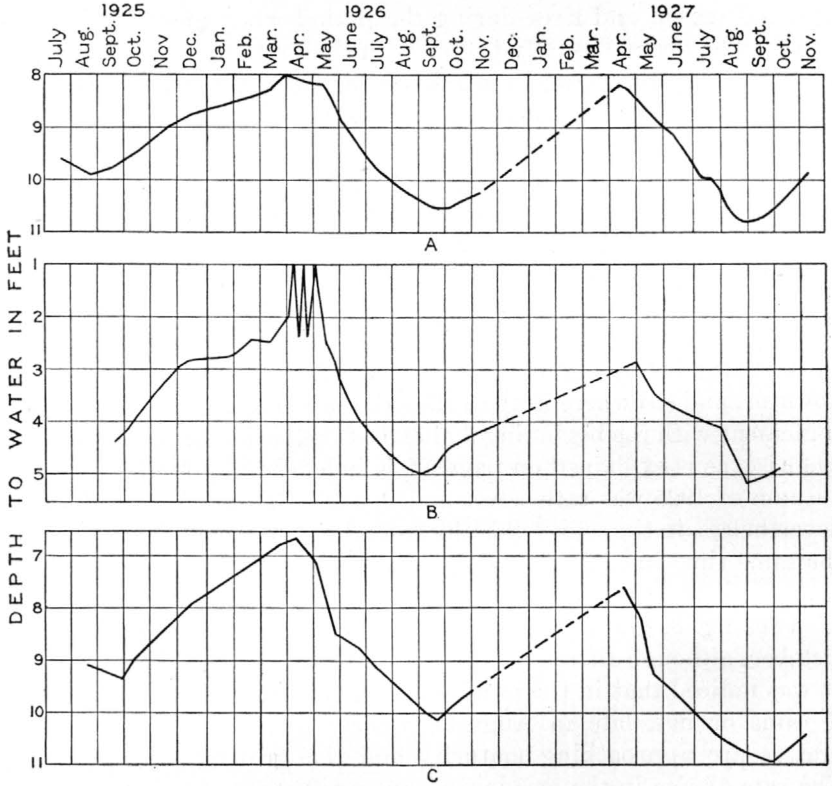


FIGURE 23.—Typical seasonal fluctuations of the water table in fields of ground-water plants

ing spring. As observations were discontinued November 16, 1927, the highest levels for the climatic year 1927–28 are not shown. It is estimated that each year the volume of soils saturated in the Milford district as the water table moved upward amounted to about 50,000 acre-feet.

Highest and lowest water levels observed each season in wells near Milford from the fall of 1925 to the fall of 1927

Well No.	Location				1925–26				1926–27				1927	
					Lowest		Highest		Lowest		Highest		Lowest	
	T. S.	R. W.	Sec.	Quarter	Date	Depth to water (feet)	Date	Depth to water (feet)	Date	Depth to water (feet)	Date	Depth to water (feet)	Date	Depth to water (feet)
A	28	11	36	NW.	Sept. 26	9.32	Apr. 10	6.68	Sept. 20	10.18	Apr. 23	7.61	Oct. 1	10.95
B	28	11	36	NE.	Sept. 5	10.34	Apr. 15	8.23	Oct. 1	(a)	May 9	8.92	do	(a)
C	28	10	17	NW.	Oct. 7	5.87	Apr. 12	3.88	do	6.39	Apr. 25	4.45	do	(a)
C-1	28	10	8	SW.	---	---	Mar. 13	.44	Aug. 31	3.18	May 21	.77	Sept. 1	3.30
D	28	10	7	SE.	Aug. 24	9.92	Apr. 1	7.94	do	10.33	Apr. 27	8.37	do	10.85
D-5	28	10	8	NW.	do	5.27	May 5	1.30	Sept. 1	4.58	May 1	2.20	do	5.58
D-6	28	10	8	NW.	---	---	do	.50	Sept. 20	3.20	May 21	.24	do	3.32
E	28	11	24	NE.	Aug. 31	5.57	Apr. 13	2.03	Sept. 3	5.60	Apr. 25	3.76	Aug. 30	6.17
G	28	11	25	NE.	Aug. 30	4.90	May 5	2.16	Sept. 1	5.41	May 4	3.31	do	6.01
H	28	10	19	NE.	Sept. 29	5.00	Apr. 12	2.48	Aug. 31	5.58	May 3	3.51	Aug. 31	6.20
I	28	11	25	SE.	Aug. 31	4.76	May 5	2.58	Sept. 3	5.16	May 4	3.04	do	(a)
K	28	11	35	NW.	Aug. 24	3.52	May 6	.10	Aug. 24	3.76	do	2.12	do	(a)
L	28	11	34	NE.	Aug. 31	3.54	Mar. 2	.92	Aug. 27	3.86	do	(a)	---	---
M	28	11	34	NE	do	3.74	Mar. 14	1.84	Aug. 29	4.00	do	(a)	---	---
N	28	11	25	SW.	Sept. 23	5.72	May 6	3.74	Sept. 20	6.43	do	4.50	Sept. 20	(b)
O	29	11	2	NW.	Sept. 11	5.33	May 5	3.56	Aug. 28	5.98	May 11	4.05	Aug. 31	(c)
P	29	11	9	SE.	Sept. 21	4.09	May 8	2.16	Sept. 12	4.26	do	2.40	Oct. 10	4.60
Q	27	10	17	SW.	Oct. 26	4.30	Apr. 13	3.23	Oct. 25	4.69	May 1	(b)	---	---
R-2	27	10	32	SE.	Sept. 30	3.60	May 6	1.64	Aug. 31	4.10	do	2.28	Aug. 31	4.20
R-3	27	10	32	NE.	do	2.68	Mar. 13	0	do	3.56	May 8	.60	do	3.85
1	28	11	25	SW.	Oct. 28	4.32	Apr. 8	1.20	Sept. 3	4.98	May 2	2.84	Sept. 1	5.14
2	28	11	36	SW.	Oct. 5	10.48	Mar. 15	8.13	Nov. 2	11.72	Apr. 3	7.92	Nov. 16	13.30
3	28	11	36	NE.	Sept. 16	9.88	Apr. 10	7.19	Oct. 1	10.33	Apr. 30	8.38	Sept. 31	10.75
4	28	10	31	SW.	Sept. 3	16.62	Mar. 13	14.53	Nov. 3	18.03	do	16.62	Nov. 16	19.31
6	29	10	5	NW.	Oct. 13	21.51	Mar. 5	21.25	(b)	---	---	---	---	---
7	28	10	33	SE.	Oct. 6	59.82	Apr. 27	60.71	Oct. 15	56.77	May 1	58.12	---	---
8	29	10	6	SE.	Oct. 12	30.66	Apr. 30	31.09	Nov. 3	31.31	do	31.55	Nov. 16	32.24
9	29	10	7	SW.	do	33.47	Mar. 15	33.72	do	34.11	do	34.20	do	34.82
10	29	10	6	NE.	do	20.34	do	20.20	---	---	---	---	---	---
11	29	10	16	SW.	do	50.78	Apr. 30	51.45	Oct. 2	50.49	May 1	50.80	---	---
12	29	11	13	SW.	Sept. 28	30.35	Mar. 15	30.10	Sept. 27	30.97	May 2	30.47	Nov. 16	31.17
13	29	11	13	NW.	Sept. 11	26.58	Apr. 24	26.46	do	27.48	do	26.74	---	---
14	29	11	2	NE.	Sept. 22	12.16	Mar. 15	10.46	do	(c)	---	---	---	---
15	29	11	15	NE.	Aug. 26	12.18	May 1	11.47	Aug. 25	11.96	---	---	---	---

[a] Dry. [b] Caved in. [c] Closed.

Highest and lowest water levels observed each season in wells near Milford from the fall of 1925 to the fall of 1927—Continued

Well No.	Location				1925–26				1926–27				1927	
					Lowest		Highest		Lowest		Highest		Lowest	
	T. S.	R. W.	Sec.	Quarter	Date	Depth to water (feet)	Date	Depth to water (feet)	Date	Depth to water (feet)	Date	Depth to water (feet)	Date	Depth to water (feet)
16	29	11	15	SW.	Sept. 21	12.88	May 1	11.48	Sept. 27	13.21	Apr. 28	11.82	Nov. 16	13.62
17	29	11	23	NW	Oct. 31	25.98	May 8	25.80	Nov. 2	26.51	(c)			
20	29	11	28	NW.	Sept. 26	16.67	Mar. 13	16.07	(c)					
21	29	11	33	NW.	Oct. 3	18.72	do	18.56	Oct. 25	19.27	Apr. 28	18.97	(c)	
22	29	11	33	NW.	Aug. 26	20.22	do	19.97	do	20.28			Sept. 6	20.25
23	30	11	8	NE.	Sept. 22	29.48	May 28	29.27	do	29.24	Apr. 28	29.08	Sept. 29	29.17
24	30	12	13	NW.	Oct. 31	9.00	Mar. 15	8.40	do	9.20	May 24	8.77	Oct. 29	9.40
25	30	12	9	SE.	Nov. 10	30.66	do	30.24	do	30.80	do	30.45		
25-a	30	12	27	SW.	Nov. 28	19.18	May 28	19.02	Nov. 2	19.34	do	19.29	Oct. 29	19.45
26	29	11	20	SW.	Oct. 26	10.50	May 18	9.80	(b)					
27	29	11	20	NW.	Dec. 16	14.42	May 8	13.91	(b)					
28	29	11	17	NE.	Aug. 26	18.40	do	17.14	Sept. 17	18.61	Apr. 28	17.46	(c)	
29	29	11	17	NE.	Sept. 26	14.07	do	12.74	do	14.24	(a)			
32	28	11	34	NW.	do	24.75	do	23.58	Oct. 25	25.03	(c)			
34	28	11	23	NE.	Aug 25	16.10	May 30	15.70	do	16.24	Apr. 29	15.15	(c)	
36	28	10	4	SE.	Dec. 18	24.32	Apr. 15	24.33	Nov. 1	24.62	May 28	24.70	Oct. 31	24.97
37	28	10	4	NW.			May 6	4.08	Aug. 31	6.81	do	4.45		
38	28	10	3	SE.	Oct. 8	99.65	May 2	99.73	Nov. 1	99.75	do	99.77	Oct. 25	99.83
39	27	10	16	NE.	do	86.92	May 14	86.99	Oct. 22	87.11	do	87.20	Oct. 31	87.36
40	28	10	14	NW.	Oct. 19	188.45	May 8	189.69	do	189.80	do	189.85		
41	27	10	32	SE.	do	19.35	Mar. 15	17.90	do	19.67	May 9	18.22	Aug. 31	19.85
43	27	10	7	NE.	Oct. 22	17.26	May 27	16.22	Oct. 27	17.90	May 3	16.20	Oct. 15	18.00
44	26	10	30	NE.	do	9.14	May 1	8.50	Oct. 25	10.04	May 23	(a)		

a Dry. b Caved in. c Closed.

CAUSE OF FLUCTUATIONS

What is the explanation of the daily fluctuation of the water table? The processes that take place can be visualized by referring to Figure 24, which gives a diagrammatic cross section of one of the experimental vegetation tanks, which were so constructed and operated as to reproduce conditions as they are conceived to exist

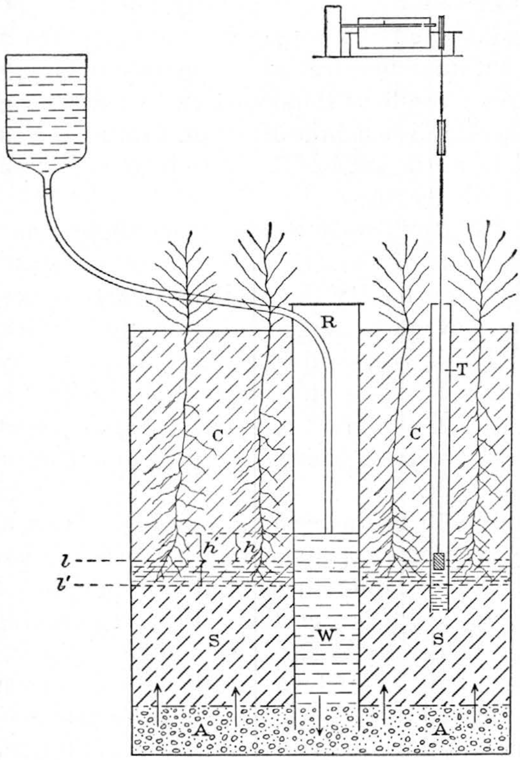


FIGURE 24.—Diagrammatic cross section of experimental vegetation tank. A, Water-bearing gravel bed; S, saturated soil. A and S together form the zone of saturation, but the material of S is much less permeable than that of A, and S therefore acts as an imperfect confining bed for the underlying artesian water. C, Capillary fringe; *l*, *l'*, belt of water-table fluctuations; *h*, artesian head in morning; *h'*, artesian head in evening; R, recharge well; T, water-table well

in the field. Below the water table (*l* or *l'*) the material (S) is saturated—that is, its interstices or pore spaces are completely filled with water. Above the water table water is supplied to the soil (C) by capillary action, but in the capillary fringe the pores are only partly filled with water. Capillary force exerts a tension or pull that tends to draw water upward from the zone of saturation into the capillary fringe until a state of equilibrium is reached.

In the field the capillary fringe ranges in width from less than an inch in clean gravel to as much as 8 feet or more in silt or clay. The greater part of the root systems of the ground-water plants terminate in the capillary fringe, but at numerous places small roots were seen to penetrate slightly below the water table. The fringe water is able to resist the pull of gravity but is withdrawn by the roots of the plants, and if the capillary fringe extends to the surface or comes within a few feet of the surface it may lose water by evaporation. As a result of the depletion by these agencies a capillary gradient is established in a direction toward the surface, water moves upward from the zone of saturation to supply the deficiency, and the water table declines.

The ground water evidently comes up by slight artesian pressure from permeable beds of sand or gravel at some depth beneath the water table. During the day the capillary fringe is depleted by the plants, and the movement of ground water by capillary action to meet the depletion is more rapid than recharge by hydrostatic or artesian pressure. Therefore the water table declines and the head increases. During the night transpiration and evaporation losses are small, the water table moves upward, and the pressure head declines.

From about 6 to 10 in the evening and again from about 6 to 10 in the morning recharge approximately balances discharge, and for a few hours the water table is nearly at a standstill. This state of equilibrium would be reached earlier both in the evening and in the morning if it were not for a lag in some of the operations. At or soon after sunset, the rate of transpiration and evaporation declines to a small fraction of the rate that prevails during the day, but for a time the plants continue to draw some water to fill their circulatory systems, which have become somewhat depleted. (Nearly all plants become slightly wilted during the day, particularly on hot days, and tend to have a drooping appearance at night, quite in contrast with their fresh, turgid appearance in the morning.) Moreover, during the day the recharge of the capillary fringe from the zone of saturation lags somewhat behind the discharge by plant action. By midnight, or slightly before, the veins of the plants have become filled with water. Meanwhile capillary equilibrium has been nearly established in the capillary fringe, and during the hours from midnight to morning there is little movement of water to the fringe from the zone of saturation.

Between midnight and 4 a. m. the water table is approximately at a mean elevation for the 24-hour period, and therefore the head is also approximately at a mean, provided there is no net gain or loss in water-table elevation during the 24-hour period. If the water table has a net fall during the 24 hours, the head in the early morning hours mentioned is slightly above the noon to noon mean; and if it has a net rise, the head is slightly below the mean but the difference is generally not great. The velocity of water moving through a rock or soil varies approximately as the hydraulic gradient. Therefore if the slight losses by transpiration and evaporation between midnight and 4 a. m. are neglected, as well as the slight difference between the hydraulic head at this time and the true mean for the day, the hourly rate of recharge from midnight to 4 a. m. may be accepted as the average rate for the 24-hour period. The total quantity of ground water withdrawn by transpiration and evaporation during the 24-hour period can then be determined by the formula $q=y(24r\pm s)$, in which q is the depth of water withdrawn, in inches, y is the specific yield of the soil in which the daily fluctuation of the water table takes place, r is the hourly rate of rise of the water table from midnight to 4 a. m., in inches, and s is the net fall or rise of the water table during the 24-hour period, in inches. In field experiments the quantities on the right-hand side of the formula except the specific yield can be readily determined from the automatic records of water-table fluctuation.

EFFECT OF GRAVEL AND PEAT

The character of the soil and subsoil apparently has a notable effect on the ability of the alfalfa to maintain itself on subsurface moisture. It was found that natural subirrigation was more effective in some fields where the depth to the water table was 10 to 12 feet than in others where the depth was only 6 to 8 feet. Conditions within the individual fields also seemed to vary materially, even where the depth to the water table was comparatively uniform. In all the fields that were not irrigated or only partly irrigated the stand was thicker and the growth more vigorous in some places than in others, and in nearly all such fields there were some bare spots. This was particularly noticeable in the fall, when the water table was 2 to 3 feet lower than in the spring. It was the common belief of the ranchers that the bare spots and the places of stunted growth were underlain by a stratum of gravel above the water table, which prevented the roots from penetrating to ground water. The investigation showed that the gravel was present in some localities but not in others. Well A, from which the graphs shown in Figures 3 and 4 were obtained, penetrated 8½ feet of gray clay loam and black loam, below which it passed through coarse sand and gravel.

