A SOIL SURVEY IN THE PECOS VALLEY, NEW MEXICO.

By THOS. H. MEANS AND FRANK D. GARDNER.

INTRODUCTION.

The southeastern part of the Territory of New Mexico comprises three distinct topographic features. The mountains of central New Mexico, including the Guadalupes, White, and Sacramento mountains, with the Santa Fe Range, mark the western boundary of the great series of plains extending westward from the mountains of Arkansas. On the eastern boundary of the Territory of New Mexico the Great Staked Plains are the most important feature. These plains form an elevated plateau with a uniform slope to the east. The western escarpment of the plateau forms the eastern limit of the Pecos Valley. The Staked Plains once, without doubt, extended to the foot of the mountains, with their western boundary somewhere near the present foothills which bound the east slope of the mountains, but the gradual uplifting of the western edge of the plain, together with excessive erosion along the base of the mountain, formed what is now known as the Pecos Valley. The present topography of the land is the result of the erosion and sedimentation of the stream in this valley—the Pecos River. At some period in its history, a time perhaps corresponding with the glacial period of the North, the Pecos carried much more water than at present, and during this time dams formed along the river either of hard ledges of rock or, by the filling up of narrow gorges with drifting material, caused the water to back up into shallow basins extending over great areas of country. In these basins or inland lakes the waters descending from the mountains deposited large quantities of sediment. The most pronounced basin of this type has been recognized and named the Tayah Basin. This basin lies on the lower Pecos, with its northern extremity near the Texas-New Mexico line, and extends for an undetermined distance to the southward.

Between the Delaware and the Black rivers, in a stretch of broken country, a second dam probably existed, and this obstruction backed the water up to some distance beyond Carlsbad. The sediments entering this basin were largely from calcareous rocks of the Guadalupe Mountain, and the soil formed from these sediments, weathering under the arid conditions of New Mexico, carries large quantities of carbonate of lime.

Between Carlsbad and Seven Rivers the Pecos flows through rough country along the foothills of the Guadalupe Mountains, and in this section of the river another obstruction once existed. The lake formed by this dam extended as far north as Roswell and an undetermined distance westward from the Pecos. In this basin were deposited the sediments which form the soils of the Roswell and Hagerman farming district.

There are many minor basins and features of the Pecos River which were not studied, since their bearing upon the subject in hand is only of secondary interest.

The rocks out of which the valley was cut vary in age from the carboniferous of the Guadalupes through the Permian Red beds of the upper Pecos, above Roswell, to the Jura-Trias and cretaceous sediments of the Staked Plains.

The carboniferous rocks are composed almost entirely of magnesian limestone, with beds of shaly limestone and thin sandstone. Such rocks form poor soils under the arid conditions existing, since they contain large quantities of lime without much potash or phosphoric acid.

The Red beds consist of red sands and shales, with heavy beds of massive gypsum. Gypsum crystals are common throughout the formation, and indicate formation from inclosed basins of sea water.

The Pecos River drains nearly the whole of the southeastern third of the Territory of New Mexico. Rising on the east side of the Santa Fe Range, the stream flows as a typical mountain stream through the rocks of the mountains; then entering the horizontal rocks of the mesa country the stream assumes a meandering course broken at intervals by gorges and canyons. The general character of the Pecos below Roswell is a series of basins filled with lake sediments and separated by rough country and hard rocks, through which the Pecos River is at present cutting.

The main tributaries of the Pecos all come from the western side, and they, too, are mountain streams, rising in the White, Sacramento, and Guadalupe mountains. The upper branches of these streams flow throughout the year, but as soon as the level mesa country is reached most of the streams sink into their beds. During times of high water the streams flow throughout their entire courses. The water which sinks along the upper stream courses follows under ground the general course of the rivers and appears along the basins near the Pecos in the form of springs. During its course through the ground the water dissolves small quantities of soluble matter and most of the springs contain the common alkali salts.

Above Roswell the main Pecos has few tributaries of any size. From Eden south small quantities of water flow in its channel throughout the year, though as far south as Roswell the flow sometimes is hardly more than 50 cubic feet per second.

At Roswell there are several permanent sources of supply which flow an estimated quantity of about 200 cubic feet per second. The Berendos, a series of large springs, rise from the edge of the large gypsum plains which extend for a distance up the Pecos Valley. The water from these springs has its origin in the crevices and underground channels of these gypsum plains, which form part of the Red Beds, and no doubt comes from the upper Pecos, the streams entering from the west across this gypsum plain. All of the waters coming from gypsum areas contain more soluble matter than do waters from the limestone strata of the underground river basins. This can be accounted for upon the assumption that the gypsum had its origin in inclosed basins of sea water, which always contains calcium sulphate in solution, concentrating through evaporation. Owing to the small solubility of the gypsum, this is the first salt crystallized out, and even though the water does not concentrate so far as to precipitate a large proportion of the sodium chlorid and the other more soluble salts, yet it includes small quantities of these salts.

There are three sources or springs from these gypsum plains, all of which unite into one stream flowing approximately 50 cubic feet per second.

The North and South Spring rivers rise from the underflow of the Hondo Basin, and the same basin furnishes the artesian water of Roswell. The springs rise in ponds from a number of small sources, and these small sources no doubt come from different depths, as their difference in temperature and chemical composition correspond very nearly with the temperature and composition of a number of wells of different depths around Roswell. The water is found in the lower layers of the cone of Hondo alluvium, which was formed as the flood waters overflowed into the basin of the Pecos. The water, coming as it does from the Hondo River, enters the Pecos at Roswell. In the upper parts of the river irrigation water in sufficient quantity to irrigate a few small farms is found, but after passing the Capitan Mountains east of Lincoln the river rapidly loses its water, and before Roswell is reached the river bed is dry during part of the year.

The artesian water at Roswell corresponds in composition nearly with the water of the Spring rivers. The temperature of the spring and artesian water is high—from 68° to 72° F. The water in the artesian wells rises to about the height of the springs, and since the level of the springs is below the level of the plain around Roswell, the use of artesian water for the irrigation of these plains is not possible.

Below Roswell is a series of draws emptying into the Pecos River. These draws are generally dry, but in their lower part below the Northern Canal small springs of ever-flowing water are found. Most of this water can be accounted for as coming from the Northern Canal by seepage.

The Felix River enters the Pecos a few miles north of Hagerman and, though dry during part of the year, it has a few permanent springs near its mouth. The Peñasco and Cottonwood are also streams of this type.

At Seven Rivers an artesian basin, similar to the Roswell artesian basin, is found. At this place there is a settlement which uses the waters of the springs and the Seven Rivers for irrigation.