In the spring and early summer, when the water table was at depths of less than 8½ feet, the growth of alfalfa plants in the vicinity of the well was rapid and vigorous. Later in the season, when the water table declined into the stratum of sand and gravel, the plants around the well assumed a slightly yellow appearance and apparently ceased to grow. Auger holes put down in other localities in the same field where the alfalfa had entirely died out encountered dry gravel at depths of 3 to 5 feet, several feet above the water table. Two auger holes, each 8 feet deep, were put down in the fall of 1927 in an alfalfa field that had not been irrigated for six years, in NW. ¼ sec. 19, T. 28 S., R. 10 W. One was sunk where the stand was thick and vigorous, and the other at a point about 30 feet away, where the plants had been growing well when the first cutting was made, late in June, but had later become stunted and unhealthy in appearance. Both holes reached the water table at a depth of 7¾ feet. The hole where the growth was heavy penetrated clay loam and sandy clay loam all the way down, and below 3½ feet the earth was moist. Bits of alfalfa roots were brought up by the auger from this hole at a depth of 7½ feet. The hole in the poor stand of alfalfa cut through 6 feet of loam similar in texture to the soil penetrated by the other hole but much drier. Between 6 and 7 feet it encountered 10 inches of coarse peaty soil, which was quite dry, though just above the water table. Bits of alfalfa roots came from this hole at different depths down to 6 feet, but none were found in the peat stratum nor below it.

In another field that had not been irrigated for a year, in the NE. ¼ of the same section, two holes were put down, one in a patch of heavy alfalfa and the other in a spot where the growth was stunted. The first penetrated 8 feet of loam and sandy loam and reached water at 8.8 feet in sand. From the depth of 4 feet down to the water table the soil was moist. The second hole, about 40 feet distant, cut through a foot of top loam and then penetrated about 6 feet of coarse peaty soil underlain by sand in which water was reached at 9 feet. The peaty soil was dry all the way down, although the bottom of the stratum was only 1½ feet above the water table. Two auger holes in a naturally subirrigated field in sec. 30, T. 28 S., R. 10 W., one in heavy alfalfa and the other in a patch of stunted growth, disclosed underground conditions similar to those in sec. 19. In these fields and in others that were examined the alfalfa usually had a fairly uniform and vigorous growth in the early part of the growing season and did not show signs of distress until the middle or later part of the summer. The stunted areas were materially larger in 1927 than they were in 1926, and the writer has been informed that they became still larger in 1928 and that on this account several fields which had depended for years on natural subirrigation were supplied with pumped water in that season. This situation undoubtedly was due to a decline in the water table. Each year the water table beneath the area devoted to raising alfalfa seed is lower in the late summer and early fall than it is in the spring and early summer. This explains why in some fields better success was attained in the early part of the season than in the later part. Furthermore, as mentioned elsewhere in this report, there was during the period of the investigation a net yearly decline in the water table, which it is understood continued in 1928. The total net decline including that of 1928 was not very great, and under favorable conditions the roots of the plants should have been capable of following the water downward. It is probable that where they have failed to do so moisture has been cut off as a result of the water table declining below gravel or other coarse materials in which the interstices are so large that capillary tension is broken. The plant has therefore been unable to obtain the sustenance that would enable the roots to penetrate deeper, and the growth has stopped or been greatly retarded.

MILFORD EXPERIMENT STATION

It was an interesting thing to find that nearly everywhere in the localities investigated there are pronounced daily fluctuations of the water table in areas of ground-water plants. It was more significant to find that the amplitude of the daily fluctuations varies with the stage of plant growth and with the vigor and density of the vegetation and that when plant growth ceases the fluctuation stops. This shows that the fluctuations are a measure of the daily use of water by the plants. To make practical use of the field data, however, it is necessary to interpret the fluctuations in terms of the amount of water used by the plants. At least half the work of the Escalante Valley investigation was devoted toward that end.

The problem was approached in several ways. Cylinders were driven near observation wells in fields of different kinds of ground-water plants, so as to inclose columns of undisturbed soil, and the rise and fall of the water table in the inclosed columns after the addition or subtraction of measured amounts of water were carefully noted.

Ground-water plants were raised in four tanks, filled with soils of the types to which the plants are partial and provided with an automatic measured water supply and otherwise so equipped as to duplicate as closely as possible conditions that exist in the field. To determine the discharge of ground water by evaporation alone two of the vegetation tanks were provided with a companion tank filled with bare soil of the same type as that in the corresponding vegetation tank, the water table in it being maintained at similar depths. In this way the attempt was made to differentiate transpiration losses from evaporation losses.

Daily water-table fluctuations similar to those that occur in the field were obtained in the vegetation tanks. These fluctuations were correlated with the daily ground-water discharge as indicated by the measured water supply delivered to the tanks.

The amount of water required to produce a unit weight of dry vegetable matter in the tanks was computed, and the coefficient of ground-water discharge thereby obtained was applied to the field.

In order to have a common basis for comparison a determination was made of the ratio between all ground-water discharge disclosed by the tank experiments and water-surface evaporation for corresponding periods.

The chief items of the experimental equipment were as follows: Nine specific-yield tanks driven as cylinders and later sealed to inclose columns of undisturbed soil; four vegetation tanks—alfalfa one, greasewood one, and salt grass two; seven soil tanks; four water-surface evaporation pans; rain gages; an anemometer; and a maximum and minimum thermometer.

The evaporation and transpiration studies were carried out chiefly on a small tract of land adjacent to the Union Pacific Railroad about half a mile south of Milford. (See pls. 6, *B*, 7, *A* and *B*.) The tract was fenced, and a well was put down on it. At the start this station was equipped with one soil tank, two evaporation pans, a rain gage, an anemometer, and a maximum and minimum thermometer. As the work progressed 3 vegetation tanks, 2 soil evaporation tanks, 1 specific-yield tank, and 2 evaporation pans were added. One vegetation tank and one soil tank were established in open fields near the central experimental station, and eight of the specific-yield determinations were made in more or less widely distributed fields, all, however, within a radius of 5 miles of the station.

EXPERIMENTS WITH PLANTS GROWN IN TANKS

APPARATUS AND METHODS

In order to interpret the fluctuations of the water table in terms of quantity of water discharge, conditions as they are conceived to exist in the field were reproduced by growing alfalfa, greasewood, and salt grass in tanks filled with soil and equipped with an automatic device for supplying measured quantities of water to the plants by subsurface irrigation. (See pls. 8, *A* and *B*, and 9, *A*, and fig. 24.)

Alfalfa plants four months old were transplanted into tank 1, seven small greasewood shrubs were transplanted into tank 2, and a depth of about 24 inches of salt-grass sod was placed in tank 3. The tanks were circular and made of 22-gage galvanized metal, and all were water-tight. Tanks 1, 2, and 3 were 48, 46, and 44 inches in diameter, respectively, and each had a depth of 54 inches. All were set in the ground with the rim just far enough above the surface to prevent storm water from entering at the sides. About 6 inches of clean gravel (fig. 24) was placed at the bottom of each tank, and they were then filled with soil. A well (W) was sunk in the center of each soil column to the bottom of the tank and was cased with galvanized metal, which was perforated only in the bottom 6 inches, where gravel was penetrated. This well, called for convenience the recharge well, was used to introduce water into the tank. Smaller wells (T), also cased, were sunk through the belt of fluctuation of the water table but were terminated in the saturated soil about a foot above the gravel. The casings in these small wells were perforated to permit free access of ground water at all stages of the water table, and hence the water levels in them showed the position of the water table.

A simple device was set up whereby water was automatically fed into the recharge well as rapidly as was necessary to keep the water surface in the well constantly at any desired level. The device consisted of a 3-gallon or 5-gallon bottle to which a 6-foot length of 1-inch garden hose was tightly fitted. The bottle was set upside down in a wooden frame placed just outside the tank, and the hose was dropped into the recharge well and fastened by means of a clip which kept the lower open end at a fixed level. When the water in the well fell below this level some water escaped from the bottle and was replaced by air. In this way the water in the recharge well was kept at a fairly uniform level, and a slight but comparatively constant hydraulic or artesian head was imposed on the water in the gravel at the bottom of the tank. By means of a graduated scale painted on the outside of the bottle the amount of water discharged into the tank during the periods between successive observations was ascertained.

It was found that during the daytime, when the plants were absorbing water from the capillary fringe or directly from the soil in the zone of saturation, the water table declined, as it commonly does in nature. This created an artesian head in the water in the gravel bed equal to the difference between the level of the water table and that of the water surface in the recharge well. Under this head the water moved upward through the soil at a rate which, according to the well-established Darcy's law, was directly proportional to the permeability and thickness of the saturated soil and also to the head of the water.

Observations were made at frequent intervals during the day and night to determine the water added to the zone of saturation, the increase or decrease of storage in this zone, and the quantity of water discharged from this zone for any given period. At night absorption by the plants became very slight and withdrawal from the zone of saturation by capillarity gradually diminished to a small amount. The upward percolation, however, continued under the artesian head, and hence the water table rose from its position at h' in the evening to that of h the next morning. Inasmuch as the rate of percolation varies directly as the head, it decreased during the night as the head decreased from a maximum of h' in the evening to h in the morning. In fact, the rate of percolation decreased somewhat more rapidly than the head, because the thickness of the soil through which percolation occurred increased somewhat as the water table rose. In the later part of the night, when withdrawal from the zone of saturation had become nearly or quite negligible, the data as to the quantity of water withdrawn from the bottle during a given period gave information as to the rate of upward percolation, and, the average head and thickness of saturated soil during the period being known, the approximate permeability of the soil could be computed. By observing the rise of the water table during the period it was possible to compute the volume of water that was required to saturate a unit volume of soil and thus determine the specific yield of the soil. It was obviously possible to make a complete inventory of the water supply in the entire system for any period of the day or night and thus to interpret the fluctuations of the water table in terms of quantity of water discharged from the zone of saturation by transpiration and evaporation. Theoretically the only source of error in these computations was that produced by withdrawals from the zone of saturation which may have occurred during the later part of the night. The form of the daily curves for water-table fluctuation, however, indicates that such withdrawals were small in amount and probably produced relatively unimportant errors in the computations.

ALFALFA

The experiment with alfalfa was carried out in tank 1 for the purpose of interpreting daily water-table fluctuations in naturally subirrigated alfalfa fields, with special reference to the Hendrickson field, in which wells A and A–1 were located. The tank was 48 inches in diameter and 54 inches deep. It was installed early in April, 1926, and was filled with a gray to black loam soil taken from the roadside adjacent to a field of alfalfa in which the stand was particularly good. A center or recharge well 8 inches in diameter was provided, together with three water-table or measuring wells, one 2 inches in diameter and the other two three-fourths inch in diameter.

The tank was supplied with about 35 plants of Grimm alfalfa taken from a field that had been seeded in July, 1925, and therefore had achieved a growth of three or four months. The roots of these plants ranged in length from 15 to 36 inches and averaged about 24 inches. About one-third of the plants died, and early in May were replaced by another batch of settings from the same field, most of which lived. Gradually the surviving plants increased in size and the growth thickened until by August 1 the stand had reached

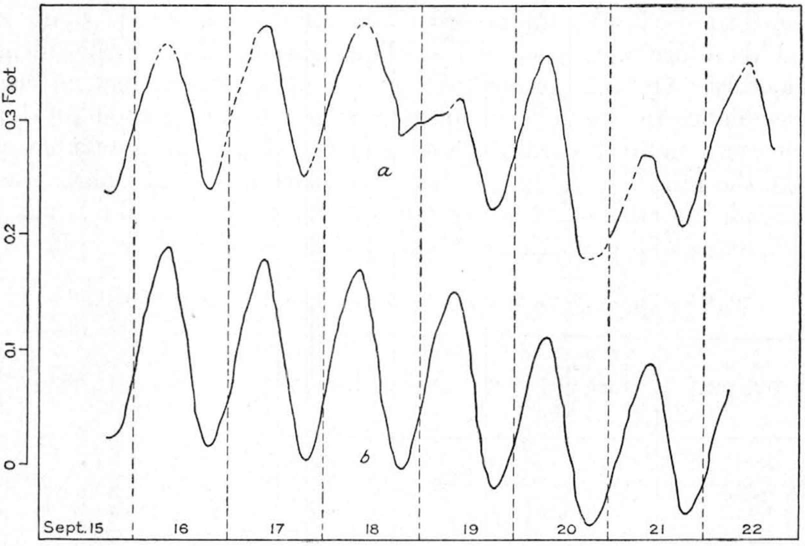


FIGURE 25.—Comparison between daily fluctuations of the water table in the alfalfa tank (No. 1) (*a*) and in Hendrickson's alfalfa field (*b*)

a density apparently about equal to the average density in the Hendrickson field. (See pl. 9, *A*.) It was necessary to apply some water to the surface of the soil during the early stage of plant growth in May and June, and two small surface irrigations were provided after the first and second cuttings of the crop in July and August, respectively. Early in the spring of 1927 ground squirrels destroyed some of the plants and damaged others, and a small amount of surface watering was again deemed advisable. However, the total amount of water applied to the surface was small, and in both 1926 and 1927 at least 90 per cent of the water which the plants received in addition to rainfall was derived from subsurface moisture introduced into the tank through the recharge well.

The tank was provided with an automatic water feed August 27, 1926, which was kept in operation during the remainder of the season and during most of the season of 1927. This device (see p. 65) kept the water in the well at a nearly constant level and maintained a slight pressure head on the water in the gravel at the bottom of the tank, which served to duplicate hydrologic conditions in the field. Fluctuations occurred in the water-table wells practically identical in character with those obtained in the field, the water rising during the night and going down during the day.

Graph *a*, Figure 25, shows the record of water-level fluctuations in the 2-inch water-table well of the tank during the 7 days September 15–22, 1926, as portrayed by an automatic water-stage recorder. The float used with the recorder was only 1½ inches in diameter and therefore was much too small to operate the recorder drum smoothly. On this account the graph is imperfect, but its close resemblance to graph *b*, obtained during the same period in Hendrickson's naturally subirrigated alfalfa field, is unmistakable.

In the following table the terms " daytime use " and " night use " indicate the amount of water fed into the tank from the recharge well, expressed as depth in inches over the surface of the soil.

Water requirement and water-table fluctuation in tank 1, in inches

Date (1926)	Daytime use	Daytime drawdown	Night use	Night rise	Date (1926)	Daytime use	Daytime drawdown	Night use	Night rise
Aug. 29–30	0.085	1.44	0.076	0.84	Sept. 21	0.127	1.56	------	------
Aug. 30–31	.115	1.56	------	------	Sept. 22–23	[a].230	1.68	------	------
Aug. 31–Sept. 1	------	------	.10	.96	Sept. 23–24	.120	1.20	0.131	1.56
Sept. 1–2	.125	1.20	.067	.96	Sept. 26–27	.115	.96	0.140	1.44
Sept. 3–4	------	------	.113	1.08	Sept. 27–28	[a].250	------	------	------
Sept. 4–5	[a].212	------	------	------	Sept. 28–29	.127	1.56	.121	1.44
Sept. 5–6	.117	1.20	.108	1.08	Sept. 29–30	------	------	.110	.60
Sept. 7–8	------	------	.138	1.44	Sept. 30–Oct. 1	.126	.48	[b].067	1.08
Sept. 8–9	.130	2.88	.118	.84	Oct. 1–2	[a].176	------	------	------
Sept. 9–10	.117	1.08	.115	1.08	Oct. 2–3	.102	.84	.065	1.00
Sept. 10–11	.121	1.08	.114	.96	Oct. 17–18	------	------	.140	------
Sept. 14–15	.124	1.20	.128	1.32	Oct. 18–19	.079	.72	.098	.36
Sept. 15–16	.150	1.32	.127	1.44	Oct. 19–20	.086	.84	.101	.96
Sept. 16–17	[a].260	------	------	------	Oct. 20–21	.083	.60	.095	.84
Sept. 17–18	[a].150	1.68	.155	1.68	Oct. 21–22	[a].185	------	------	------
Sept. 18–19	.153	.96	.174	.24	Oct. 22–23	.91	.72	.060	.78
Sept. 19–20	.098	.60	.151	1.80	Oct. 23	.06	.78	------	------

[a] Day and night. [b] Water-supply tube obstructed by ice.

During the period a total depth of 7.5 inches of water was supplied, an average of 0.214 inch daily. The average rise during the night amounted to 1.18 inches in the ¾-inch water-table well and to 1.05 inches in the 2-inch water-table well, the mean for the two wells being 1.12 inches. On the basis of night observations made in 1927 it is estimated that 45 per cent of the rise took place between midnight and 4 a. m., representing a rise of 0.126 inch an hour.

If we use this figure for r and 5.5 as the specified yield (see Table 9) in the formula $q=y(24r\pm s)$ we get 0.166 inch as the amount of ground water discharged daily, which is 78 per cent of 0.214 inch, the true discharge. The discrepancy in these figures probably is due in part to the effect of daily changes in temperature, the amount of the night rise probably being reduced somewhat by a slight decline in the tank temperature during the night. During the period when these figures were obtained the top of the tank was covered with a mulch of sawdust, but this blanket was more or less disturbed by the wind and was only partly effective as a heat insulator. A series of experiments with the specific-yield tanks disclosed that the water table declined from 0.15 to 0.30 inch with a fall of 1° centigrade in the temperature of the soil in the tanks and rose correspondingly with a rise in temperature. Owing to fluctuations in the water table resulting from transpiration by the plants, it was impossible to determine the correction for temperature in the vegetation tanks.

Owing to damage by squirrels in the spring of 1927 the alfalfa put on comparatively little growth in May, and the stand throughout the season was lighter than in 1926. The average amplitude of the daily water-table fluctuations in the tank and the consumption of water were correspondingly less. Table 7 gives the amount of ground water discharged monthly from the tank both by evaporation and by transpiration in 1926 and in 1927, expressed as depth in inches over the soil area, the weight of the water consumed, and the weight of the alfalfa produced in both years.

SALT GRASS

Salt grass transplanted from a near-by meadow was grown in tank 2. The fill in the tank consisted of 6 inches of gravel, 24 inches of dark-gray clay loam, and 18 inches of salt-grass sod, the soil and sod taken from the meadow. The tank was provided with a 3-inch center or recharge well and with three water-table wells, one 2 inches in diameter and two 0.75 inch in diameter.

The sod was placed in the tank April 15, 1926, and was liberally sprinkled with water at frequent intervals until the end of the first week in May, when subirrigation was begun by water introduced through the center well. This proved satisfactory for a time, but during hot weather early in June the new growth began to show signs of distress and sprinkling was again resorted to, a depth of 2.06 inches of water being thus applied to the surface of the sod during the month. By July 1 the plants seemed to be doing well and apparently had become adjusted to their new environment. Accordingly subsurface watering was resumed and was continued until the end of the experiment in the fall of 1927. One small surface watering was also made about a week after the crop was cut in August, 1927. The grass did fairly well the first year, but the stand was thin and normal growth was not attained until 1927. The tank was equipped with an automatic water-supply unit during September and October, 1926, and during a considerable part of the season of 1927. The experiment proved to be a disappointment in so far as fluctuations in the water table were concerned. The expected nighttime rise and daytime decline failed to develop. The water table rose and fell slightly, but these fluctuations seemed to be due to slight fluctuations in the water level in the recharge well and to be independent of the discharge of ground water by the transpiration of the salt grass. In all the experiments as the temperatures rose in the morning water was forced out of the bottle by the expanding air at a rate above normal. In the evening the opposite took place and the rate of flow was retarded. This variation in the rate of flow had little effect on the water level in the 8-inch well of the alfalfa tank, but it produced fluctuations of appreciable magnitude in this tank and in the greasewood tank. The failure to obtain the characteristic water-table fluctuations in this tank may thus have been due in part to the small size of the recharge well.

Tank 9 was filled with soil from a bare spot on the meadow, a few feet from the place where the salt-grass sod and soil in tank 2 was obtained, and was operated as a soil evaporation tank. The soil in this bare spot apparently was excessively alkaline, perhaps considerably more alkaline than the soil put into tank 2. On this account or for some other reason the rate of ground-water discharge from tank 9 was abnormally low—very much lower, in fact, than was observed in any other of the soil evaporation experiments. (See Table 8.) Moreover, as the soil in tank 2 was overlain by a thick salt-grass sod, it is not safe to assume that evaporation from it was comparable with evaporation from tank 9 or from any of the soil tanks. Therefore no attempt is made to separate evaporation losses from transpiration losses in tank 2.

The total discharge of ground water from tank 2, expressed as depth in inches over the surface of the sod, amounted to 14.73 inches in 1926 and 17.88 inches in 1927. (See Table 7.) The yield of salt grass in the tank in 1927 after being oven dried was 0.47 pound, representing 1,950 pounds to the acre. The ratio between the weight of the ground water discharged jointly by transpiration and evaporation and the dry weight of the salt grass was approximately 2,077 to 1 in 1927.

The experiment with tank 4 was undertaken to determine the rate of evaporation and transpiration from salt-grass sod in place. The tank cylinder was 36 inches deep and 18 inches in diameter and was driven until its top was flush with the surface of the sod. The soil for about 2 feet all around it was then removed and the soil column at the base of the cylinder severed, after which a bottom was soldered on, thereby creating a water-tight container. Many lateral roots of the salt grass were cut by the cylinder as it was driven downward, but the sod was otherwise undisturbed, and the soil beneath it remained in place and in its natural state. The growth of the inclosed salt grass was checked to some extent. Some of the grass shoots died, but the greater part survived, and during the summer of 1927 the density of growth within the cylinder was about 75 per cent of the density in the surrounding meadow. Two wells were sunk in the inclosed soil column, one 2 inches and one 0.75 inch in diameter. Water was introduced into the larger well, and fluctuations of the water table were observed in the smaller one. Measured quantities of water were supplied from August 1 to November 1, 1926, and from May 1 to October 25, 1927. A slight leak developed at first, but this was stopped after several applications of liquid asphalt had been made along the line of contact between the base of the cylinder and the bottom plate. The space around the tank was kept open for two months after the application, to make sure that the leak did not again develop.

The soil within the tank was a sandy loam of the type found beneath a considerable part of the Milford salt-grass meadows. Its specific yield, according to figures obtained from 11 trials (Table 9), ranged from 2.35 to 5.39 and averaged 3.43. The water supplied to the tank amounted to a depth of 9.12 inches plus rainfall in the period August 1 to November 3, 1926, and to 22.59 inches plus rainfall in the period May to October, 1927. (See Table 7.) The growth of grass within the tank was untouched in 1926. It was trimmed close to the surface of the sod on May 1, 1927, and the crop was cut on August 10 and November 1. The total crop for the season amounted to 0.143 pound, oven dried. Practically no growth was put on after October 1, the growing season comprising the months of May to September, or approximately 150 days. During these months the discharge of ground water from the tank amounted to 193 pounds, representing a depth of 21.4 inches over the surface of the tank. The ratio between the weight of ground water discharged jointly by transpiration and evaporation and the weight of dry salt grass produced was approximately 1,350 to 1.

GREASEWOOD

Tank 3 was installed April 10, 1926. The usual 6 inches of gravel was placed in the bottom, and the tank was then filled with brown clay loam from a field adjoining the experiment station in which a vigorous stand of greasewood and shad scale was growing.

It was at first supposed to be a simple matter to obtain small greasewood shrubs suitable for transplanting, but a careful search failed to disclose seedlings or very shallow-rooted plants anywhere in the valley. Even the smallest shrubs seemed either to have roots of their own penetrating to considerable depths or to be attached to roots of near-by larger plants that penetrated deeply. In short the roots everywhere seemed to reach the water table or the overlying capillary fringe, and the task of obtaining plants with root systems intact therefore proved to be difficult. Several attempts were made to dig out plants in the lowlands near Milford where the water table was only about 6 feet deep, but in every attempt the central or tap root or important lateral rootlets were severed. Finally some small plants 6 to 15 inches high were found at the top of a low cut bank adjacent to the bed of the Beaver River 5 miles north of Milford, and there seven plants with tap roots 4 to 6 feet long were obtained, though all were more or less injured during the digging operation. The seven plants were transplanted into the tank April 12, 1926. Only four survived, and for several weeks these grew very slowly. By the middle of the summer, however, they had a thrifty appearance, and during August and September their growth was rapid. The plants wintered well and grew vigorously the following season. In the fall of 1927 they were 18 to 24 inches high and filled the space of the tank. (See pl. 8, *B*.)

An automatic water-supply unit was installed over the tank August 26, 1926, and was kept there until September 29, 1926. It was reinstalled May 11, 1927, and operated for a considerable part of the growing season of that year.

The tank was provided with two water-table wells in 1926, one 2 inches and the other 0.75 inch in diameter, the larger one close to the rim of the tank and the other about halfway between the rim and the recharge well. Observations showed that pronounced daily fluctuations took place in both wells, with the difference, however, that those in the 2-inch well were somewhat erratic and appeared to be governed to a degree by minor changes of level in the recharge well, while those in the 0.75-inch well were very uniform from day to day and resembled closely fluctuations observed in fields of greasewood. Early in July, 1927, the 0.75-inch well caved in, and in place of it two 0.5-inch wells were put down, 180 degrees apart, about halfway between the recharge well and the tank rim. Both of these wells displayed the characteristic daytime decline and nighttime rise. The amplitude of the fluctuations, however, was seldom the same in both wells, and there seemed to be no fixed relation between them, although the average amplitude of the fluctuation over a period of several weeks was found to be about the same for both wells. The nightly rise in both wells shown by 22 sets of evening and morning measurements between July 13 and August 27, 1927, is given in the table below. These measurements have been selected because they were made with particular care and were unaffected by any break in the continuity of the automatic water supply.

Nightly rise of water table in tank 3, in feet

	2-inch well	0.5-inch wells			2-inch well	0.5-inch wells	
July 13–14	0.01	0.18	0.18	Aug. 5–6	0.08	0.10	0.17
July 14–15	.04	.17	.15	Aug. 6–7	.07	.09	.18
July 15–16	.24	.13	.14	Aug. 10–11	.11	.13	.10
July 16–17	.07	.11	.12	Aug. 11–12	.15	.15	.14
July 18–19	.15	.12	.14	Aug. 12–13	.09	.07	.11
July 19–20	.09	.10	.07	Aug. 17–18	.02	.09	.12
July 20–21	.07	.15	.14	Aug. 19–20	.09	.16	.17
July 21–22	.15	.14	.13	Aug. 22–23	.12	.07	.07
July 22–23	.07	.11	.11	Aug. 23–24	--------	.10	.08
July 23–24	.06	.08	.14	Aug. 26–27	.15	.09	.11
July 26–27	.09	.16	.18				
July 27–28	.02	.16	.15	Average	--------	.12	.13

The soil fill in evaporation tanks 5 and 7 was of the same general character as the fill in tank 3, the soils in all three being taken from points closely adjacent in the same field.

For equal depths to the water table the rate of ground-water discharge by evaporation from tank 7 was greater than that from tank 5, and it is possible that the rate from tank 3 was greater than that from tank 7. It was noted that when the water table in all three tanks was at about equal depths the soil a few inches below the surface in tank 3 seemed slightly more moist than that in either tank 5 or tank 7. For purposes of computation, however, it will be assumed that for equal depths to ground water the evaporation discharge from tank 3 was equal to that from tank 7.

The total discharge of ground water from tank 3 during periods of plant growth amounted to 11.84 inches in 1926 and to 25.20 inches in 1927, or to 37.05 inches altogether. (See Table 7.) The discharge by evaporation on the basis of the record of tank 7 amounted to 9.25 inches in the two seasons. The remainder, 27.06 inches, is taken to represent the total discharge by transpiration. This amount of water would weigh 1,612 pounds. The total growth put on by the plants during the experiment weighed 1.37 pounds after being oven dried. On this basis 1,180 pounds of water was required to produce 1 pound of dried greasewood.

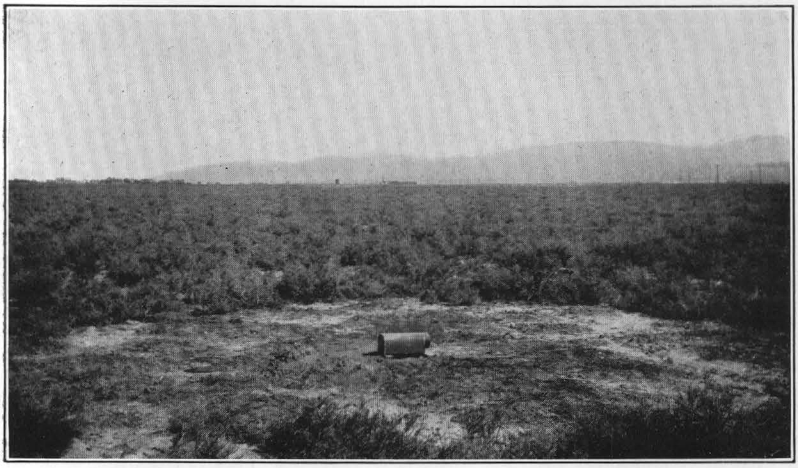
The production of 1.37 pounds in the tank, which had an area of 11.46 square feet, is equivalent to 5,200 pounds to the acre. This is about 12 times the estimated amount of growth put on annually by greasewood of average density in the Escalante Valley area.

TESTS OF SPECIFIC YIELDS

How much water is moved as the underground belt in which the fluctuations occur is alternately saturated and unwatered? It is evident that the daily fluctuations vary in amplitude with the amount of water discharged from the zone of saturation by transpiration and evaporation. But the amount of the daily rise and fall is a function also of the texture of the material in the belt of fluctuation, which controls the capacity of the material to give up water under the pull of gravity after being saturated. This capacity is expressed by the specific yield (y), mentioned on page 61, as the only quantity on the right-hand side of the formula $q=y(24r\pm s)$ that can not be determined from the automatic records of water-table fluctuations. The specific yield of a rock or soil with respect to water is the ratio of (1) the volume of water which after being saturated it will yield by gravity to (2) its own volume. It is a measure of the volume of pore space alternately emptied and filled during the daily fall and rise of the water table, or it may be defined as the depth of water that drains out of the soil as the water table declines or enters the soil as the water table rises, expressed as a percentage of the depth of soil alternately drained or resaturated. For example, if the removal of a quantity of water representing a depth of 0.1 inch on a given area causes the water table to decline 1 inch under the area, the specific yield of the soil in which the decline takes place is 10.

Determinations of specific yield were first made with the disturbed soils with which the tanks were filled, and it seemed for a time as if the questionable figures thereby obtained were the best that were to be had. After considerable experimenting, however, a method was developed by which determinations were made with undisturbed soils in the fields where ground-water plants were growing. The essential steps in the process were as follows: Cylinders of 16-gage galvanized steel were driven vertically downward so as to inclose undisturbed columns of soil. The cylinders were then sealed at the bottom to make them water-tight, and they were also protected against evaporation at the top. Measured quantities of water were introduced into or taken from the cylinders, and the resulting rise or fall of the water table was observed.

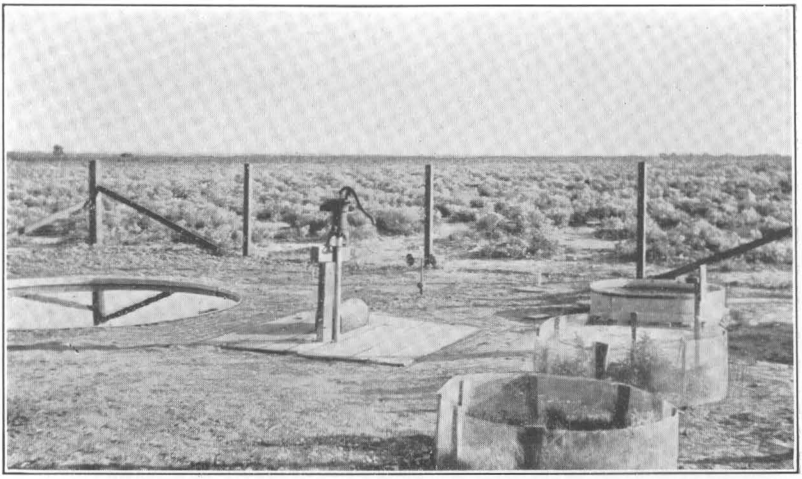
Altogether nine cylinders were driven—one 18 inches in diameter and 54 inches high, three 18 inches in diameter and 36 inches high, three 12 inches in diameter and 36 inches high, and two 12 inches in diameter and 18 inches high. With the exception of the 54-inch cylinder all were driven nearly to the water table. All were sunk



A. RECORDER OVER A WELL AT THE CENTER OF A CIRCULAR TRACT WITH A RADIUS OF 20 FEET FROM WHICH GREASEWOOD WAS CLEARED

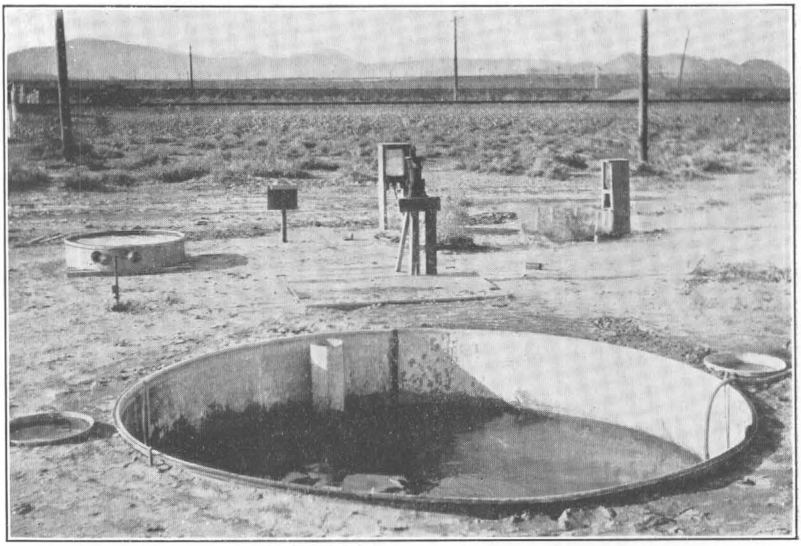
The graph in Figure 19 was obtained from this well.

B. GENERAL VIEW OF EXPERIMENT STATION MAINTAINED BY THE UNITED STATES GEOLOGICAL SURVEY NEAR MILFORD, UTAH



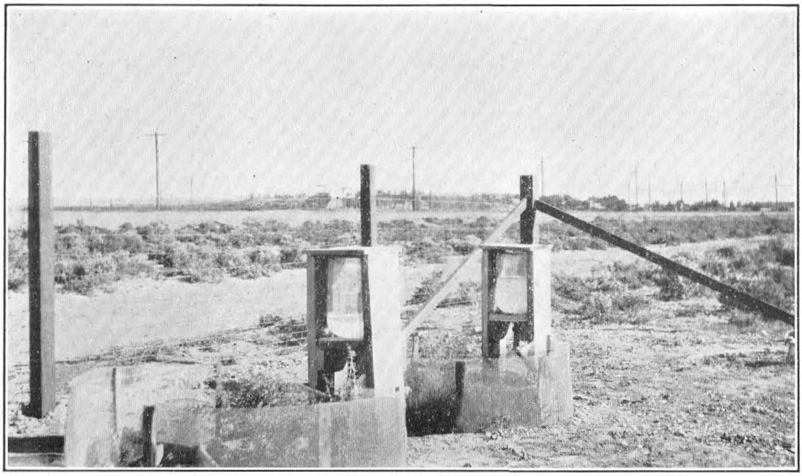
A. PART OF THE MILFORD EXPERIMENT STATION

Showing evaporation pans, vegetation tanks, well, and other equipment.