At Seven Rivers the valley of the Pecos closes in and the country is more broken until Carlsbad is reached. Here the Pecos runs close to the foothills of the Guadalupe Mountains. The principal streams draining the Guadalupe slopes from the east are Dark Canyon, Black River, and Delaware River. Both of the two latter run water throughout the year, though the flow becomes as low as 10 cubic feet per second during part of the season.

The Pecos enters the basin of the ancient lake Toyah about the New Mexico-Texas line, and flows through this basin to a distance of perhaps 50 miles beyond Barstow and Pecos City. Below this point the river is of no interest agriculturally.

THE CLIMATE OF THE PECOS VALLEY.

The climate of the Pecos Valley is arid—that is to say, the rainfall is insufficient to furnish enough water for the growth of crops over the entire valley: The drainage and surface water, however, is sufficient to irrigate a certain percentage of the land. The amount of land which can be irrigated stands in a direct relation to the rainfall and run off, provided the water is stored. The average monthly and yearly rainfall for the four years—1895 to 1898, inclusive—is shown in the accompanying table as compiled from the Weather Bureau records:

Rainfall at stations in Pecos Valley.

Month.	Mountain stations.				Valley stations.		
	East Las Vegas.	Galina Springs.	Fort Stanton.	Lower Peñasco.	Puerta de Luna.	Roswell.	Carlsbad.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
January	0.60	0.48	0.70	0.93	0.93	0.60	0.34
February	.77	.51	.80	.22	.08	.52	.29
March	.76	.48	1.10	.06	.40	.35	.22
April	.82	.61	.70	.72	.32	1.06	.31
May	2.95	2.54	1.00	.52	1.36	1.22	1.22
June	1.99	1.10	1.90	2.13	1.58	3.02	2.32
July	4.13	5.14	3.10	5.99	3.51	3.83	2.59
August	3.43	2.43	4.00	3.11	3.06	1.91	2.35
September	1.62	1.13	2.30	1.61	1.07	1.05	1.09
October	1.93	1.31	1.50	2.24	1.24	1.88	1.05
November	.37	.43	.80	.10	.45	.34	.21
December	.68	.79	1.10	.86	1.09	.52	.64
Year	20.05	16.95	19.00	18.49	15.12	16.30	12.64

The stations given represent both the mountain and valley country. East Las Vegas, Galina Springs, Fort Stanton, and Lower Peñasco, are all in the mountains or foothills, while Puerta de Luna, Roswell, and Carlsbad are in the valley proper. The record at Fort Stanton is an average of seventeen years, ended 1891. The other records are for four years only. The greater part of the rain falls during the summer months, from May to October, inclusive, in the form of heavy showers—local and of short duration. Falling, as it does, in torrents upon a dry surface, large quantities of the water flow over the ground and great floods are common in the streams. The lost rivers entering the Pecos from the west all have large bowlders in their beds, indicating violent torrents at some time during the year. Streams like the Dark Canyon at Carlsbad and the Felix south of Roswell, which are dry during the greater part of the year, have been known to suddenly fill their channels to overflowing with turbulent water from the heavy rains over the foothills and mountains. Streams of this character are the most difficult to manage, and when their control is attempted the works must be of such a cheap nature as to allow replacement every few years, or so substantial and so well protected by waste ways that their destruction is impossible. The first dam constructed 6 miles above Carlsbad, was considered well protected with waste gates, but a heavy flood from the upper Pecos filled the dam so rapidly that water overflowed its crest and cut its way through the dam in a few minutes. A disaster of similar nature in Lake Macmillan was only prevented by cutting the dike which runs west from the dam.

The temperature of southern New Mexico is uniformly high in the valley, with very low relative humidity. The evaporation from a water surface is great. It has been estimated at 10 feet annually, though no complete years' records have been kept. During the spring of 1899 the evaporation from Lake Macmillan was measured as high as 4½ inches per week. This represents probably a maximum evaporation for that locality. The mild character of the winters, the moderate elevation of the valley, and the dryness of the atmosphere all tend to render the climate beneficial to persons suffering with pulmonary diseases.

HISTORY OF IRRIGATION IN THE PECOS VALLEY.

Twenty years ago farming in the Pecos Valley was confined to a few small farms under irrigation. Long subject to raids from hostile Indian tribes, agriculture was confined to stock raising. The first white men to enter the valley were cattlemen, who did all in their power to discourage general farming, and as late as 1889 irrigation was found only on a few small places where ditches had been taken out of the streams. At Roswell the permanent water of the Spring rivers and the ease with which it could be put on the land, encouraged the most extensive farming. Private ditches were run from the North and South Spring rivers, and the extension of these same ditches forms the irrigation system of Roswell today. In the lower valley irrigation was confined to two farms in the Pecos Valley.

In 1889, encouraged by the success of irrigation in Arizona and southern California, a large company was formed to develop the Pecos Valley, and the present systems of irrigation are in a great measure the result of the investments made by this company. The plans of the company contemplated installing an enormous irrigation system, heading in the canyon above Carlsbad. The canal was mapped to extend as far south as the New Mexico-Texas line. In Texas a second system was to irrigate large tracts of land around Pecos City and Barstow. These plans contemplated the simple diversion of the Pecos, for, according to the statement of competent engineers, as published in the company's pamphlets, the flow of the Pecos is 1,000 cubic feet per second at its lowest stage. The Pecos, as a matter of fact, flows as low as 100 cubic feet, at low stage, a few miles above Carlsbad. The construction of the large storage reservoirs easily overcame this error on the part of the consulting engineer, but at the same time it introduced a difficulty in the use of the water which is very nearly insurmountable—that is, the concentration of the waters through evaporation.

Upon the establishment of the irrigation plant at Carlsbad settlers were brought in from Europe. Most of these people were ignorant of American agricultural practices, and particularly ignorant of agriculture under irrigation. The officers of the irrigation company attempted to follow blindly the practices of other irrigation districts. Attempts were made to introduce plants, trees, and shrubs from southern Europe. Large amounts of money were spent upon theoretical schemes, misleading statements were made about the wonderful productiveness of the soil. and the credulous immigrant invested all his wealth at the suggestion of the promoters. Misled, living in a land so different from their native country, many of the attempts of the settlers resulted in failure. There can be no question but that many of these early failures were due to ignorance on the part of the farmer, and also were due to the attempt to grow on a large scale plants entirely unsuited to the climate or soil. Extensive farming, that is to say farming on a large scale, has also been the cause of many failures. Irrigation farming to be successful must first be intensive, then extensive. Ignorance of the true conditions existing in soil and water and the attempt of the original promoters to conceal the true state of affairs from the settlers have also been the source of much failure. Since the farmers have begun to realize that grapes, fruits, grains, and truck crops were not the kind of crops which gave encouraging results at the start, a gradual change in the agricultural practices has taken place. Alfalfa and cattle or sheep raising are at present the industries of the valley, and with such change a much more healthy state of affairs has sprung up. In the Carlsbad district, and to a lesser extent throughout the valley, sugar beets form a money crop at the present time.