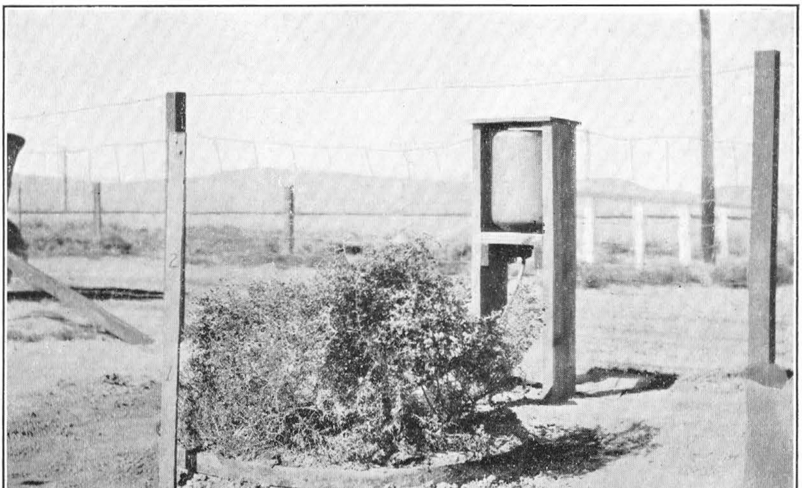


B. PARTLY DISMANTLED EXPERIMENT STATION, NOVEMBER, 1927

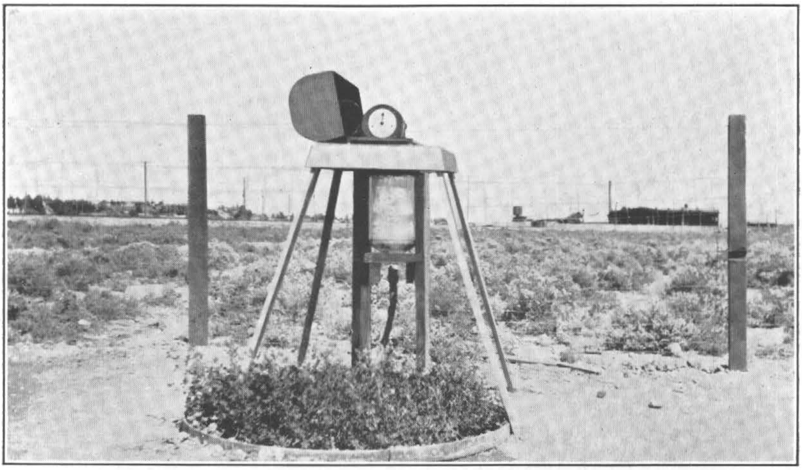
Showing 12-foot evaporation pan with still well exposed and adjoining 20-inch pans.



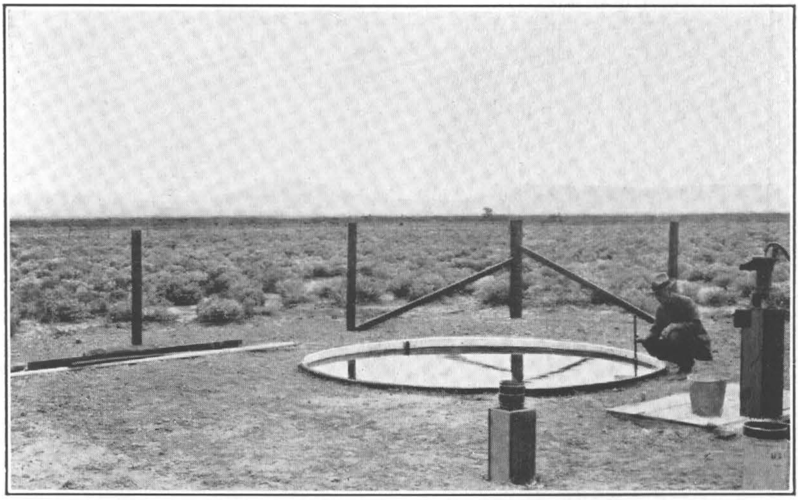
A. SALT-GRASS AND GREASEWOOD TANKS WITH AUTOMATIC WATER FEED
View taken in early stages of experiment, in July, 1926.



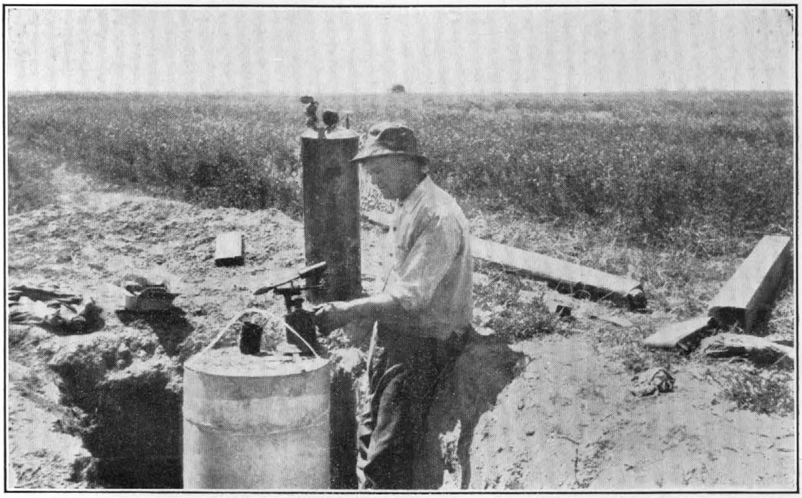
B. GREASEWOOD TANK AT THE END OF THE EXPERIMENTAL WORK, IN NOVEMBER, 1927



A. ALFALFA TANK EQUIPPED WITH AUTOMATIC WATER FEED AND WATER-STAGE RECORDER



B. TWELVE-FOOT EVAPORATION TANK AT THE MILFORD EXPERIMENT STATION



A. CYLINDER USED IN TESTS OF SPECIFIC YIELD

Photograph taken after the cylinder had been excavated and raised to the surface of the ground.

B. PROCESS OF SEALING THE BOTTOM OF THE CYLINDER as closely as possible to selected observation wells, and they were put down in the fall, so as to inclose the soils in which the summer water-table fluctuation had occurred.

In order to reach the water table with one of these cylinders a pit 4 by 6 feet was sunk to a level above the water table equal to the height of the cylinder, the proper level being determined by sinking a small test hole to water and making observations with a wye level. The rim at one end of the cylinder was slightly beveled off in order to provide a cutting edge, and a heavy drive cap was provided consisting of short pieces of 3-inch plank under a block of undressed green oak. Operations were begun by placing the cylinder with cutting edge down, after which the cap was placed on its upper end and it was slowly driven downward, care being taken to keep it in a vertical position. Two methods of driving were used with about equal success—in one the cylinder was driven with a maul wielded by one man in the bottom of the pit; in the other, the drive was provided by a pole about 6 inches in diameter and 12 feet long used pile-driver fashion, two men being required to handle it, one in the pit and the other standing on a plank over the pit. As the cylinder moved slowly downward the pit was deepened, the bottom of the pit being kept about 6 inches above the lower edge of the cylinder. In this way the friction on the outside of the cylinder was kept at a minimum, and at the same time sufficient support was provided at the bottom to keep the cylinder in a vertical position. When the lower edge of the cylinder reached the water table, the driving was stopped, but the outside excavation was continued until it was slightly below the lower edge of the cylinder. Then with a wire the soil column was sawed off even with the bottom of the cylinder, a bale was attached, and with the aid of a lever the cylinder with its included soil was slightly raised and a bottom was soldered to it. (See pl. 10, *A* and *B*.) Two small wells were then sunk in the inclosed soil, one to the bottom of the soil column and the other to a somewhat lesser depth. These wells were cased and stopped with cork. Finally the cylinder was provided with a cover to prevent evaporation.

In making determinations of specific yield in these cylinders, water was gradually introduced into the wells until the soil column was saturated practically to the top. Withdrawals were then made until the water table had subsided to the desired position in the column. Then water was alternately taken from or added to the deeper well, and the resulting changes in the water table in both wells were observed. Equilibrium was not established until about 24 hours after the addition of water and about 48 hours after its removal. Pronounced changes in barometric pressure between the time of addition or withdrawal and subsequent water-level observations seriously interfered with the results. On this account it was necessary to make the observations in fair weather. Part of the time it was necessary to make corrections for fluctuations in the water table produced by changes in temperature.

OBSERVATIONS OF EVAPORATION

EVAPORATION FROM FREE WATER SURFACES

The experimental equipment for observations of evaporation included two water-surface evaporation pans. (Pl. 7, *A* and *B*, and pl. 9, *B*.) One, a standard Weather Bureau pan 4 feet in diameter and 10 inches deep, was mounted above ground on a grid of 2 by 4 inch timbers in accordance with standard specifications and was kept filled with water to a depth of about 8 inches. The other, a circular pan 12 feet in diameter and 3 feet deep, was set in the ground with its rim about 3 inches above the surface and was kept filled with water to about the level of the ground. Evaporation observations were made continuously during three periods—August 4 to November 30, 1925, March 12 to October 31, 1926, and April 23 to October 31, 1927. The results by months are assembled in Table 3, which gives also the ratios of evaporation from the larger pan to that from the smaller one, together with the total monthly wind movement, mean monthly temperature, and relative humidity. When a rain occurred between daily observations the depth of precipitation as shown by a rain gage a few feet away was deducted from the observed depth of water in the pans after the rain. The figures, therefore, give total evaporation losses and are independent of rainfall. The measurements agree closely with Sleight's figures [11] obtained at Denver in 1915–16 on the comparative rates of evaporation from a standard Weather Bureau pan and from a 12-foot pan set in the ground. Sleight concluded that the evaporation from a 12-foot pan multiplied by 0.99 gives approximately the evaporation from a large open-water surface such as that of a reservoir or lake, provided the pan and the open-water surface are subject to the same conditions of wind, air temperature, and relative humidity. He found that the evaporation from the standard pan was exactly 1.5 times the evaporation from the 12-foot pan. The average ratio found at Milford during the three years of observation was 1.476 to 1. During the periods of highest evaporation—May 1 to October 31, 1926, and May 1 to October 31, 1927—the ratio was 1.489 to 1 and 1.495 to 1, respectively.

[11] Sleight, R. B., Evaporation from the surfaces of water and river bed materials: Jour. Agr. Research, vol. 10, pp. 232–237, 1917.

Some interesting data were obtained in 1927 with two small evaporation pans operated in connection with the 12-foot pan. These small pans were 20 inches in diameter and 30 inches deep. They were kept for a time in a floating position within the 12-foot pan, one close to the southeast side of the pan and the other close to the northeast side, these being the two directions of the prevailing winds. While in this position the water in the small pans was kept at approximately the same level as that in the large pan. After a time the small pans were removed and sunk in the ground adjacent to the 12-foot pan with their rims at the height of its rim, one at the southeast side of the large pan and the other at the northeast side, and with the water surface kept about on a level with the water surface in the large one.

The results, given in Tables 4 and 5, show that the evaporation from both small pans was greater than that from the large pan but that evaporation from the small pan on the windward side of the large pan was very much greater than that from the small pan on the leeward side, both when the small pans were floating in the large pan and when they were sunk in the ground adjacent to it. The total evaporation during 76 days in the period May 4 to August 16, 1927, amounted to 23.34 inches in the 12-foot pan, 28.44 inches in the floating pan on the windward side, and 24.49 inches in the floating pan on the leeward side. The evaporation during 24 days in the period between August 19 and September 22, 1927, amounted to 7.89 inches in the 12-foot pan, 10.15 inches in the sunken pan on the windward side, and 8.76 inches in the sunken pan on its leeward side. In the tables transpiration and evaporation losses determined from the tank experiments are expressed both as depth of water in inches and as ratios of evaporation for simultaneous periods from the water surface of the 12-foot tank.

Table 2 gives the monthly precipitation and the number of fair, partly cloudy, and cloudy days each month at the Milford experiment station.

EVAPORATION FROM SOIL IN TANKS

Although transpiration by plants accounts for the greater part of the ground-water discharge in Escalante Valley, there is also an appreciable loss by evaporation from the soils of the shallow ground-water areas. Approximately 40,000 acres of the central valley floor is underlain by ground water at depths of 10 feet or less. In a part of the lowlands of the Milford district the water table is at the surface or within a foot or two of it in the early spring and is only 3 to 5 feet below the surface in the fall, when at its lowest level. Computations of the amount of the evaporation from the soil were needed for two reasons—in order to obtain figures on the actual discharge by this agency and in order to differentiate evaporation losses from transpiration losses in the tank experiments with alfalfa and greasewood. Alfalfa is grown in the valley for the most part on lands where the water table is 8 feet or more below the surface and where presumably there is no discharge of ground water by evaporation, and the heaviest stands of greasewood occur where the depth to water is from 10 to 25 feet. In the tank experiments with the alfalfa and greasewood the water table was maintained at depths ranging from 2 to 4 feet below the surface of the tank, and a material part of the recorded discharge occurred by evaporation. It was necessary, therefore, to compute this loss before a coefficient of discharge by transpiration could be worked out that would be applicable generally to alfalfa and greasewood fields. The differentiation was accomplished by observing the rate of evaporation of ground water from bare soils of the same kind as the soils in which the alfalfa and greasewood were raised. In the salt-grass tanks the water table was maintained at depths not greatly different from those found in the heaviest salt-grass meadows. For this reason and because of a doubt as to whether the rate of evaporation from a bare soil is comparable with that from a heavy salt-grass sod less stress was placed on the differentiation of evaporation from transpiration losses in the salt-grass experiments.

Studies of ground-water evaporation from bare soils were made with seven tanks from 18 to 42 inches in diameter and from 30 to 96 inches deep. These tanks were numbered 5, 6, 6a, 7, 8, 9, and 10. (See Table 6.) Five of them contained an artificial fill, and two, 7 and 10, were so driven as to inclose natural soils in place. The filled tanks were constructed from 20 or 22 gage galvanized metal and were reinforced at the top with strap iron or angle iron. Their installation was comparatively simple. A pit having a diameter considerably larger than that of the tank was first excavated. A grid of 2 by 4 inch timbers was laid on the bottom of the pit, and the tank was placed on it in a vertical position, with the rim about even with the surface of the ground. The tank was then filled with soil, which was tamped down so as to have about the same density as it had in the natural state. The tanks containing soil in place were installed by driving the cylinder into the soil, cutting the soil column, and sealing a plate to the bottom of the cylinder in the manner described on page 75. Each tank was provided with a center recharge well, into which measured quantities of water were introduced, and with one or more smaller wells in which observations of water level were made.

The soil in tanks 5, 7, and 8 was of the same type as that used in the greasewood tank, all four tanks being filled from points a few feet apart within the experimental inclosure. This was a brown clay loam containing considerable alkali. Soils of this type are widespread over the valley floor and occur in a considerable part of the shallow ground-water areas where evaporation is active. Greasewood and shad scale seem to thrive best in such soil. Tank 7 inclosed natural undisturbed soil, and tank 8, its twin, contained soil fill. These tanks were operated in conjunction with one another in order to get data on relative rates of evaporation from disturbed and undisturbed soils. Tank 5 was constructed deeper than any others in order to determine the approximate depth of the water table, below which no ground water escapes by evaporation or the discharge is so small as to be negligible.

Tanks 6 and 6a were filled with soil of the same type as that used in the alfalfa tank, a dark gray to black sandy clay loam containing considerable humus and practically free from alkali. This is the best agricultural soil of the valley and has been found to be particularly well adapted to the production of alfalfa seed. Tank 6 was kept in operation during the season of 1926. In 1927 tank 6a, a considerably deeper tank, was substituted for it. Tank 9 was filled with a black clay loam heavily impregnated with alkali, taken from a barren flat on the edge of a salt-grass meadow about half a mile from the experiment station. Tank 10 was driven in a salt-grass meadow near the experimental plot, in an area that had been covered for several years with scrap sheet metal and on this account was free from grass.

The soil-tank apparatus was rather crude, but it was the best that could be devised with the available time and funds. It was found impossible to keep the water table at a constant level, and changes in barometric pressure introduced some inaccuracies, the water level in the observation wells tending to be slightly higher than the true water table during periods of declining pressure and slightly lower during periods of increasing pressure. It was not surprising to find, therefore, that computations of ground-water discharge for a given depth to the water table varied materially for different sets of observations. These differences, however, are smoothed out materially when the ground-water discharge is expressed as a percentage of the evaporation from a water surface for the same period. Then if a mean is taken of several computations of discharge for the given depths and the results are plotted the relation between the ground-water evaporation and depth of water table is found to be fairly regular and consistent.

The results of the soil-tank observations are summarized in Table 8 and in part are shown graphically in Figure 26. The table gives the total discharge of ground water during the month expressed as depth in inches and as a percentage of the evaporation from the surface of the 12-foot water pan. The graphs indicate the variations that occurred in ground-water evaporation from tanks 5 to 9 (expressed as a percentage of the evaporation from the 12-foot pan) with changes in the depth to the water table. The figures for ground-water discharge do not include evaporation of rainfall. The precipitation during the observations was comparatively light, and the rains for the most part were torrential and penetrated the soil for only a few inches or at the most a foot or two.

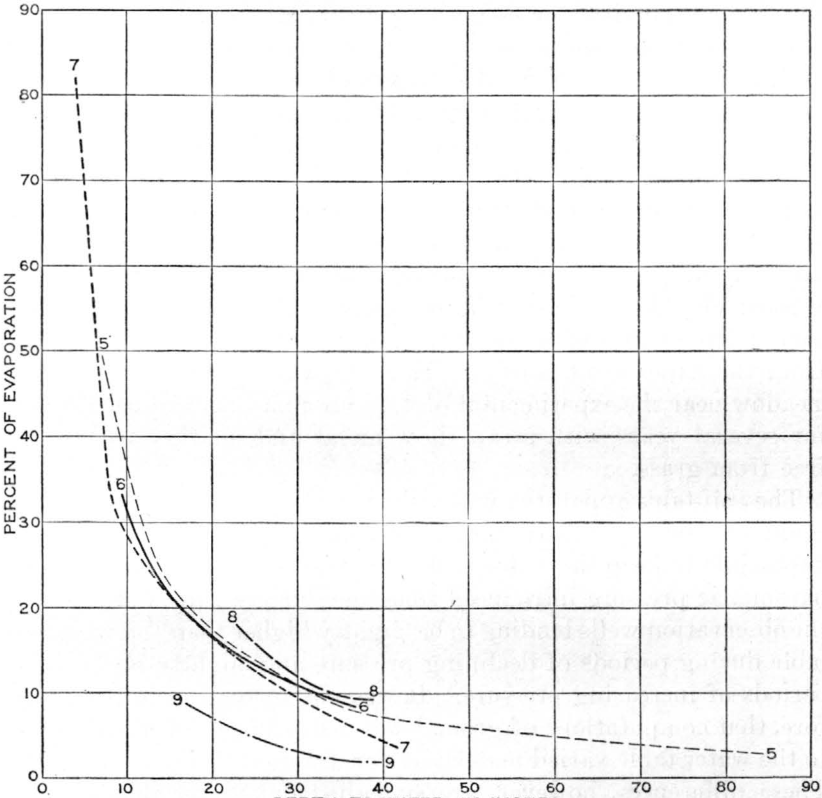


FIGURE 26.—Variations in ground-water evaporation with depth to water table, expressed in percentage of evaporation from 12-foot tank with free water surface

A few observations showed a rise of the water table in the tanks after rains, but the rise was invariably small. When such a rise occurred the tank record for several days after the rain was neglected, and estimates of discharge based on the average for the same depths during other parts of the season were substituted.

The rate of ground-water evaporation in all the tanks was comparatively high when the depth to water was 1 foot or less and was comparatively low when the depth to water was 2 feet or more. The rate of evaporation in tank 7, which contained undisturbed soil, was lower than it was in tank 8, which contained a fill of the same kind of soil, but the difference was not great. The high rate of evaporation computed for tank 6a may have been due to a slight leak.

INTERPRETATION OF THE DATA IN TERMS OF GROUND WATER

The investigation shows that beneath the tracts of ground-water plants in Escalante Valley and in other near-by valleys in Utah and Nevada the water table usually declines during the day and rises at night throughout the season of plant growth. The daytime decline occurred in every such field investigated, but in a few of them no rise was recorded at night. Where the night rise was not observed either the soils are highly permeable or a high specific yield of the soils is associated with a small consumption of ground water. Under the first of these conditions recharge during the day keeps pace with discharge, and a night rise is not to be expected. Under the second condition a slight rise probably takes place, but it is so slight as to be practically unappreciable. The key to the interpretation of the daily fluctuations of the water table in terms of ground water consumed by the plants lies in the specific yield of the soils in which the fluctuations take place and in the rise of the water table during the middle hours of the night, when the ground-water discharge is practically negligible and the hydraulic head induced by the daytime drawdown is about average for the 24 hours. The investigation indicates further that the annual growth put on by the plants is an index of the ground-water supply which they consume during the season.

The quantities r and s on the right-hand side of the formula $q=y(24r\pm s)$ are comparatively easy to measure. They were obtained in the course of the experimental studies from about 50 test wells. The specific yield (y), however, is exceedingly difficult to determine. Cylinders used to ascertain specific yield were driven adjacent to seven observation wells—well A–1, in Hendrickson's naturally subirrigated alfalfa field; well D, in a field of shad scale and greasewood at the Milford experiment station; well D–2a, in a salt-grass meadow 600 feet east of the station well; well D–3a, in a field of greasewood 400 feet north of the station; wells D–6 and D–6a in a salt-grass meadow 900 feet east of Milford railway station; and well G–2, in a field of greasewood 2 miles south of Milford.

Automatic water-stage recorders were maintained on these wells either continuously or long enough to permit a reasonably accurate estimate of the average night rise during the entire growing season.

The annual growth of the vegetation around these wells was computed. For the alfalfa around well A–1 this was done by measuring the crop in the stack and oven-drying small samples from it. The growth of grasses and shrubs around the other six observation wells mentioned was computed by measuring off small plots of average density and then determining the weight of vegetable matter produced on them after it had been oven dried. This weight was compared with the weight of plant growth put on by the plants in the vegetation tanks with a measured water supply.

The first table below gives the seasonal discharge of ground waters by the plants surrounding the seven observation wells as computed from the formula $q=y(24r\pm s)$. The second table gives the seasonal discharge of ground water by the plants surrounding the same observation wells as computed from the annual growth of these plants. This was done by multiplying the weight of plant matter in pounds to the acre produced around the wells by the number of pounds of water required to produce a pound of dry vegetable matter of the same character in the tank experiments.

Seasonal discharge of ground water by the plants surrounding seven observation wells as computed from the formula $q=y(24r\pm s)$

Vegetation	Well	Specific yield of water-bearing materials [a] (*y*)	Rise of water table (inches)		Decline of water table (*s*) (inches)	Total discharge of ground water (depth in inches)
			Average daily (24*r*)	Total		
Alfalfa	A–1	7.3	2.4	340	40	27.6
Salt grass	D–2A	3.4	2.0	300	36	11.5
Do	D–6	2.9	3.2	480	32	14.8
Do	D–6A	3.6	1.8	270	32	10.8
Shad scale and greasewood	D	1.5	1.9	270	39	4.61
Greasewood	D–3A	1.3	2.0	280	39	4.2
Do	G–2	3.5	0	0	32	1.0

[a] See Table 9.

Seasonal discharge of ground water by the plants surrounding seven observation wells as computed from the annual growth of the plants

Vegetation	Well	Ratio of weight of ground water discharged to weight of vegetation produced in tank experiments	Annual growth around wells (pounds to the acre)	Total discharge of ground water (depth in inches)
Alfalfa	A–1	1,030	6,000	27.2
Salt grass	D–2A	1,350 (D–2A, D–6, D–6A)	3,500	22.0
Do	D–6		2,800	16.6
Do	D–6A		2,100	12.5
Shad scale and greasewood	D	1,180 (D, D–3A, G–2)	600	3.1
Greasewood	D–3A		500	2.6
Do	G–2		500	2.6

The ratios of ground-water discharge to plant growth used in the computations are shown in the third column of the second table and are obtained from the data afforded by the vegetation tanks as follows: For alfalfa the mean between 1,100 and 960, the ratios shown in 1926 and 1927 in the alfalfa tank experiment, is used. In this figure transpiration alone is taken into account, because in the alfalfa field surrounding wells A and A–1—in fact, in all the Milford alfalfa fields—the water table lies too deep to be affected directly by evaporation. For the salt grass around wells D–2A, D–6, and D–6A the figure used is the ratio shown by the records of tank 4 in 1927 between weight of ground water discharged jointly by transpiration and evaporation and weight of dry salt grass. This ratio is materially less than the corresponding ratio computed for tank 2, but conditions in tank 4 were more nearly normal than those in tank 2, the sod and soil in tank 4 being in place and practically undisturbed except for the cutting of the lateral roots of the salt grass as the tank cylinder was driven downward, whereas tank 2 contained soil fill and transplanted sod.

The average depth to the water table in tank 4 during the growing season, however, was 6 to 9 inches less than the average depth to the water table in wells D–2A, D–6, and D–6A, and the use of the ratio 1,350 to 1 therefore probably gives results that are somewhat too high. For the greasewood and greasewood-shad-scale association surrounding wells D–3A, G–2, and D the ratio obtained in the greasewood tank experiment is used. In this ratio transpiration alone is taken into account. The discharge of ground water in the fields surrounding these wells is accomplished wholly or almost wholly by transpiration, the water table beneath all three being from 5 to 10 feet deep throughout the growing season. The assumption that the ratio 1,180 to 1 is applicable to the shad-scale-greasewood association around well D, is however, somewhat arbitrary. The tank experiments did not include the raising of shad scale, and no data are available as to how much water is required to produce a unit weight of that shrub. It is believed, however, that no great error will be made if it is assumed that the coefficients for the two shrubs are substantially the same.

The two methods of computation give figures for the discharge of ground water in the Hendrickson alfalfa field that are almost exactly the same. Their very close agreement, of course, is in part accidental. The results giving the discharge around wells D–6 and D–6A in salt grass differ by only 1.8 inches and 1.7 inches, respectively, and this difference would be less if the fact that the ratio 1,350 is somewhat too high, as previously explained, is taken into consideration. The two methods give decidedly different results for the discharge around well D-2A, the figures being 11.5 and 22 inches. The specific yield cylinder used here was put down about 2 feet from the well, and the water-bearing materials into which it was driven seemed somewhat less sandy than those penetrated by the well. The computed specific yield, therefore, may have been too small, but it is believed unlikely that the discrepancy in the discharge figures can be accounted for altogether on this basis. The three sets of results giving the discharge by shad scale and greasewood around well D and by greasewood around wells D-3A and G-2 differ somewhat but are in agreement in indicating that the discharge from all three fields is small.

APPLICATION OF RESULTS TO THE MILFORD AND BERYL DISTRICTS

The final step in the Escalante Valley investigation was to make a vegetation map of the areas of ground-water discharge in the Milford and Beryl districts to determine the amount of land occupied by the chief species of ground-water plants. The map of the vicinity of Milford is given in Figure 27.

In the initial field mapping salt grass, alkali sacaton, and associated marsh and meadow grasses were given one classification, greasewood another, shad scale another, rabbit brush a fourth, and alfalfa a fifth. It was found, however, that although the meadows and alfalfa fields could be accurately outlined it was impossible to outline satisfactorily the greasewood, shad scale, and rabbit brush areas. Pure stands of these shrubs covering several acres are found here and there, but for the most part they occur in associations in which first one and then another is dominant. For this reason the areas of dominant greasewood, shad scale, and rabbit brush are not subdivided on Figure 27.

Rabbit brush is known to consume ground water. Wells put down during the investigation in fields of rabbit brush invariably developed a daily water-table fluctuation of considerable amplitude, and although no actual determination was made of the amount of ground water used by rabbit brush, the assumption that it ordinarily consumes at least as much ground water as greasewood is believed to be safe. The chief uncertainty as to the use of ground water relates to the shad scale. This shrub undoubtedly can exist without ground water. As pointed out on page 38, it apparently thrives as a dwarf growth on the slopes of the valley where the depth to water is 100 feet or more. Moreover, daily water-table fluctuations did not occur in well E-7, put down in a field of dwarf shad scale on the valley floor where the depth to ground water was less than 10 feet. On the other hand, the record (p. 82) indicates that the association around well D, consisting of shad scale and greasewood with shad scale dominant, uses slightly more ground water than is used by a

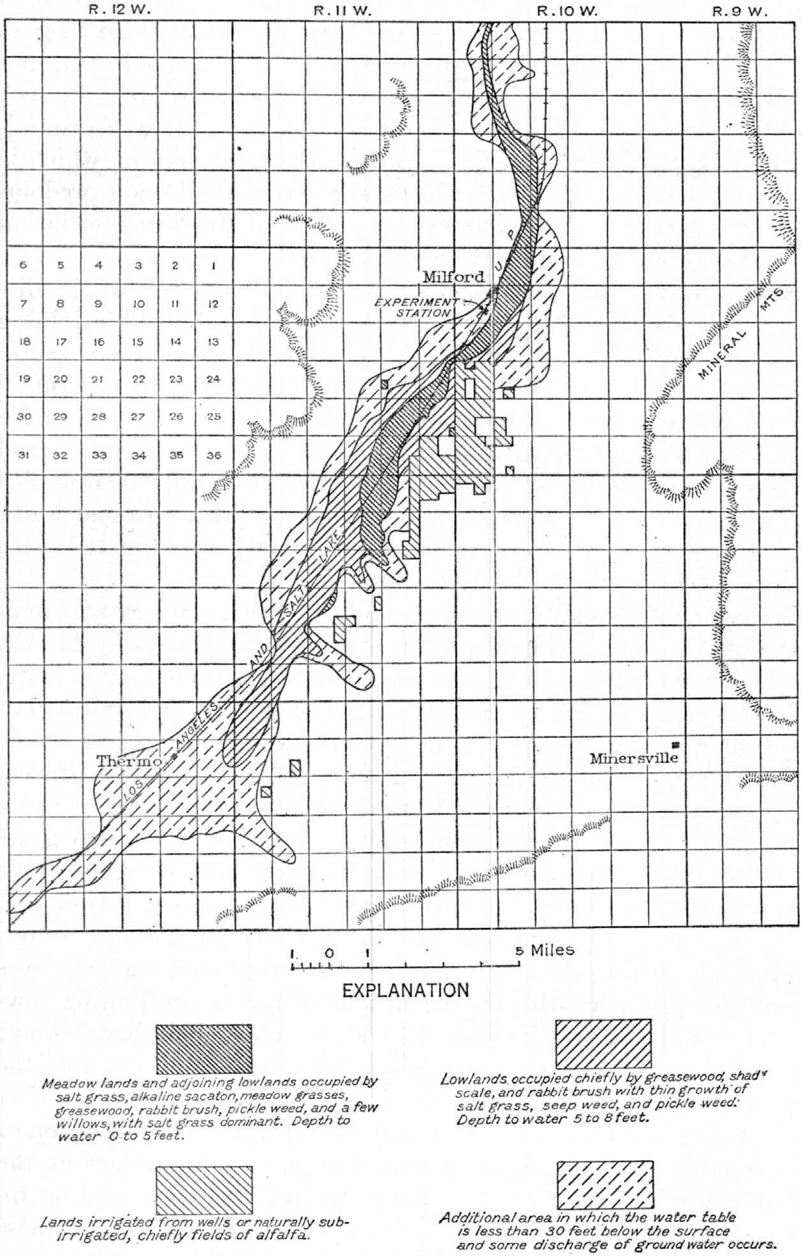


FIGURE 27.—Map of the area of ground-water discharge in the Milford district, Utah

stand of pure greasewood around well D–3A, near by. The shad scale around well D averaged from 2 to 2½ feet in height; that around well E–7 had a height of only about 1 foot. On the basis of these meager data the conclusion is reached that moderately large to large shad scale uses ground water and that dwarf shad scale does not. In the area of ground-water discharge in the Milford district shad scale occurs generally with greasewood and rabbit brush, and in such associations it is usually moderately large to large in size. There are numerous tracts of dwarf shad scale in the area of ground-water discharge in this district, however, the total area of which is not inconsiderable. In the Beryl district dwarf shad scale predominates, but larger plants occur in parts of the district in association with greasewood and rabbit brush.

On the map of the Milford district (fig. 27) the lands of the discharge area are classified as follows: A, Meadowlands and adjoining lowlands occupied by salt grass associated with greasewood, rabbit brush, and pickleweed, with salt grass dominant (depth to ground water 0 to 5 feet); B, lowlands occupied chiefly by greasewood, rabbit brush, and shad scale with scattering salt grass, seep weed, and pickleweed (depth to ground water 0 to 8 feet); C, uplands occupied by greasewood, rabbit brush, and shad scale (depth to ground water 8 to 30 feet); D, lands irrigated or naturally subirrigated with ground water, chiefly fields of alfalfa.

The meadowlands and adjoining lands in which salt grass is dominant comprise approximately 2,600 acres. Salt grass is by far the largest ground-water user in this area. Its average density is materially less than its density around wells D–2A, D–6, and D–6A, but an estimate of the average annual growth over the area as a whole is impossible. Some of the grass is cut, but most of it is grazed, a large part of the area being pastured by migrating herds of cattle and horses. The meadows include about 200 acres of grama grass and other unidentified grasses in which the largest daily water-table fluctuations disclosed by the investigation were obtained (fig. 13), indicating that these grasses are large users of ground water. Pickleweed, apparently a fairly large user of ground water, occurs in considerable quantities on the meadows and the adjoining lowlands. Islands of greasewood, shad scale, and rabbit brush occur here and there, and irregular tongues of these plants project into the meadows. The water table beneath the area ranges from 0 to 3 feet in the spring and from 3 to 5 feet in the fall. After consideration of the available data the figure 1 acre-foot per acre is taken as the probable discharge of ground water by transpiration and evaporation from lands of this class. The lands of class B comprise approximately 7,400 acres, lying for the most part along the trough of the valley southwest of the salt-grass meadows. The chief ground-water plants are greasewood, rabbit brush, and shad scale.

A light growth of salt grass occurs among the shrubs on a part of the area, and seepweed and pickleweed are present to some extent. The greasewood and rabbit brush vary considerably in vigor, being moderately large and of a healthy appearance in some localities and rather small and stunted in others. The shad scale generally is moderately large and vigorous. The depth to the water table ranges in different parts of the area from 0 to 5 feet in the spring and from 3 to 8 feet in the fall. The soils of the area vary considerably in color and texture, but a reddish-brown to brown clay loam predominates. Most of the lands of the area contain too much alkali to be successfully cultivated.

On the basis of the computations of ground-water discharge given on page 82, the figure 2½ acre-inches per acre is selected as a reasonable estimate of the depth of water transpired by the ground-water plants of this area. From the results of the soil-tank experiments (Table 8) it is believed that the discharge of ground water by evaporation in the area may be approximately an equal amount and that the joint discharge by transpiration and evaporation is therefore about 5 acre-inches per acre. On this basis the total annual discharge of ground water from areas of class B would amount to approximately 3,100 acre-feet.