The Roswell area is the result of a gradual development by private resources, and the growth has been slower and more substantial. The company bought up the greater part of the land, with the water rights, in order to obtain control of the surplus water from the Spring rivers and the Berendos for use in the Northern Canal. The Northern Canal was constructed as a part of the general scheme for the valley, but it has never been used as far as originally mapped. Under the canals now owned by the irrigation companies a water right is sold with the land, but a yearly water rent of $1.25 per acre is charged. The rental supposes the use of 2½ acre-feet of water per acre. Under the private canals and the land recently sold by the Roswell Land and Water Company in the Roswell area, an interest in the ditch is deeded with the land, the irrigator yearly contributing his share toward the support of the ditch.

THE IRRIGATION SYSTEMS OF THE PECOS VALLEY.

Excluding the small private irrigation ditches, which are found along the head waters of all of the tributaries of the Pecos River, there are four great systems of irrigation in the valley.

The Roswell irrigation system derives its water from the North and South Spring rivers, and the North, Middle, and South Berendos. From each of these sources a number of small ditches are taken out which supply the farms of the district. These canals were originally constructed by private enterprise, but were later bought up by the irrigation companies and their surplus water turned into the Northern Canal for use at Hagerman.

The Northern Canal system receives the unused, waste, and drainage water from the Roswell district, together with water from the Hondo when that stream is flowing. The Northern Canal flows from 90 to 125 cubic feet of water per second. The canal starts at a dam in the Hondo directly east from Roswell. This diverting dam collects the various waters of the Berendos, North Spring River, and the Hondo River, and where the canal crosses South Spring River a second dam is constructed, which diverts the water of the South Spring River. For a distance of nearly 20 miles below South Spring River no water is taken out from the canal. On both sides of the Felix, level farming land is watered from the Northern Canal. The canal extends to a distance of about 5 miles beyond the Felix River.

The Southern Canal system derives its water from the Pecos River by storage. Two large reservoirs have been constructed—one at Seven Rivers, being 8 miles long and an average of 1¾ miles wide, while the second, a much smaller reservoir, is situated 6 miles above Carlsbad. From the lower reservoir the water is turned into a canal 70 feet wide at the top. Four miles below the dam the canal divides, the main branch crossing the Pecos by a terreplein and flume and the smaller branch following around the east side of the river. The eastern branch at present stops at a point opposite Carlsbad, though the canal was planned to run about 18 miles below Carlsbad and discharge into an alkali lake (Lake Surprise). The western branch or Southern Canal proper carries from 200 to 225 cubic feet of water per second. The canal is 35 feet wide at the top and has a fall of 1½ feet in 5,000. Over a great part of its course only the lower side is banked, and the water extends back into draws forming smaller lakes with a considerable storage capacity, though the loss by seepage and evaporation from these lakes is considerable and overbalances the advantage of storage. The water is taken out from the main canal through a system of head gates situated at convenient points. These main laterals are in turn divided into laterals and sublaterals. The entire control of the gates is in charge of the "ditch riders," who open and close the gates as the water is desired. The water right is sold with the land, though a yearly rental of $1.25 per acre is charged. This is the basis of 2½ acre-feet of water. A record is kept of the amount of water used by each irrigator and a proportional charge is made for all water used in excess of this quantity.

Some trouble has been anticipated from the filling of reservoirs by silt. No records are at hand to determine the amount which has been deposited during the time the reservoirs have been used; but large quantities of mud have been and at every flood are being deposited. The water of the Pecos at flood carries from 5 to 10 per cent by volume of silt, the greater part of which is deposited while standing in the reservoirs. This engineering feature of the problem of water storage requires very careful consideration before more large storage reservoirs built on these mud-ladened flood streams.

At the town of Carlsbad a substantial masonry dam has been constructed, which furnishes sufficient power for the electric lights of the town, and also pumps water to a masonry reservoir upon the hill east of town.

About 13 miles below Carlsbad the Hagerman Canal takes water from a small diverting dam across the Pecos. This small canal was planned originally to supply water to a farm on the east bank of the Pecos River in the basin of the old Lake Surprise. The canal was afterwards extended nearly 10 miles, in one place widening out into a lake 1½ miles long and one-half mile wide, with an average depth of 30 feet. This lake was formed by a short dam, the canal being taken out at one end of the dam. This canal and lake have been abandoned for several years and the canal is used only as far as the Hagerman farm, a distance of perhaps 2 miles from the dam. The canal runs through sand dunes nearly all of its course and great difficulty is experienced in keeping it clear of drifting sand.

The Barstow and Pecos City system was originally planned to cover great tracts of the level land of the Toyah Lake basin. All of the irrigation on the west side of the river has been abandoned and the present system waters the east side around Barstow. The water is diverted from the Pecos without storage, taken out on the west side, flumed across to the east side, and distributed.

THE ROSWELL DISTRICT.

The Geology of the Roswell Area.

The Roswell area, lying as it does upon the junction of the Pecos and Hondo rivers, consists of more or less perfect terraces cut by these streams in the basin sediments which once filled the valleys of the streams. Rock is not exposed, except in a few areas on the bluffs bordering North Spring River on the north. Here the gypsum of the plains to the north is exposed and in all of the soils of the Roswell sheet gypsum is found in some quantity, in places forming a pure gypsum subsoil, but of such a local nature and in such small areas that these points were not mapped. Crossing the North Spring River and Hondo bottoms the land ascends to the second terrace, upon which is nearly the whole of the farming district of Roswell. Above this is the upland prairie or third terrace—land too high to receive water from the spring rivers. There has been more or less intermixture of the soils of these terraces, but their general characteristics are well preserved.

SOILS.

The soils of the Roswell area have been classified under four types:

1. Pecos sandy loam.
2. Roswell sandy loam.
3. Roswell loam.
4. Hondo meadows.

These types are indicated in colors on the accompanying map. The lightest shade represents the upland terraces of Pecos sandy loam, and the deeper shades represent the Roswell sandy loam and the Roswell loam. The Hondo meadows are represented by a different color.

THE PECOS SANDY LOAM.

The Pecos sandy loam is a light loamy soil covering great areas of the prairie land above the canal and extending up the Hondo River along its terraces. This soil represents the uppermost terrace of the basin deposits. The boundaries of the soil and of the basin were not determined, but the basin is known to extend over a territory more than 15 miles in width from the Pecos and extending from the Hondo south nearly to Seven Rivers. The native vegetation consists of blue and black gramas, woollyfoot, a little mesquite and needle grasses, together with occasional cacti and yuccas. The plains are entirely unwooded with the exception of a row of trees along each side of the Hondo.