Subdivision C takes in the higher uncultivated lands of the area of ground-water discharge and covers altogether about 18,000 acres. The water table beneath these lands is from 8 to 30 feet deep, and probably no ground water is lost by evaporation. The lands practically everywhere support an association of greasewood, rabbit brush, and shad scale, the stand of which ranges from light to moderately heavy. The greasewood is noticeably more vigorous than the greasewood found on the lands of subdivision B, where the water table is shallower. The rabbit brush is only of moderate size and vigor. Shad scale is usually of fair to large size where it is associated with other shrubs, but where it occurs by itself it is usually small. The aggregate area of dwarf shad scale is considerable, perhaps several thousand acres. It is believed that 2 acre-inches per acre is a fair figure to assume for the discharge of ground water from these lands. On this basis the aggregate annual discharge of ground water would amount to 3,000 acre-feet.

Class D includes the lands that were under cultivation in 1927 and derived their water supply from ground water. Altogether these lands comprised approximately 3,500 acres, nearly all of which was devoted to the production of alfalfa, seed being the principal crop. About 2,500 acres of the alfalfa was from 2 to 8 years old, and undoubtedly received at least a part of its water supply from the zone of saturation by natural subirrigation; approximately 300 acres of it depended entirely on natural subirrigation. The remaining 1,000 acres consisted of grain and potato land or land newly planted to alfalfa and depending entirely on pumped water. There were 54 pumping plants in the district, of which 6 were operated by gasoline engines and 48 by electric motors; the average capacity for all plants was about 7 horsepower.

Electric power was delivered at a flat rate, and no record was kept of the amount of power consumed by each plant; if such a record had been available, it might have served as a basis of estimating the total pump discharge. Numerous measurements of pumping-plant discharge were made by the writer. From these measurements and from statements of a considerable number of the plant owners, it is estimated that the average discharge of all pumps in the area was approximately three-quarters of a second-foot, that the average period of pump operation amounted to 65 days of 24 hours, and that the total quantity pumped in the district during the season amounted to about 5,000 acre-feet. If in addition to the pumped water it is assumed that the 2,500 acres of old alfalfa consumed on the average 1 acre-foot an acre by natural subirrigation, the figure 7,500 acre-feet is reached as the estimated total discharge of ground water from the cultivated lands. Another way of arriving at an estimate is as follows: Both the formula and the plant-growth methods of computation are in agreement in indicating that the ground-water discharge by the alfalfa in Hendrickson's field amounted to about 27 inches from the beginning of the season until the cutting of the second crop for seed on September 10. After the seed was harvested. the field was pastured, and therefore it was not possible to compute the amount of the growth during the remainder of the season. The application of the formula to the daily fluctuations of the water table shows, however, that about 4 inches of ground water was discharged thereafter, and thus the total discharge from the field for the season amounted to about 31 inches.

About 200 acres of the 2,500 acres of old alfalfa in the district was devoted to the production of alfalfa hay. It is estimated that the average yield from this hay land was about 25 per cent greater than the yield from Hendrickson's field and that the average consumption of ground water, most of which was pumped, was at least 50 per cent greater. The average growth of alfalfa in the fields devoted to seed raising, however, was not more than 50 to 60 per cent of the growth in Hendrickson's field. If the growth in all the old alfalfa fields, including Hendrickson's field and the hay land, was equal to 60 per cent of the growth in Hendrickson's field and the net consumption of ground water was proportional to the growth, the average net consumption of ground water in these fields for the season was between 18 and 19 inches.

The remaining 1,000 acres of the 3,500 acres included in class D consisted of about 200 acres planted to grain, potatoes, and other vegetables and 800 acres about equally divided between lands planted to alfalfa about 1 year old and raw lands recently cleared and being put in crop. Some of this 1,000 acres was heavily irrigated, and some of it, especially the lands in year-old alfalfa, was irrigated rather lightly. Many of both the older and the younger fields were a quarter to half a mile from the pumping plants, and some were a mile or more away. The electrical plants were operated 24 hours a day. More or less water was wasted on this account, and there were further losses of considerable magnitude due to sheer carelessness and neglect on the part of some of the pumping-plant owners. The evaporation studies show that the loss due to this cause must have been fairly high.

To estimate the gross discharge of ground water from the older alfalfa fields the figures 18 to 19 inches given above as the net discharge should be increased by several inches to allow for the losses by seepage and evaporation incident to the use of pumped water on these lands. This increase if added to the excess over 18 to 19 inches represented by the gross use of ground water on the 1,000 acres of newer lands would probably bring the average annual use of ground water on all the land up to about 24 acre-inches. On this basis the total estimated discharge of ground water from the cultivated lands for the year would be 7,000 acre-feet, as compared with the 7,500 acre-feet determined by estimating the pumpage and natural discharge separately.

Small springs occur along the trough of the valley south of Milford. The Hay Springs, in sec. 15, T. 29 S., R. 11 W., are the largest. The discharge from these springs develops small ponds during the winter, which overflow and jointly produce a stream of 100 to 125 gallons a minute that flows down the valley and is stored in a small reservoir formed by a dam across the bed of the Beaver River about 5 miles north of Milford. With the coming of warm weather and awakening of plant life, all these springs except the Hay Springs disappear, together with the ponds formed by them. The Hay Springs are perennial and maintain throughout the summer a pond of 12 acres or so in extent. The total annual discharge from these springs is relatively small and is estimated as 100 to 150 acre-feet.

The total discharge of ground water from the Milford district in 1927 is estimated as approximately 16,000 acre-feet, divided as follows in accordance with the estimates set forth above.

	Acre-feet
Area A	2,600
Area B	3,100
Area C	3,000
Area D	7,000-7,500
Springs	100-150

Considerably less water was pumped in 1926 than in 1927, and it is estimated that the total discharge in 1926 was approximately 15,000 acre-feet. Under the draft of these two years the water table declined somewhat (see pp. 57-58), and thus the discharge of ground water from the district was obviously greater than the recharge. It is estimated that during the 2-year period, October 1, 1925, to October 1, 1927, the decline produced a net unwatering of water-bearing materials amounting to approximately 15,000 acre-feet of these materials. If the water drained from these materials amounted to 10 per cent of their volume, there was a net withdrawal from underground storage amounting to about 1,500 acre-feet during the 2-year period.

It was reasonable to expect that in the years following 1927 the water table would continue to decline even if the pumpage did not increase and that the rate of decline might increase if the rate of pumpage were increased. Such a decline is normal and almost always accompanies a disturbance of the natural balance between ground-water discharge and ground-water recharge. As the water table continues to decline, however, more and more ground water should be salvaged from areas A and B that is now dissipated by evaporation and by transpiration of the salt grass and meadow grasses. It is not inconceivable that a large part of the natural discharge from area A may ultimately be salvaged, together with much of the water that is now dissipated by evaporation from area B.

It is problematical, however, how much can be salvaged from the water that is now consumed by the greasewood, rabbit brush, and shad scale in areas B and C. These plants are deep rooted, and the roots may be capable of following the water table down to depths of 40 feet or more.

It would be impracticable, moreover, to attempt to destroy these shrubs, both because of the very large area which they cover and because, at least with greasewood, new growth promptly springs up after the old plants are cut down, and the new growth undoubtedly consumes more ground water than the old.

Some of the ground water that now passes through the Milford district and is lost so far as Milford lands are concerned could also be salvaged, though the total amount of such salvage is likely to be small. The fall of the valley along its trough averages only about 4½ feet to the mile, and the water-bearing materials in the trough are in general comparatively fine. Under these conditions the down-valley movement of water must be very slow, perhaps only a few inches or at the most a foot a day. If the rate of movement is as great as 1 foot a day it would take more than 700 years for water to reach Milford from the vicinity of Beryl.

It seems probable from the facts above set forth that as a result of the lowering of the water table sufficient water will be salvaged to make it safe to supply 3,500 acres with water under a duty of 2 acre-feet to the acre, representing 7,000 acre-feet annually. It is possible, in fact, that this acreage could be increased, but in view of the uncertainty as to how much can be salvaged from the water now consumed by deep-rooted plants, the safe pumping yield of the Milford district should be regarded as well under 10,000 acre-feet a year.

The area within which most of the ground-water discharge takes place in the Beryl district is shown in Figure 28. It covers about 60,000 acres, nearly half of which is underlain by ground water at depths ranging from 7 to 10 feet. There is no part of it, however, where the water table is less than 7 feet beneath the surface at any time of the year, and it can safely be assumed that the discharge of ground water by evaporation in the district is practically negligible. The chief ground-water plants of the area are greasewood, rabbit brush, and shad scale. In three or four localities tongues of greasewood, which presumably use ground water, project beyond the mapped boundary of the area. A thin growth of salt grass occurs in places among the shrubs in the lowest parts of the basin, but there are no salt-grass meadows anywhere in the area. In some localities seepweed and pickleweed are present, but the total area where they occur is small. Small, irregular patches of sagebrush are numerous in parts of the area. The greasewood shows a wide range in vigor but averages of fair size and density. Some large rabbit brush is found in places, but for the most part this shrub occurs as a medium to short growth. Large shad scale also occurs in parts of the area, but over the district as a whole the growth is predominantly small.

It is estimated that small or dwarf shad scale and sagebrush cover practically half of the 60,000 acres within the area of ground-water discharge. Neither of these shrubs is believed to be a ground-water plant. It is further estimated that the discharge of ground water by greasewood, rabbit brush, and large shad scale on the remaining half of the area amounts to 2 inches per acre per year. On this basis the annual discharge of ground water from the Beryl district by plants amounts to approximately 5,000 acre-feet. In addition to this there is some discharge of ground water by movement down the valley toward the vicinity of Lund. (See pl. 1.) The quantity that thus migrates is believed, however, to be small. The slope along the trough of the valley in this locality is only about 4 feet to

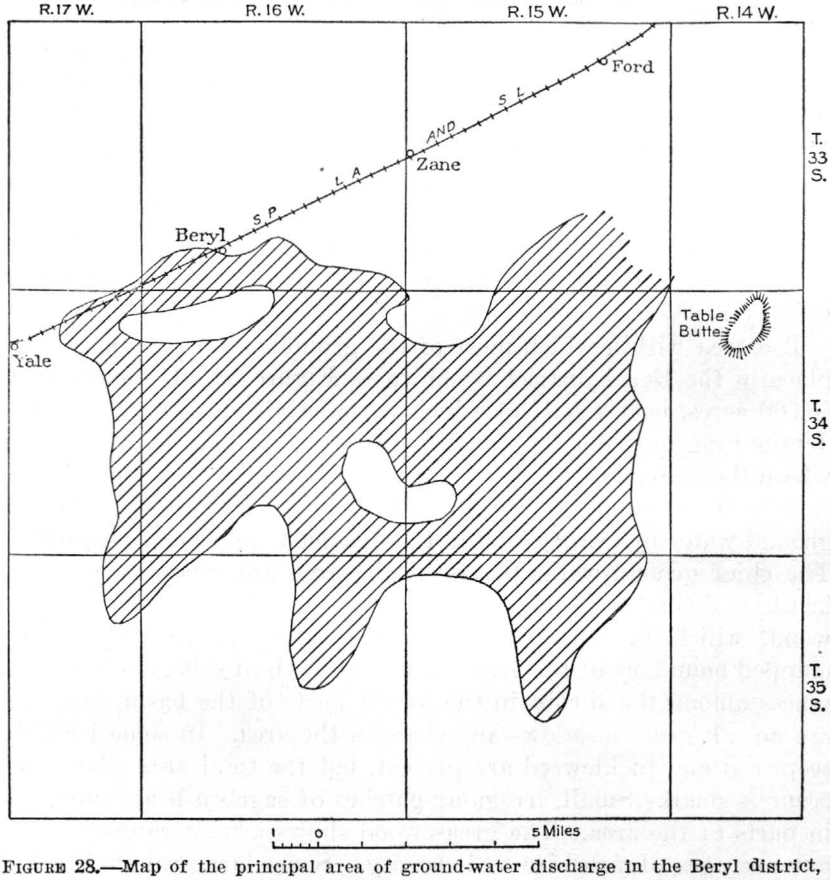


FIGURE 28.—Map of the principal area of ground-water discharge in the Beryl district, Utah

the mile, and the materials of the fill, particularly in the vicinity of Table Buttes, are very fine. It is believed that comparatively little can be salvaged from the supply of water that is now being dissipated by greasewood, rabbit brush, and shad scale unless the water table is lowered at least 20 to 30 feet. Some may be salvaged from the down-valley flow, but at the most this may amount to only a few hundred acre-feet a year. Development of ground water in the Beryl district, therefore, must be made in large part at the expense of storage. There is about 70,000 acres in the district underlain by ground water at depths ranging from 7 to 30 feet. This central area is subject to the inflow of ground water from an additional ground-water basin surrounding it, comprising more than 200,000 acres. The total amount of stored water that could be removed by pumping without lowering the water table unduly is therefore great. If the water table throughout the 70,000-acre area were lowered 1 foot by pumping and if the materials thereby unwatered should yield 10 per cent of their volume in water the total supply recovered would amount to 7,000 acre-feet.

Considerable experimenting has been done with the use of ground water for irrigation in the Beryl district. Seventeen pumping plants have been installed in different parts of the district, and tracts of varying sizes irrigated from them. (See pl. 1.) Most of these experiments have failed, and most of the pumping plants are unused. Not all the reasons for failures are known, but the use of shallow alkali ground water and the poor quality of the land selected for irrigation undoubtedly caused part of the failures.

QUALITY OF GROUND WATER

Analyses of waters from 12 wells in different parts of Escalante Valley are given in the table below. The analyses show the composition of the dissolved mineral matter and indicate the suitability of the waters for irrigation and for domestic uses that are affected by the mineral content. Such analyses do not show the sanitary condition of the waters, and statements based on the results are made without reference to possible pollution of the waters.

Analyses of well waters from Escalante Valley, Utah

[Parts per million]

	1	2	3	4	5	6
Silica (SiO_2)	55	72	53	[a] 61	[a] 68	16
Iron (Fe)	.42	.27		[b] 2	[b] 4	
Calcium (Ca)	59	63	262	44	45	77
Magnesium (Mg)	21	27	35	12	16	41
Sodium (Na)	31	45	[c] 89	27	52	[c] 91
Potassium (K)	3.8	4.5				
Bicarbonate (HCO_3)	174	156	196	146	189	231
Sulphate (SO_4)	105	166	289	29	2	254
Chloride (Cl)	35	43	376	43	80	74
Nitrate (NO_3)	1.0	.16	Trace.			
Total dissolved solids	403	518	1,378	344	517	668
Total hardness as $CaCO_3$ (calculated)	234	268	799	159	178	361
Date of collection	Nov. 29, 1927.	Nov. 29, 1927.	Oct. 13, 1923.	([d])	([d])	Oct. 13, 1923.
Analyst [e]	M. D. F.	M. D. F.	C. S. H.	H. H.	H. H.	C. S. H.

[a] Reported as "siliceous matter."
[b] Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$).
[c] Calculated.
[d] Analysis from U. S. Geol. Survey Water-Supply Paper 217, "Water resources of Beaver Valley, Utah," published in 1908.
[e] M. D. F., Margaret D. Foster, U. S. Geological Survey; C. S. H., C. S. Howard, U. S. Geological Survey; H. H., Herman Harms, State chemist of Utah.

Analyses of well waters from Escalante Valley, Utah—Continued

[Parts per million]

	7	8	9	10	11	12
Silica (SiO_2)	49	[a] 161	40	[a] 90	44	24
Iron (Fe)		[b] 10		[b] 3	.39	0
Calcium (Ca)	126	32	62	47	67	133
Magnesium (Mg)	78	15	12	10	26	127
Sodium (Na)	[c] 454	57	[c] 18	8	130	727
Potassium (K)					9.6	
Bicarbonate (HCO_3)	171	171	161	104	193	495
Sulphate (SO_4)	657	4	57	0	194	35
Chloride (Cl)	565	87	37	12	145	1,570
Nitrate (NO_3)	Trace.		Trace.		1.2	0
Total dissolved solids	2,113	689	339	330	716	2,937
Total hardness as $CaCO_3$ (calculated)	635	142	204	158	274	853
Date of collection	Oct. 14, 1923.	(d)	Oct. 15, 1923.	(d)	Oct. 15, 1927.	(d)
Analyst [e]	C. S. H.	H. H.	C. S. H.	H. H.	M. D. F.	W. M. B.

[a] Reported as "siliceous matter."
[b] Iron and aluminum oxides (Fe_2O_3+Al_2O_3).
[c] Calculated.
[d] Analysis from U. S. Geol. Survey Water-Supply Paper 217, "Water resources of Beaver Valley, Utah," published in 1908.
[e] W. M. B., W. M. Barr, U. S. Geological Survey; M. D. F., Margaret D. Foster, U. S. Geological Survey; C. S. H., C. S. Howard, U. S. Geological Survey; H. H., Herman Harms, State chemist of Utah.

1. Drilled well, 400 feet deep, in SE. ¼ sec. 3, T. 35 S., R. 15 W., 12 miles southeast of Beryl, Utah; owned by R. D. Clark of Los Angeles, Calif.
2. Drilled well, 360 feet deep, in SE. ¼ sec. 3, T. 35 S., R. 15 W., 12 miles southeast of Beryl, Utah; owned by R. D. Clark, Los Angeles, Calif.
3. Dug and drilled well 30 feet deep, in SE. ¼ sec. 30, T. 34 S., R. 16 W., 6 miles south of Beryl, Utah; owned by D. F. Shelley, formerly railroad agent at Beryl.
4. Drilled well 207 feet deep, at Beryl, Utah; owned by Los Angeles & Salt Lake Railroad.
5. Drilled well 585 feet deep, at Lund, Utah; owned by Los Angeles & Salt Lake Railroad.
6. Drilled well 340 feet deep, in NW. ¼ sec. 9, T. 32 S., R. 13 W., 7 miles northeast of Lund, Utah; owned by Hugo Hunt.
7. Dug and drilled well 40 feet deep, in NW. ¼ sec. 31, T. 30 S., R. 12 W., 1 mile northeast of Nada, Utah; owned by C. Culmsee.
8. Drilled well 401 feet deep, at Thermo, Utah; owned by Los Angeles & Salt Lake Railroad.
9. Drilled well 57 feet deep, in SW. ¼ sec. 30, T. 28 S., R. 10 W.; owned by Dr. Addison Bybee, 3¼ miles south of Milford, Utah.
10. Drilled well 305 feet deep at Milford, Utah; owned by Los Angeles & Salt Lake Railroad.
11. Drilled well 57 feet deep, in NE. ¼ sec. 23, T. 28 S., R. 11 W., 3½ miles southwest of Milford, Utah; owned by Karl S. Carlton.
12. Drilled (flowing) well 215 feet deep, in sec. 17, T. 26 S., R. 10 W., 12 miles north of Milford, Utah; owned by J. C. White.