This great tract of plain has been little cultivated on account of the scarcity of water. A storage system on the Hondo has been planned which if ever carried out will irrigate thousands of acres of this beautiful upland soil. The area of the Pecos sandy loam was examined in several places for alkali. Borings were made along the line of the old stage road from Roswell to Carlsbad and a few borings 6 or 7 miles farther west. Within the top 6 feet of the soil very little soluble matter was present, but in some places below this point small quantities of salts occur—in some cases as high as 0.25 per cent. The following table shows the results of the examination of this soil:

Soluble salt content of Pecos sandy loam.

Depth.	181.	182.	183.	186.	189.	190.	192.	193.
Feet.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	0.09	0.04	0.08	0.07	0.07	0.07	0.08	0.06
2	.05	.05	.05	.11	.09	.09	.07	.07
3	.04	.10	.05	.11	.09	.09	.11	.26
4	.06	.22	.04	.07	.13	.11	.08	.32
5	.26	20	.04	.07	.16	.12	.11	.33
6	.27	.17	.03	.10	.15	.13	.15	.30
7	....	....	....	....	.15	....	....	.24
8	....	....	....	....	.16	....	....	.21
9	....	....	....	....	.17	....	....	.23
10	....	....	....	....	.22	....	....	.53
11	....	....	....	....	.21	....	....	....

There need be no apprehension that this quantity of salt will ever damage the lands where adequate drainage is either natural or is artificially provided. However, seepage waters may collect and damage the land. When water is applied in quantity to a great tract of level land such as this, the seepage water is very apt to find difficulty in getting to the streams, and therefore collects until too near the surface of the ground for safety. This seepage water will also, without doubt, damage the lower lands and draws unless these are protected by underdrainage.

This area of Pecos sandy loam is underlaid only at a considerable depth by clay which will permit ready percolation of the seepage waters. This clay is exposed where the sandy loam has been removed, and is seen well developed in the Roswell loam. A typical section of the Pecos sandy loam, to a depth of 6 feet, would show a uniform loam throughout, so that this clay will not interfere with underdrainage should such be desired.

The texture of this soil is represented in the following table:

Mechanical analyses of soils of Pecos sandy loam.

Diameter.	Conventional names.	4115. Roswell, 6 miles S.E. (0-12 inches).	4123. Roswell, 10 miles S.W. (0-24 inches).	4125. Greenfield, 10 miles W. (0-24 inches).	4126. Roswell, 10 miles S. (0-24 inches).	4128. Roswell, 12 miles S. (0-24 inches).
Millimeters.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
2 to 1	Gravel	....	....	....	....	....
1 to 0.5	Coarse sand	1.11	Trace.	Trace.	Trace.	Trace.
0.5 to .25	Medium sand	2.55	3.95	1.52	1.22	2.05
.25 to .1	Fine sand	14.12	16.45	9.15	6.97	9.76
.1 to .05	Very fine sand	38.57	29	34.10	29.61	33.11
.05 to .01	Silt	13.17	15.18	17.34	19.30	19.02
.01 to .005	Fine silt	9.63	9.76	9.70	12.10	10.35
.005 to .0001	Clay	13.62	17	18.45	21.90	13.77
Salts[a]		1.60	3	1.85	1.46	1.46
Loss at 110° C.		2.70	3.30	5.28	4.98	4.59
Loss on ignition		2.75	3.30	3.85	3.94	4.55

[a] Dissolved in 1½ liters of water used in mechanical analyses, mainly gypsum.

The mechanical analysis of this soil, when first made by the customary method in this division, showed as much as 30 per cent clay. This differed so much from the field observations, for in the field these soils were classed throughout as sandy loams, that the source of the difference was investigated. A microscopical examination of the soils showed them to be composed of small conglomerations of clayey matter cemented by carbonate of lime. By agitation with large quantities of water this carbonate of lime was partially dissolved, the clay loosened, and the resulting analysis would make the soil appear heavier than the field judgment would warrant; also it was found that there was a quantity of matter in the soil which dissolved in the water used in the analysis. This was not in all cases alkali, but was more likely to be gypsum and carbonate of lime, both of which are slightly soluble in pure water. This soluble matter is always included in the clay by the method employed in the analysis, and thus served to make the soil appear heavier than it really was. This soluble matter was determined in all cases and subtracted from the clay. The amount of soluble matter is given, but must not be confused with the alkali determination given in other tables.

The action of water upon this soil in the field produces nearly the same results as were observed in the laboratory, and where irrigated a difference can be seen in the apparent clay content of the soil. After irrigation continued for some time the sandy loam changes in appearance and character to a loam or even to a clay loam.

THE ROSWELL SANDY LOAM.

This soil differs from the Pecos sandy loam in being a little heavier, though the top foot of soil may be nearly of the same texture. It is underlaid at from 1 to 2 feet by a loam, and this in turn is underlaid at 5 feet by a clay loam or clay.

The native vegetation of this soil was originally the same as on the Pecos sandy loam, but since irrigation water has been applied all waste tracts are now covered with salt grass and alkali weeds.

The texture of this soil in the field was considered different from the soils of the prairies. The difference was so slight that the results of the mechanical analysis fail to show it, as appears from the following table; still the mechanical analysis is not considered perfectly reliable in these soils for the reasons stated above.

Mechanical analyses of soils of Roswell sandy loam.

Diameter.	Conventional names.	4099. Roswell, 3 miles SE.	4108. Roswell, 5 miles E.	4112. Roswell, 5 miles SE.
Millimeters.		*Per cent.*	*Per cent.*	*Per cent.*
2 to 1	Gravel			
1 to 0.5	Coarse sand	0.35		Trace.
0.5 to .25	Medium sand	1.90	.40	2.20
.25 to .1	Fine sand	15.87	12.40	17.80
.1 to .05	Very fine sand	30	32.80	34.22
.05 to .01	Silt	14.83	15.65	14.46
.01 to .005	Fine silt	8.90	10.22	8.03
.005 to .0001	Clay	15.66	15	17.10
Salts dissolved in 1½ liters of water used in mechanical analysis, mainly gypsum		1.74	4.50	1.60
Loss at 110° C		3.13	3.40	2.61
Loss on ignition		7.15	6.25	3.60

There is little question but that the arrangement of the soil grains plays a great part in the field judgment of the texture. The application of the irrigation water separates the floccules and to a small extent gives the soil a much heavier appearance than the mechanical analysis shows. This fact is plainly to be seen in the Pecos Valley soils