The analytical results are in line with the results of experimental studies and actual experience in the production of crops under irrigation in different parts of the valley.

Except in the district immediately south of Milford the shallow ground waters of the entire valley have a high alkali content that makes them poor for irrigation. Their hardness and their alkali content make them almost unfit for domestic use. Analyses 3 and 7 represent waters from shallow wells that are typical of the greater part of the valley. Analysis 9 represents a water that is suitable for irrigation and would be considered a good average water for domestic use in many parts of the country where the ground water is all moderately hard. Analysis 11 shows a water that would be acceptable in most places. Samples 9 and 11 were obtained near Milford.

The deeper well waters apparently are suitable for irrigation in all parts of the valley except locally in the north end. Analyses 1, 4, 5, 6, 8, and 10 represent typical deeper well waters. They would be classed as satisfactory either for irrigation or for domestic use.

In the lowlands at the north end of the valley from Black Rock south to about the middle of T. 26 S., R. 10 W., both shallow and deep ground waters are poor. Analysis 12 represents a water that is probably typical for the deeper water of this area. It is unsuitable for irrigation and not satisfactory for domestic use.

DAILY FLUCTUATIONS IN STREAM DISCHARGE PRODUCED BY WITHDRAWAL OF GROUND WATER BY TREES AND SHRUBS

Hydrographs obtained from streams in arid regions during the season of plant growth frequently display daily changes in stage similar to fluctuations in water levels shown by wells in fields of ground-water plants in Escalante Valley. A hydrograph obtained by the writer on the Mimbres River, N. Mex., in the summer of 1928,

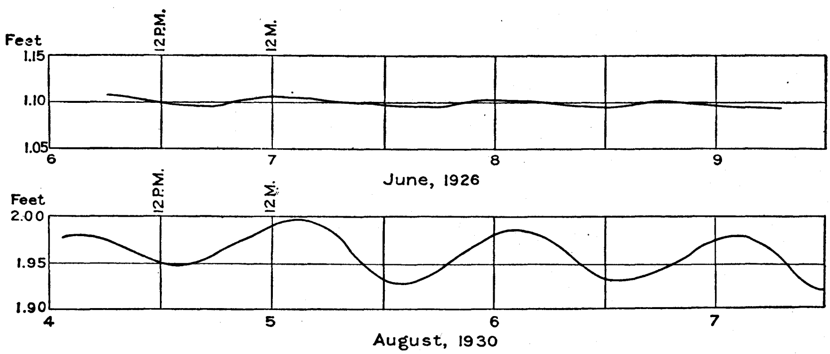


FIGURE 29.—Hydrographs of the South Fork of the Mills River at the Pink Beds, Pisgah National Forest, N. C., for June 6 to 9, 1926, and August 4 to 7, 1930

during a period of drought, showed daily fluctuations in stage amounting to about 1 inch, the decline occurring during the day between 10 and 6 o'clock and the rise during the night. These fluctuations apparently were due to the withdrawal of ground water by trees on river bottom lands above the gaging station. The fluctuations disappeared during the later part of the summer, when rains were frequent and the bottom lands were moist.

A similar performance of small streams has been observed in humid regions. E. D. Burchard, hydraulic engineer in the United States Geological Survey, reports that several small streams in western North Carolina fluctuate in stage daily during periods of drought in the summer and that the fluctuations do not occur at other times. This is illustrated in Figure 29, showing two hydrographs of the South Fork of the Mills River, one obtained in June, 1926, during a period of frequent small showers, and the other obtained in August, 1930, during a drought.

The following statement is quoted from the preliminary mimeographed report already cited:

It is interesting to speculate whether facts of considerable significance would be disclosed if an investigation similar to the one in Escalante Valley were carried out along some stream in connection with stream gaging and studies of utilization of water. The hydraulic engineer knows in a general way that the amount and character of stream discharge are influenced by the character and density of plant growth in the area drained by the stream, but if he could determine how greatly the discharge is affected, his work might be substantially aided. Regions where knowledge on this question would have important economic value are those where feasible reservoir sites exist along the middle or lower courses of streams whose upper reaches drain large areas of marshy meadow and timbered swamps. Ordinarily these swampy areas are considered only in the light of their value as stream regulators, and the fact is overlooked that they are areas wherein enormous quantities of water are lost by evaporation and transpiration. If these losses could be determined with a fair degree of accuracy the engineer would know whether the expense of draining the swamps and marsh lands and storing the reclaimed water in reservoirs below would be justified.

Without doubt the discharge of streams during the summer is everywhere depleted by vegetation, for the plants transpire large quantities of water, a part of which if not thus consumed would reach the streams. This is important because during the growing season, especially during the late summer and fall, the discharge of the streams is usually low and the water is correspondingly valuable for irrigation, power, and other uses. It is shown by many experiments, including those carried out in Escalante Valley, that the amount of water annually transpired by the plants, though roughly proportional to their annual growth, is not exactly proportional, because some plants transpire more water than others in producing a unit weight of vegetable matter. The subject clearly is one of great importance and deserves much more attention than has heretofore been given to it.

TABLES

TABLE 1.—*Precipitation data for Escalante Valley*

[Compiled from records of U. S. Weather Bureau]

Station	Length of record (years)	Precipitation (inches)												
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Black Rock	23	0.66	0.87	0.99	1.10	1.06	0.29	0.64	0.67	0.81	1.06	0.60	0.50	9.25
Milford	19	.75	.94	1.01	.99	.58	.20	.99	.65	.49	.98	.70	.90	9.18
Frisco	13	.50	.79	.90	.57	.88	.39	.84	.79	.96	.76	.39	.49	8.26
Minersville	24	.89	.95	1.49	.85	1.03	.39	1.04	.96	.90	.91	.80	.83	11.04
Nada	9	1.44	1.10	1.46	1.04	1.17	.26	1.28	1.04	.57	1.07	.69	.96	12.08
Pinto	26	1.50	1.42	1.90	1.13	1.05	.35	1.42	1.79	1.27	1.49	1.04	1.08	15.44
Enterprise	14	2.55	2.21	2.04	1.30	.87	.47	1.46	1.21	1.38	1.09	.99	1.38	16.95
Modena	26	.73	1.20	1.30	.79	.87	.40	1.26	1.83	1.12	.82	.80	.96	11.50

TABLE 2.—*Monthly precipitation at Milford Experiment Station and number of fair, partly cloudy, and cloudy days each month*

Year and month	Precipitation	Fair days	Partly cloudy days	Cloudy days	Year and month	Precipitation	Fair days	Partly cloudy days	Cloudy days
1925	*Inches*				1926—Contd.	*Inches*			
August 4-31	0.15	22	6	0	August	0.42	28	3	0
September	.35	26	3	1	September	.28	26	4	0
October	1.50	25	2	4	October	.20	28	3	0
November	.98	----	----	----					
					1927				
1926					April 3-30	0	8	0	0
March 12-31	.18	11	5	4	May	1.02	26	2	3
April	1.04	17	8	5	June	.10	26	4	0
May	.78	19	10	2	July	.91	24	7	0
June	.06	26	4	0	August	.47	26	4	1
July	.54	27	4	0	September	.50	23	5	2
					October	1.47	25	4	2

TABLE 3.—*Evaporation, wind movement, and mean temperature observed at Milford Experiment Station and relative humidity recorded at Weather Bureau station in Modena, Utah.*

Year and month	Evaporation			Wind movement	Mean temperature	Relative humidity [a]
	Standard pan	12-foot pan	Ratio, 12-foot pan to standard pan			
1925	*Inches*	*Inches*	*Per cent*	*Miles*	°*F.*	
August 4-31	10.80	7.64	70.8	3,068	67.4	51
September	9.29	6.44	69.3	3,128	58.4	46
October	5.27	3.62	68.7	2,544	47.5	54
November [b]	1.70	1.52	89.0	2,540	36.8	----
1926						
March 12-31	2.57	1.77	67	1,839	41.7	----
April	6.28	4.14	65.9	3,299	50.0	60
May	10.41	7.20	69.2	3,333	56.4	44
June	14.44	9.63	66.7	3,142	67.3	30.4
July	13.82	9.09	65.8	3,194	71.8	37.4
August	14.57	9.67	66.3	3,691	71.2	40.8
September	11.84	8.12	68.6	3,865	59.4	32.4
October	7.75	5.12	66.1	3,133	48.8	35.2
Total and average, May to October	72.83	48.83	66.9	20,358	62.5	----
1927						
April 23-30	2.82	1.85	65.6	857	59.0	45.3
May	11.97	8.27	69.1	3,906	54.9	36.0
June	14.98	10.20	68.1	3,786	65.8	34.8
July	14.22	9.72	68.3	3,119	73.0	38.6
August	13.63	8.93	65.6	3,476	69.3	46.2
September	11.11	7.13	64.2	3,594	64.3	46.2
October	6.74	4.45	66.0	2,536	47.8	41.4
Total and average, May to October	72.65	48.70	67.0	20,417	62.5	----

[a] Mean 6 a. m. and 6 p. m.
[b] Standard pan covered with ice Nov. 4-10 and 15-16.

TABLE 4.—*Relative evaporation from 12-foot pan and from 20-inch pans floating therein, 1 anchored at the windward side and the other at the leeward side of the large pan*

Date	Direction of wind	Evaporation (inches)				
		12-foot pan	Floating pan on windward side	Floating pan on leeward side	Excess in pan on windward side: Inches	Excess in pan on windward side: Per cent
1927						
May 4	N	0.20	0.24	0.28	−0.04	−17
May 5	S	.37	.55	.31	.24	77
May 11	SW	.17	.23	.19	.04	21
May 12–13	N	.45	.56	.53	.03	6
May 14–17	SW., SE	1.32	1.74	1.62	.12	8
May 18	N	.25	.34	.26	.08	30
May 19	SW	.48	.60	.38	.22	58
May 20–21	N	.28	.56	.48	.08	17
May 22	S	.11	.16	.13	.03	23
May 23	N	.17	.22	.19	−.03	−16
May 24–26	S	.96	1.28	1.08	.20	18
May 27	S	.47	.53	.46	.07	15
May 28–30	NE., NW	.63	.80	.72	.08	11
May 31	SE	.27	.31	.25	.06	24
June 2	N	.19	.26	.24	.01	4
June 3–4	SW	.41	.49	.42	.07	16
June 5	N	.18	.28	.20	−.08	−40
June 9	NE	.28	.28	.28	0	0
June 10–16	SW	1.71	2.09	1.84	.25	14
June 19	SW	.37	.52	.43	.09	21
June 23	SW	.64	.72	.65	.07	11
June 24	SW	.38	.52	.44	.08	18
June 25	SW	.38	.50	.40	.10	25
June 26	SW	.50	.56	.54	.02	4
July 1–4	SW	1.57	2.18	1.76	.42	24
July 7–9	SW	.60	.79	.71	.08	11
July 13	NE	.27	.35	.32	.03	9
July 15–18	SW	1.52	1.73	1.54	.19	12
July 19	SW	.40	.51	.41	.10	24
July 20–21	NE	.54	.73	.65	.08	11
July 22–24	SW	.81	.68	.62	.06	10
July 25	N	.20	.18	.11	.07	63
July 26–28	SW., S., SE	.78	1.01	.89	.12	14
July 30 to Aug. 2	SW	1.59	1.98	1.81	.17	9
Aug. 3–4	SW	.62	.77	.74	.03	4
Aug. 5–6	SW	.25	.41	.38	.03	8
Aug. 7–11	SW	1.18	1.96	1.55	.41	27
Aug. 13	SW	1.58	.56	.43	.13	30
Aug. 16	N	.26	.29	.26	.03	11
		23.34	28.44	24.49		

TABLE 5.—*Relative evaporation from 12-foot pan and from 20-inch pans 30 inches deep sunk in earth, 1 on the windward side and the other on the leeward side of the large pan*

Date	Direction of wind	Evaporation (inches)				
		12-foot pan	Sunken pan on windward side	Sunken pan on leeward side	Excess on windward side: Inches	Excess on windward side: Per cent
1927						
Aug. 19–21	N	0.66	0.86	0.84	0.02	2
Aug. 22–23	SW	.74	.90	.78	.12	15
Aug. 24–25	SW	.70	.92	.78	.14	18
Aug. 26–29	SW	.99	1.01	.79	.22	28
Aug. 30–Sept. 2	SW	1.03	1.40	1.24	.16	13
Sept. 2–4	SW	.82	1.24	.95	.29	30
Sept. 5	SW	.27	.41	.36	.05	14
Sept. 8	NE	.37	.48	.49	−.01	−2
Sept. 9–12	SW	1.17	1.39	1.15	.24	21
Sept. 16–17	N	.18	.27	.24	.03	12
Sept. 18–22	SW., S	.96	1.27	1.14	.13	----------
		7.89	10.15	8.76		

TABLE 6.—*Experimental tanks*

No.	Diameter	Depth	Character of soil	Nature of soil column	Character of ground-water determinations
	Inches	*Inches*			
1	48	54	Gray to black loam	Fill	Discharge by transpiration of alfalfa.
2	44	54	Dark-gray clay	do	Discharge by transpiration of salt grass.
3	46	54	Brown clay	do	Discharge by transpiration of grease wood.
4	18	36	Gray sandy clay loam	Natural	Discharge by transpiration of salt grass.
5	48	96	Brown clay	Fill	Discharge by evaporation.
6	20	36	Black loam	do	Do.
6a	18	54	do	do	Do.
7	18	54	Brown clay	Natural	Do.
8	18	54	do	Fill	Do.
9	42	48	Dark-gray clay	do	Do.
10	18	30	Dark-gray clay loam	Natural	Specific yield and discharge by evaporation.
11	18	36	Gray clay and sandy clay loam.	do	Specific yield.
12	12	36	Gray sandy clay loam	do	Do.
13	12	18	do	do	Do.
14	12	36	Brown clay	do	Do.
15	12	18	Brown-gray clay	do	Do.
16	12	36	do	do	Do.

TABLE 7.—*Ground-water discharge by evaporation and transpiration*

Tank 1 (alfalfa)

Year and month	Average depth to water (inches)	Estimated evaporation and transpiration (depth in inches)			Per cent of evaporation from water surface in 12-foot pan	Rainfall (inches)
		Evaporation	Transpiration	Combined		
1926						
June	36	0.70	0.74	1.44	15	0.06
July	39	.60	3.06	3.66	40	.54
August	32	.75	5.50	6.25	80	.42
September	28	.75	6.50	7.25	90	.28
October	31	.45	3.94	4.39	77	.20
		3.25	19.74	22.99		1.50
1927						
April		[a].30	[a]1.70	[a]2.00		.63
May		[a].60	[a]2.90	[a]3.50		1.02
June	33	.80	2.34	3.13	31	.10
July	38	.60	5.38	5.98	61	.91
August	37	.60	3.72	4.32	48	.47
September	39	.45	3.58	4.03	56	.50
October	33	.30	2.60	2.90	65	1.47
		2.75	22.22	25.86		5.10

[a] Estimated.

1926. Alfalfa produced, 1.13 pounds, oven dried=4,034 pounds per acre. Estimated weight of ground water transpired, 1,244 pounds. Ratio, 1,100 pounds of water to 1 pound of alfalfa.

1927. Alfalfa produced, 1.46 pounds, oven dried=5,200 pounds per acre. Estimated weight of ground water transpired, 1,400 pounds. Ratio, 960 pounds of water to 1 pound of alfalfa.

TABLE 7.—*Ground-water discharge by evaporation and transpiration*—Contd.

Tank 2 (salt grass, transplanted sod)

Year and month	Average depth to water (inches)	Estimated evaporation and transpiration (depth in inches): Evaporation	Transpiration	Combined	Per cent of evaporation from water surface in 12-foot pan	Rainfall (inches)
1926						
May	28			1.06	15	0.78
June	21			1.75	18	.06
July	36			1.92	21	.54
August	28			6.26	64	.42
September	30			3.14	38	.28
October	41			.60	12	.20
				14.73		2.28
1927						
May	21			2.56	31	1.02
June	31			3.68	36	.10
July	28			4.70	48	.91
August	25			3.11	35	.47
September	23			2.61	36	.50
October	28			1.22	27	1.47
				17.88		4.47

1927. Salt grass produced, 0.47 pound, oven dried=1,950 pounds per acre. Ground water discharged by transpiration and evaporation, 976 pounds. Ratio, 2,077 pounds of water to 1 pound of salt grass.