The Roswell sandy loam may be considered the same as the Pecos sandy loam, with the upper part of the stratum removed, bringing the loam and clay nearer the surface. Since the alkali is more abundant in the lower layers of the Pecos sandy loam, it is evident that the salt should be more abundant in the Roswell sandy loam, which represents the lower strata of the Pecos sandy loam. Such was, no doubt, the case, though it has been found difficult to secure a sample of this soil which has not been irrigated. The following table represents the soil as near its original condition as it is possible to find:

Salt content of Roswell sandy loam before irrigation

Depth.	67.	Depth.	67.
Feet.	*Per cent.*	*Feet.*	*Per cent.*
1	0.07	5	0.36
2	.27	6	.25
3	.44	7	.20
4	.54	8	.20

After irrigation water has been applied to this soil a very different state of affairs is found to exist. The greater part of the soluble matter is dissolved in the irrigation water, and should this water be able to sink into the lower subsoil and flow off into the country drainage, most of this salt would be entirely removed from the soil and do no further damage. This soil, however, becomes heavier and more compact in its lower strata, and consequently the percolating water finds difficulty in penetrating to the stream channels. Thus accumulations of water follow and evaporation from the surface of the soil concentrates the soil moisture near the immediate surface of the ground. The salt either crystallizes out onto the surface of the ground or diffuses down into the soil slowly. If this state of affairs is allowed to go on unchecked the surface of the soil becomes too saline for agricultural plants to grow and the soil is abandoned to salt grass and other alkali vegetation.

The accompanying table shows the conditions found to exist in such soils after unchecked evaporation from a wet soil.

Soluble salt content of Roswell sandy loam after irrigation.

Depth.	135.	142.	27.	54.	144.	47.
Feet.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	0.09	0.06	0.45	0.66	0.16	0.41
2	.15	.06	.18	.44	.13	.52
3	.28	.10	*a*.30	.52	.12	.48
4	.26	.14	.15	*a*.47	.10	.42
5	.32	.18	.17	.33	*a*.10	.39
6	.34	.18	.17	.33	....	*a*.35
7	....	....	....	....	....	.36

a Water encountered.

Samples 135, 142, 144 illustrate soils in which water is not standing near the surface. Here the original salt has been washed down and away through the subsoil. In the other samples water has accumulated in the subsoil, and at the time examined stood at the depths noted. Through fluctuation in the level of this water table, the standing water at other seasons approaches much nearer the surface.

A general relation is to be seen between the depth to standing water and the amount of alkali within the surface foot of soil. The amount of alkali within the surface foot is the controlling factor in the cultivation of these soils; and, since agricultural plants refuse to grow with ½ of 1 per cent alkali, the evaporation from the surface has already damaged some of the soils referred to in the table.

ROSWELL LOAM.

This soil differs from the Roswell sandy loam in having the clay near the surface. A typical section shows about 4 feet of loam underlaid by heavy loam and clay.

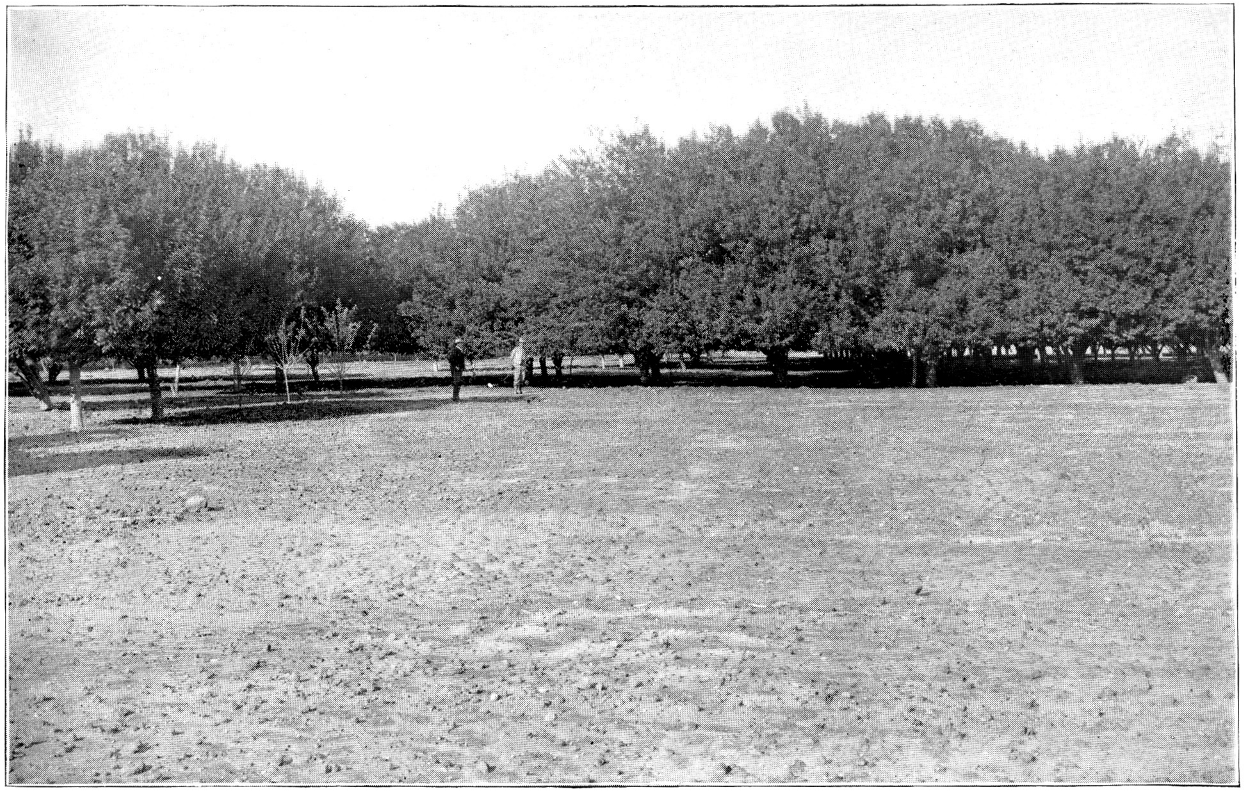
The Roswell loam is represented on the soil map by an area in the center of the Roswell sandy loam. This area is underlaid by impervious clay throughout, and, wherever it has been watered without proper drainage, water can usually be found at a depth of from 3 to 5 feet. The conditions of this soil with reference to alkali are nearly the same as in the Roswell sandy loam, but wherever evaporation has been allowed to progress unchecked the surface soil is at present charged with alkali. In some places this has gone on to such an extent that the soil should be classed as an alkali flat.

Soluble salt content of Roswell loam.

Depth.	33.	34.	39.a	41.	48	49.
Feet.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent*	*Per cent.*
1	0.19	b 1.34	1.69	2.76	0 42	0.72
2	.15	.45	60	.93	.28	.36
3	c .22	.31	.43	1.14	c .22	c 31
4	35	.31	.32	1.04	.20	.31
5	.36	.33	(c)	1.25	.16	.34
6	.36	.29	....	c 1.04	.14	.32
8	....	....	....	.72	....	....
10	....	....	....	44	....	....
12	....	....	....	.32	....	....

a Never irrigated. b Water at surface c Water encountered.

Sample No. 33 represents the soil in nearly its best condition as regards alkali, but with standing water too near the surface. The texture of the Roswell loam in the field was classed as heavier than the Roswell sandy loam, though mechanical analyses of a few samples show very little difference. This again illustrates the difficulty of interpreting the texture of a soil from a mechanical analysis alone. The change in arrangement of the soil particles by the action of irrigating waters and the presence of the clay nearer the surface give the impres-



OLD APPLE ORCHARD, 5 MILES SOUTHEAST OF ROSWELL, N. MEX.

Where good natural drainage is found fruit trees do wonderfully well.

sion in the field that the Roswell loam is a heavier soil than the Roswell sandy loam or Pecos sandy loam, and it has been so classed. This shows that the holding power and its penetrability to water are often important factors in determining the character of a soil as well as the size of the grains.

THE HONDO MEADOWS.

Under the title of Hondo Meadows are included the low-lying lands along all of the streams, but, with the exception of a narrow strip along part of the South Spring River and a small part immediately along the Pecos, these meadow lands on the soil map are all along the Hondo River and around its junction with the Pecos. The term *meadow* is used in the same sense as in humid regions, and means low land, naturally wet from the proximity of the stream, though in the arid climate of the Pecos Valley the low-lying lands need not necessarily be wet before irrigation.

The soil of these meadows is formed from recent alluvium, and in its physical properties represents this mud, being heavy and silty. A typical section of the Hondo meadow land shows 3 feet of clay loam underlaid by clay.

The water of the Hondo is very muddy, and when fields are flooded with this water a thin deposit is left. The fertilizing value of the silt in suspension is considerable; in fact an analysis shows it to contain more plant food than the mud of the Nile River in Egypt.

Chemical composition of Hondo and Nile sediment.

	Hondo mud (Skeats).	Nile mud (Mackenzie).
Insoluble matter and silica	43.6	58.17
Iron oxide and alumina	21.4	24.75
Oxide of manganese		.09
Magnesia	2.1	2.42
Lime	5.7	3.31
Potash	1.19	.68
Soda		.62
Sulphuric acid	1.96	.20
Phosphoric acid	.3	.21
Carbonic acid		1.55
Organic matter	9.8	8.00
Nitrogen in organic matter	.32	.12

The application of water containing this mud can not but be of benefit to most lands in the valley. Its wealth of plant food is above that of the ordinary soils, and the nitrogen it contains should be of special value. The sediment often amounts to as much as 10 per cent by volume of the water, it is stated.

This analysis may be taken to represent the composition of the Hondo meadow soil. This soil is the richest in plant food of all the soils mapped. The sediment of the river represents the richest portion of the soils of the upper valley.

From the position of these lands, subject to weathering from below by seepage waters from the higher lands, the evaporation from the surface of the soil has accumulated quantities of salt within the soil and at present nearly the whole of this rich land is given over to salt grass. Cultivation has been attempted at several points and the effect of underdrainage on the soils is readily noticeable. On section 33, one-half mile east of Roswell, a truck patch has been laid out on the Hondo bottom. Near the bluffs sloping from the second terrace to the bottoms the land is wet and alkaline and the growth of tender truck crops uncertain or impossible. Toward the bank of the Hondo, which at this point is cut down 8 feet below the level of the meadows, the soil is better drained and truck crops do well. Should drains be cut from the river back to the bluffs at intervals, the water seeping out from the uplands would be drained away and the salt already in the bottoms could be washed into the Hondo and so carried away. On section 34 an alfalfa field is growing on the Hondo flats. Along the foot of the bluffs, 150 yards from the river, the soil is wet and boggy, with salt grass the only vegetation. Close by the stream banks, however, the growth of alfalfa is heavy and luxuriant and grades down until, less than 100 yards from the escarpment of the terrace, it fails entirely to grow.

Perhaps the best illustration of the effect of drainage is seen upon the farm of Mr. Charles Bremond, on section 31. Here the Hondo makes a bend, and close to the river all around the bend the soil is in far better condition than farther back. The mechanical analysis of the Hondo bottom land shows it to be a much heavier soil than any other exposed in the valley. The sediment as originally deposited contains very little more clay than the Roswell loams, but from its position, being wet nearly all of the time, the soil particles break down and a much heavier soil is formed. The two analyses in the table represent the two conditions of the soil—the first column representing the sediment immediately after its deposition and the other soil formed from the weathering of this sediment.

Mechanical analyses of soils of the Hondo meadows.

Diameter.	Conventional names.	4145. Roswell, 3 miles E.	4119. Roswell, 1 mile E.
Millimeters		*Per cent.*	*Per cent.*
2 to 1	Gravel		
1 to 0.5	Coarse sand	Trace.	
0.5 to .25	Medium sand	1.46	0.76
.25 to .1	Fine sand	5.58	4.85
.1 to .05	Very fine sand	21.04	10.65
.05 to .01	Silt	35.69	12.35
.01 to .005	Fine silt	7.13	17
.005 to .0001	Clay	14.52	34.65
	Salt dissolved in mechanical analysis	.95	5.40
	Loss at 110° C	5.57	7.47
	Loss on ignition	7.89	8.63

Figure 1 gives sections through Roswell, Carlsbad, Otis, and Florence and shows the relation of the soil at the different parts of the valley.

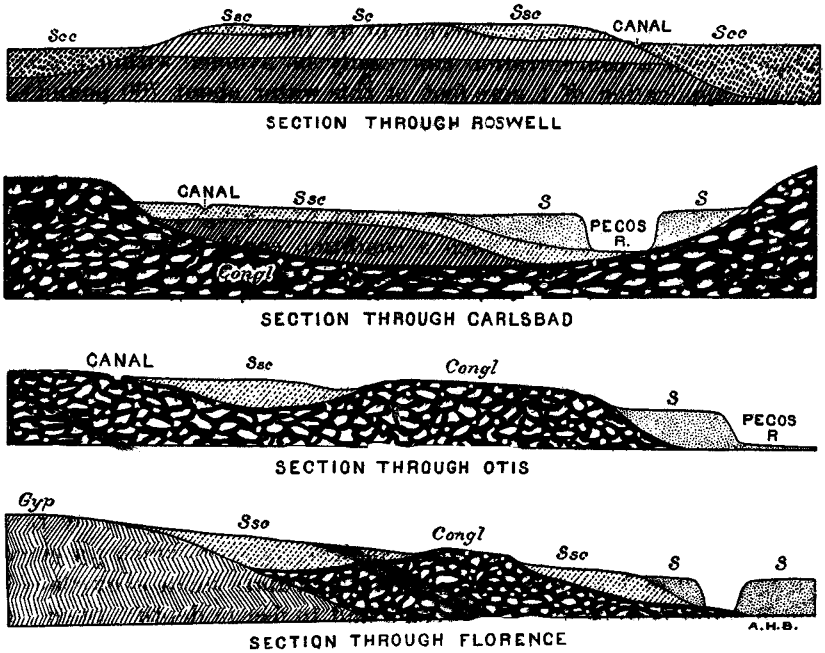


FIG. 1.—Sections in Pecos Valley, New Mexico.
(*S* = sand; *Ssc* = sandy loam; *Sc* = loam; *Scc* = clay loam; *C* = clay; *Congl* = conglomerate; *Gyp* = gypsum.)