Tank 3 (greasewood)

Year and month	Average depth to water (inches)	Evaporation	Transpiration	Combined	Per cent of evaporation from water surface in 12-foot pan	Rainfall (inches)
1926						
June	40	0.58	0.52	1.10	11	0.06
July	40	.54	1.42	1.96	22	.54
August	31	.97	2.58	3.55	36	.42
September	24	1.06	3.19	4.25	52	.28
October	40	.42	.56	.98	17	.20
		3.57	8.27	11.84		1.50
1927						
May	30	.82	.82	1.64	20	1.02
June	27	1.20	3.64	4.84	47	.10
July	28	1.06	5.54	6.60	68	.91
August	28	1.07	4.83	5.90	66	.47
September	26	.93	3.48	4.41	62	.50
October	15	1.33	.48	1.81	40	1.47
		6.41	18.79	25.20		4.47

Tank 4 (undisturbed salt-grass sod and soil, gray to black sandy clay loam)

Year and month	Average depth to water (inches)	Evaporation	Transpiration	Combined	Per cent of evaporation from water surface in 12-foot pan	Rainfall (inches)
1926						
Aug. 1–7	12			0.92	[b] 60	0.01
Aug. 11–29	12			3.63	[b] 64	0
Sept. 2–10	14			1.20	[b] 59	0
Sept. 16–24	11			1.52	[b] 65	0
Sept. 24 to Oct. 3	13			.73	[b] 56	.04
Oct. 3–24	27			.70	19	.10
Oct. 24 to Nov. 3	15			.42	27	0
				9.12		.15
1927						
May	23			2.78	33	1.02
June	24			5.70	56	.10
July	25			5.80	50	.91
August	21			4.00	44	.47
September	23			3.13	27	.50
October	24			1.18		1.47
				22.59		4.47

[b] Tank exposed in open pit.

No attempt was made in 1926 to determine the amount of growth made by the salt grass in this tank. The 1927 crop was cut August 10 and November 1 and weighed 0.143 pound after being oven dried. This is the equivalent of 3,500 pounds per acre.

TABLE 8.—*Discharge of ground water by soil evaporation*

Period	Average depth to water table	Evaporation (depth in inches)	Per cent of evaporation from water surface of 12-foot pan
Tank 5 (brown clay loam)			
	Inches		
Dec. 1, 1925, to Apr. 1, 1926	63	0.34	---------
1926			
April	66	.19	5
May	68	.30	4
June	50	.68	7
July	58	.66	7
August	66	.35	4
September	77	.26	3
October	82	.23	4
		2.67	
1927			
May 18–31	11	1.15	31
June	22	1.61	16
July	39	.68	7
August	40	.56	6
September	43	.53	7
October	32	.44	10
		4.76	
Tank 6 (dark-gray to black loam)			
1926			
June	9	3.01	31
July	12	2.34	26
August	15	1.92	20
September	15	1.86	23
October	9	.99	19
		10.12	
Tank 6a (dark-gray to black loam)			
1927			
May 15–19	15.12	0.68	59
May 27 to June 12	30.96	1.87	46
June 13 to July 17	29.16	3.48	30
July 25 to Aug. 5	42.96	.37	14
Aug. 15 to Sept. 30	32.40	3.67	32
Aug. 24 to Sept. 1	29.04	.58	25
Tank 7 (brown clay, undisturbed soil)			
1926			
June	33	0.62	7
July	35	.44	5
August	41	.25	3
September	37	.37	5
October	21	.48	9
		2.16	
1927			
May	20	1.57	19
June	19	1.77	17
July	20	1.80	18
August	33	.91	10
September	35	.54	8
October	22	.39	9
	25	6.98	14
June to October	26	5.41	13
Tank 8 (brown clay fill)			
1926	*Inches*		
July	40	1.30	14
August	42	.80	8
September	41	.67	8
October	30	.80	14
		3.57	
1927			
April 20–30	30	.30	12
May	27	1.26	15
June	31	1.18	11
July	31	1.20	12
August	35	.85	10
September	38	.67	10
October	36	.46	10
	34.6	5.92	---------
July to October, 1926	38	3.57	---------
July to October, 1927	35	3.16	---------
Tank 9 (dark-gray clay loam)			
1925			
August	20	1.49	19
September	21	1.26	17
Oct. 1, 1925, to Apr. 30, 1926	24	0	---------
1926			
May [a]	24	.47	6.5
June	25	.39	4.1
July	28	.31	3.4
August	30	.24	2.5
September	38	.21	2.6
October	38	.11	1.8
		1.73	
Tank 10 (dark-gray clay loam)			
1927			
May 31 to June 15	16.56	1.44	35
May 31 to June 3	24.72	.28	29
June 7–8	9.00	.23	---------
June 8–9	11.40	.16	---------
June 9–14	16.34	.40	33
June 14–15	20.76	.10	---------
Sept. 6–17	14.00	.71	22
Sept. 17–22	17.40	.34	40
Sept. 22–30	22.92	.29	---------
Sept. 30 to Oct. 6	27.00	.16	---------
Oct. 7–14	17.40	.33	---------
Oct. 14–21	22.42	.23	---------
Nov. 7–13	15.24	.28	---------

[a] May 1, tank emptied and refilled with same type of soil, free from grass roots.

TABLE 9.—*Specific yield*

[Corrections made for changes in storage in tank wells]

Tank 1 (gray to black loam fill)

Period	Water added or withdrawn (depth in inches)	Depth to water (inches)		Rise (+) or fall (−) in water table	Specific yield
		At beginning of experiment	At end of experiment		
1926				*Inches*	
June 23–28	−0.45	27.48	36.24	−8.76	3.5
July 17–18	+.40	43.44	32.40	+11.04	3.6
July 27–28	+.67	52.08	38.40	+13.68	4.9
July 31 to Aug. 1	+.61	46.44	37.68	+9.96	5.6
Aug. 6–9	+2.61	51.00	25.44	+25.56	7.6
Aug. 12–13	+.44	32.04	27.00	+5.04	7.3
Aug. 18–19	+.90	40.44	27.96	+12.48	6.7
Aug. 19–20	+.64	27.96	19.44	+8.52	6.7
Oct. 16–17	+1.11	45.84	27.72	+18.12	5.6
Oct. 31 to Nov. 3	+.82	38.04	31.68	+6.36	8.2
1927					
May 13–14	+.89	40.00	23.28	+16.73	5.3
June 15–18	+.31	34.32	24.36	+9.96	3.1
Sept. 23–24					6.6
Nov. 8–9					2.1
Average					5.5

Tank 3 (brown clay fill)

Period	Water added or withdrawn (depth in inches)	At beginning of experiment	At end of experiment	Rise (+) or fall (−) in water table	Specific yield
1926					
May 19–20	−0.22	9.24	19.80	−10.56	2.0
June 2–6	+.35	43.08	40.32	+2.76	4.9
July 1–4	+.50	44.64	31.56	+13.08	2.8
July 12–15	+.30	45.36	40.44	+4.92	3.0
July 28–30	+.32	48.48	37.68	+10.80	2.3
Aug. 6–7	+.41	48.84	36.12	+12.73	3.2
Aug. 7–8	+.41	36.12	22.56	+13.56	3.0
Aug. 9–10	+.07	26.88	21.60	+5.28	2.2
Aug. 10–11	+.25	21.60	21.48	+.12	
Aug. 11–12	−.18	21.48	22.56	−1.08	
Aug. 19–20	+.31	44.16	28.20	+15.96	1.9
1927					
Sept. 23–25	+2.36	51.60	15.24	+36.36	6.5
Average					3.2

Tank 4 (undisturbed salt-grass sod and gray to black sandy clay loam)

Period	Water added or withdrawn (depth in inches)	At beginning of experiment	At end of experiment	Rise (+) or fall (−) in water table	Specific yield
July 18–19	+1.23	30.00	4.20	+25.80	4.20
July 21–22	+.64	13.44	1.56	+11.88	5.39
Aug. 6–8	+.66	21.96	6.96	+15.00	3.00
Aug. 18–19	+.50	21.50	10.32	+11.11	3.34
Aug. 19–20	+.44	10.32	2.40	+7.92	3.40
Aug. 22–23	+.33	12.72	8.28	+4.44	3.51
Aug. 30 to Sept. 1	+.90	23.40	6.60	+16.80	3.63
Sept. 5–6	+.41	21.36	10.44	+10.92	2.75
Sept. 7–9	+.46	17.28	9.60	+7.68	2.92
Oct. 19–20	+.23	28.80	23.52	+5.28	3.21
Oct. 24–26	+.15	21.36	17.40	+3.96	2.35
Average					3.43

TABLE 9.—*Specific yield*—Continued

[Corrections made for changes in storage in tank wells]

Tank 5 (brown clay fill)

Period	Water added or withdrawn (depth in inches)	Depth to water (inches)		Rise (+) or fall (−) in water table	Specific yield
		At beginning of experiment	At end of experiment		
1926				*Inches*	
Aug. 20–25	−0.03	64.08	72.72	−8.64	3.0
June 7–16	−.12	40.44	43.80	−3.36	4.2
June 16–24	−.74	45.56	59.88	−13.32	6.6
July 3–10	−.41	40.56	52.80	−12.24	3.8
Aug. 2–9	−.62	44.64	62.64	−18.00	3.6
Oct. 26 to Nov. 4	+.32	84.96	77.04	+7.92	4.0
1927					
May 8–11	+.37	76.43	62.88	+13.55	2.8
May 11–13	+.75	62.88	43.44	+19.44	3.9
Sept. 23–26	+.12	51.00	23.40	+27.60	3.7
Nov. 7–13	−.14	27.24	65.64	−38.40	3.5
Average					3.9

Tank 6 (gray to black loam)

Period	Water added or withdrawn (depth in inches)	At beginning of experiment	At end of experiment	Rise (+) or fall (−) in water table	Specific yield
1926					
May 30 to June 1	+0.60	14.76	0	+14.76	3.0
June 8	+.39	17.04	0	+17.04	2.0
July 4–5	+.38	15.72	0	+15.72	2.2
July 17–19	+.46	18.00	0	+18.00	2.3
July 31 to Aug. 1	+.36	20.88	9.24	+11.64	2.7
Aug. 29 to Sept. 1	+.66	26.04	2.88	+23.16	2.2
Sept. 29–30	+.67	25.32	0	+25.32	2.2
Average					2.4

Tank 6a (gray to black loam; same type of soil as that in tank 1)

Period	Water added or withdrawn (depth in inches)	At beginning of experiment	At end of experiment	Rise (+) or fall (−) in water table	Specific yield
1927					
May 17–18	+0.407	28.08	16.68	+11.40	2.8
June 6–7	+1.360	44.64	15.48	+29.16	4.1
July 3–7	+1.92	32.28	18.48	+13.80	7.4
Aug. 24–25	+.41	35.40	25.20	+10.20	3.3
Sept. 23–25	+2.52	48.84	12.60	+36.24	5.9
Average					4.7

Tank 7 (undisturbed brown clay)

Period	Water added or withdrawn (depth in inches)	At beginning of experiment	At end of experiment	Rise (+) or fall (−) in water table	Specific yield
1926					
June 16–17	−0.21	35.76	43.32	−7.56	2.8
June 17–18	+.43	42.84	28.68	+14.26	3.0
July 17–18	+.42	42.48	27.24	+15.24	2.8
Sept. 8–9	+.25	47.04	37.68	+9.36	2.7
Sept. 14–15	+.26	40.08	31.44	+8.64	3.0
Sept. 25–26	+.25	37.44	27.84	+9.60	2.7
Oct. 2–4	+.54	30.72	14.88	+15.84	3.4
Oct. 19–25	−.63	23.28	42.38	−19.08	3.6
Oct. 26–29	+.08	42.36	40.32	+2.04	2.9
Oct. 29 to Nov. 1	+.30	40.32	31.20	+9.12	3.1
1927					
May 2–5	+.08	35.88	33.36	+2.52	1.8
May 11–12	+.54	36.48	16.92	+19.56	2.7
Sept. 23–24	−.11	12.48	23.52	−27.00	4.0
Nov. 3–7	−.31	23.52	37.80	−11.04	2.7
Nov. 7–13	+.39	41.04	14.28	+14.28	2.7
Average					2.9

TABLE 9.—*Specific yield*—Continued

[Corrections made for changes in storage in tank wells]

Tank 8 (companion of tank 7; brown clay fill)

Period	Water added or withdrawn (depth in inches)	Depth to water (inches)		Rise (+) or fall (−) in water table	Specific yield
		At beginning of experiment	At end of experiment		
1926				*Inches*	
July 17-18	+0.51	45.00	35.04	+9.96	5.1
July 24-28	+.67	40.92	33.48	+7.44	6.9
Sept. 8-9	+.47	50.88	40.08	+10.80	4.4
Sept. 14-15	+.47	42.84	34.44	+8.40	5.6
Sept. 25-26	+.27	39.96	31.08	+8.88	3.1
Oct. 2-4	+.59	34.56	24.60	+9.96	5.9
Oct. 19-22	−.69	31.20	43.32	−12.12	5.7
Oct. 26-27	+.08	43.08	40.68	+2.40	3.2
Oct. 29-31	+.18	41.40	38.64	+2.76	6.5
Oct. 31 to Nov. 1	+.17	38.52	35.28	+3.24	5.3
Nov. 1-2	+.32	35.28	30.24	+5.04	6.3
Nov. 2-3	+.16	30.24	27.84	+2.40	6.7
1927					
May 2-4	+.10	37.08	36.36	+.72	7.7
May 11-12	+.47	39.72	30.24	+9.48	4.1
May 13-15	+.81	31.68	18.96	+12.72	5.9
May 17-19	+.18	22.44	21.48	+.96	6.3
July 2-6	+1.39	42.24	18.96	+23.28	5.4
Sept. 23-24	+.61	44.04	31.56	+12.48	4.9
Sept. 24-26	+.96	44.04	27.12	+16.92	5.1
Nov. 4-7	−.32	15.84	22.14	−6.30	5.1
Nov. 7-13	−.76	22.14	36.00	−13.86	5.5
Average					5.5

Tank 9 (dark-gray clay)

Period	Water added or withdrawn (depth in inches)	At beginning of experiment	At end of experiment	Rise (+) or fall (−) in water table	Specific yield
1926					
Aug. 21-27	−0.30	28.32	37.80	−9.48	3.5
Oct. 21-23	+.31	41.76	32.64	+9.12	3.4
Oct. 23-25	+.50	30.96	21.72	+9.24	5.4
Oct. 25-26	−.04			.84	4.7
Oct. 26-27	−.03			.84	3.2
1927					
May 2-7	+.03	23.64	23.16	+.48	1.6
Oct. 6-14	+.33	43.56	39.12	+4.44	5.2
Average					3.9

Tank 10 (dark-gray clay loam)

Period	Water added or withdrawn (depth in inches)	At beginning of experiment	At end of experiment	Rise (+) or fall (−) in water table	Specific yield
1927					
May 2-4	+0.08	14.28	12.36	+1.92	4.2
May 9-11	+.07	13.20	10.80	+2.40	3.0
May 17-18	+.08	10.80	8.76	+2.04	3.8
June 3-5	+.76	27.24	6.48	+20.76	3.7
June 5-7	+.34	6.48	5.52	+.96	3.5
Sept. 5-6	+.43	28.68	13.44	+15.24	2.6
Sept. 8-9	+.28	17.04	9.60	+7.44	3.1
Sept. 16-17	+.23	16.92	14.28	+2.64	5.5
Nov. 13-15	−.15	17.76	21.24	−3.48	4.1
Nov. 17-19	+.03	21.00	20.40	+.60	4.2
Average					3.8

TABLE 9.—*Specific yield*—Continued

[Corrections made for changes in storage in tank wells]

Tank 11 (gray clay and sandy clay loam)

Period	Water added or withdrawn (depth in inches)	Depth to water (inches)		Rise (+) or fall (−) in water table	Specific yield
		At beginning of experiment	At end of experiment		
1926				*Inches*	
Sept. 14–18	+1.15	21.36	14.76	+6.60	10.0
Sept. 16–18	+.23	22.08	19.68	+2.40	9.5
Sept. 19–21	−.24	19.62	23.04	−3.40	7.0
Sept. 21–23	−.16	23.04	25.20	−2.16	7.4
Sept. 26–28	−.10	27.84	28.92	−1.08	9.0
Sept. 28–31	−.06	28.92	29.82	−.90	6.7
1927					
May 9–11	+.18	21.60	17.88	+3.72	4.7
May 16–18	+.10	17.76	16.56	+1.20	8.0
June 2–5	+.14	11.76	9.12	+2.64	5.2
Nov. 3–4	+.11	30.12	27.96	+2.16	5.1
Average					7.3
Tank 12 (undisturbed dark-gray clay loam) [Correction for temperature 0.22 inch per degree C.]					
1927					
Oct. 29–30	+0.076	20.04	16.32	+3.72	2.1
Nov. 2–3	+.118	18.24	14.16	+4.08	3.2
Nov. 6–7	−.091	17.64	24.84	−7.20	1.2
Nov. 9–11	+.115	25.56	21.00	+4.56	2.5
Nov. 11–12	+.378	20.64	12.48	+8.16	4.6
Nov. 13–19	−.231	11.88	20.28	−8.40	2.7
Average					2.7
Tank 13 (undisturbed dark-gray clay loam) [Correction for temperature 0.25 inch per degree C.]					
1927					
Oct. 28–29	+0.083	15.48	12.84	+2.64	3.1
Oct. 29–30	+.086	11.04	8.64	+2.40	3.6
Nov. 2–3	+.087	6.36	2.88	+3.48	2.5
Nov. 11–12	+.189	12.84	5.40	+7.44	2.5
Average					2.9
Tank 14 (undisturbed brown clay loam)					
1927					
Oct. 29–30	+0.073	12.36	8.52	+3.84	1.9
Nov. 1–2	−.111	12.48	24.84	−12.36	.09
Nov. 6–7	+.085	23.88	17.04	+6.84	1.2
Nov. 8–9	+.083	17.52	11.64	+5.88	1.4
Nov. 13–17	+.175	26.04	9.12	+16.92	1.0
Average					1.3