WATER SUPPLY.

The water supply from the North and South Spring rivers is good; that is to say, it does not contain enough salt to be harmful to vegetation in any way. The average water contains 75 parts of soluble matter to every 100,000 parts of water. About 49 parts consist of calcium carbonate (limestone) and calcium sulphate (gypsum), which are harmless to plants and crystallize out upon evaporation of the water. The remaining 26 parts consist of salts readily soluble in water and such as are likely to remain in solution and accumulate to such a degree as to be harmful.

The following analysis by Prof. E. M. Skeats, of Carlsbad, represents the average chemical composition of the salt dissolved in the water:

Chemical composition of the North and South Spring rivers, in parts, per 100,000 parts of water.

$NaCl$	8
$CaCO_3$	18
$CaSO_4$	20
$MgSO_4$	16
K_2SO_4	2
Silica, alumina, and iron	1
Water of crystallization, etc	10
Total solids	75

Since most of our agricultural plants are able to grow with their roots in solutions containing as much as 1 per cent of these readily soluble salts, it would require evaporation and concentration of the Spring River water to one-fifteenth of its bulk in order to kill vegetation. Such a concentration can easily be avoided within the soil. By the application of 1 acre-foot of this water about 700 pounds of harmful salts are added, and, since 15,000 pounds per acre-foot can be taken as the maximum amount of salt allowable for plant growth, it would require nine years' accumulation of irrigation waters, allowing 2½ acre-feet of water for each year, and supposing none of the salt washed out of the land. Such a condition could hardly exist, for a certain percentage of the salts is washed down below the first foot. Moreover, part of the salt is annually removed in the crop. Four-tenths of 1 per cent of soluble salt in a soil capable of holding, when saturated, 40 per cent by weight of water gives a concentration of 1 per cent in the soil moisture when the soil is saturated.

UNDERGROUND WATER.

One of the maps accompanying this report shows the depth to standing water during June, 1899. The depth is shown by three shades of green, the lightest shade showing land in which water can not be found by boring 10 feet. The intermediate shade shows land in which water is to be found between 3 and 10 feet in depth. Such land as this, if the water approaches the higher limit, is in danger of becoming too wet and the level of the water table should be carefully watched; and, if it rapidly approaches 3 feet, drainage must be furnished to prevent the water from rising above 3 feet. The reason for giving this land a special tint is that it is approaching the limit, and may need drainage. The darkest tint shows land which is at present in need of drainage, for at the time it was examined water was found within 3 feet of the surface. For such land there can be no question but that its great need is underdrainage. Few plants, none of which are used as agricultural plants in the Pecos Valley, are able to grow to advantage with their roots immersed in water for more than a day or two at a time, and, as most of our common plants send roots as deep as 3 feet, the level of standing water should be kept below this level. Particularly is this true of arid regions, where there is not so much difference between soil and subsoil as in the East. Alfalfa, which is the most important crop of the Roswell area, sends its roots to great depths. Cases have been noted where the alfalfa grew luxuriantly for two or three years, but suddenly began to sicken and die. Investigation proved that the plants grew all right until the roots reached the water table. Here, in their effort to reach farther into the subsoil, the roots were partly immersed in standing water and the crop suffered.

The scale upon which this map is printed does not permit detailed representations of each section of land. There are no doubt small spots within the area shown as in need of immediate drainage which are at present in fair condition for crop production. The map is intended to show in a general way the conditions found existing during June, 1899, and must not be interpreted as representing the conditions at any other time. The entire condition of the land may change with the seasons, and during some other season of the year the water level may be very different. On the map all of the lands below the irrigating canals have standing water at less than ten feet. Such is generally true, though there are a few isolated points immediately along the bank of the Hondo, or under some land never irrigated where water stands at a greater depth than ten feet. Throughout the greater part of the Roswell loam, where clay is found near the surface of the soil and in the draws and close to the river channels, the land is wet and water stands at less than three feet.

The Alkali of the Soils.

One of the maps accompanying this report shows the conditions of the ground with reference to alkali. The three colors indicate the amount of alkali in the soil; soil containing from 0 to 0.25 per cent of alkali; soil containing 0.25 to 0.50 per cent, and soil containing over 0.50 per cent. Or the map shows (1) the areas of land which are free from harmful quantities of alkali; (2) the lands which contain harmful quantities of alkali, but not enough alkali to prevent the growing of crops; and (3) the lands which contain too much alkali for cropping.

The term alkali, as used throughout the West, designates any soluble matter in a soil or water. The term does not mean that the salts are alkaline or basic in a chemical sense, for the greater part of these salts are neutral, and in some cases even acid salts have received this name. There are two kinds of "alkali" commonly recognized, (*a*) white alkali and (*b*) black alkali.

The white alkali is composed of one or more of the following salts, named in the order of their importance: Sodium chlorid, sodium sulphate, magnesium sulphate, calcium chlorid, magnesium chlorid with, in some districts, borates and nitrates. The essential constituent of black alkali is sodium carbonate, though this salt is never pure, but is mixed with sodium bicarbonate and the salts which form the white alkali. These salts are formed through the weathering of the rocks, and in districts of light rainfall the amount of seepage through the soil is insufficient to wash them away. There is therefore an accumulation in most arid soils—the amount, other things being equal, varying inversely as the rainfall of the district.

In some places the alkali is the accumulated salt from the evaporation of inland lakes. All river water contains soluble matter, and when this water enters an inclosed basin where the waters evaporate an accumulation of salts is the result. The muds, silts, and sand left by this lake all contain soluble matter, and upon applying water by irrigation to such soils the alkali, which may not be apparent on the surface of the soil, is brought to the surface by the water, as it rises through capillary attraction. These inclosed basins sometimes represent the most difficult conditions with which the farmer has to deal, for the salt commences to accumulate in the lowest portions of the basin and extends up the sides of the basin as the amount of salt brought in increases. The great expense or even impossibility of draining such basins is the great barrier in the way of their reclamation. The Great Salt Lake of Utah is the remnant of a great lake, and its waters to-day represent the mother liquor from the concentration of great quantities of water.

In past geological ages arms of the ocean were sometimes cut off from the main ocean and the waters concentrated by evaporation until part or all of the burden of soluble matter was deposited. Beds formed in this way to-day, when elevated above the level of the sea and exposed to erosion, give rise to quantities of alkali. The Red Beds, forming the great plains north of Roswell in the Pecos Valley, and underlying the Staked Plains to the east, were deposited in this way, and though no beds of salt are found, yet all of the soils from this formation contain soluble matter. Beds of gypsum were deposited, thus indicating that the ocean water was concentrated by evaporation. Included within this gypsum are small quantities of soluble salt. If beds of these salts were ever deposited, the greater part has been removed by solution, for to-day no deposits of salt within this formation in New Mexico have been found, so far as known.[1]

Another source of alkali in the Pecos Valley is from the decomposition of volcanic rocks. To the west of the Pecos great areas of apparently recent lava are found, and associated with the lava are alkali springs of varying degrees of concentration. Some of the deposits of gypsum in the Pecos Valley can be accounted for only on the assumption that the gypsum is the result of the action of acid waters upon the limestone. Even though the lava flows were not associated with alkali springs, the decomposition of the igneous rocks would give rise to the formation of alkali salts, and without doubt the igneous rocks west of Roswell are the source of parts of the alkali salts.

The alkali of the Roswell area is entirely the white alkali, as far as observed. Many spots were pointed out as being due to the black alkali, but they were undoubtedly due to calcium chlorid. Sodium carbonate can hardly exist under the prevailing conditions.

It has been pointed out by Hilgard that gypsum is an antidote for black alkali under certain favorable conditions. If the soil be well drained and aerated, the black alkali, sodium carbonate, in contact with the gypsum is more or less completely converted into the less noxious white alkali, sodium sulphate. The reaction may be expressed thus:

$$Na_2CO_3+CaSO_4=Na_2SO_4+CaCO_3$$

[1]Since this was written it is reported that a bed of rock salt over 400 feet deep has been encountered in boring for an artesian well at Carlsbad.

On the other hand, if the soil be not well drained, that is to say, conditions exist favorable to the retention of carbon dioxid and moisture, a reverse reaction will predominate, which may be indicated thus:

$$Na_2SO_4+CaCO_3+CO_2+H_2O=Na_2SO_4+H_2Ca(CO_3)_2=2\ H\ NaCO_3+CaSO_4$$

and the sodium bicarbonate ($H\ NaCO_3$) being a very instable compound, always inverts to some extent with the formation of sodium carbonate ($Na_2\ CO_3$), the undesirable constituent of black alkali.

Somewhat similar reactions take place when gypsum comes in contact with chlorids in solution or in a wet soil. Calcium chlorid and sodium sulphate will be formed, which is indicated thus:

$$2\ NaCl+CaSO_4=Na_2SO_4+CaCl_2$$

There will now be present in the solution, sodium chlorid, calcium sulphate, sodium sulphate, calcium chlorid, as well as the ions formed by the dissociation of these salts. If the soil be well drained and sufficient water drains through it, the soluble salts thus formed are rapidly leached away; but if the soil be not well drained, that is to say, if it contains standing water near the surface, there will be a gradual evaporation of the water with a concentration of its salt contents. At first sight it would appear that the calcium sulphate, being so much less soluble than the other salts, would be precipitated as a solid before any of the other salts; more and more being formed from the sodium sulphate and calcium chlorid and precipitating in turn. But this process will take place, if at all, to a much less extent than is generally supposed. It is to be remembered that the solution is becoming more and more saturated with respect to the sodium chlorid. It follows, from the investigations of Treadwell and Reuter, and from experiments in this laboratory, which will be described later by Dr. Cameron, that the amount of gypsum dissolved—its constituents being held in solution as calcium chlorid and sodium sulphate—is very greatly increased with the concentration of the sodium chlorid.

It thus comes about that as evaporation proceeds the solution is actually becoming richer and richer in the very soluble calcium chlorid, and finally it separates as such along with or after the other readily soluble salts. On resolution, being much the most soluble of the salts in the mixture, it would be the first to dissolve, and from the fact that it has a common ion with sodium chlorid, would retard the solution of that otherwise very readily soluble salt. It would increase the solubility of the less readily soluble sodium sulphate if it remained in contact with it sufficiently long for equilibrium to take place. But if it is quickly brought to the surface by capillary forces, or by diffusion, and then quickly concentrated by rapid evaporation, there would be a concentration of the calcium chlorid in the upper portions of the crust.

In several spots in the Pecos Valley considerable quantities of calcium and magnesium chlorid were found in the *crust* on the soil. It is probable, as will be seen from the above reasoning, that but small quantities would be found at any depth in the soil itself. These crusts containing calcium chlorid have a dark appearance quite similar to the true black alkali. Indeed, they are locally known as black alkali, though their characteristic feature is the presence of much calcium or magnesium chlorid, not that of sodium carbonate. The reasons for this blackened appearance are not obvious, and the evidence at hand is too meager to warrant any suggestion at present. It is worthy of note that these spots are of necessity damp or wet—a condition favorable to the formation and retention of carbonic acid. But it will require further investigation to say definitely whether this be a factor in the production of the observed results.

Analyses of alkali crusts from the Roswell area.

No.	Locality.	Calcium sulphate.	Magnesium sulphate.	Sodium sulphate.	Sodium chlorid.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
4092	Sec. 35, T. 10 S., R. 28 E	14.17	28.05	47.99	9.82
4093	Sec. 35, foot of gravel hill	9.09	38.42	41.15	11.33
4097	Bremond crust	13.58	15.73	35.77	34.90
4107	Black crust, Bremond	6.85	12.86	50.90	29.41
4139	High spot, Michelet	45.57	17.53	1.44	35.46
4149	Tule crust, E. of Northern canal	4.03	21.64	64.77	9.57

Of the salts shown in these analyses sodium chlorid is the most harmful to plants. It is generally stated that most agricultural plants can grow with 0.25 per cent within the surface foot of the soil, while of the sodium and magnesium sulphate plants can withstand as much as 0.50 per cent. Observations upon the growth of alfalfa in the Roswell soils showed that it was just able to grow when from 0.40 to 0.50 per cent of alkali was present. The figure 0.50 has been taken as the maximum limit, and though plants are able to grow with this amount of salt in a soil the growth is uncertain and light, in fact 0.25 per cent damages crop growth to a great extent. This range is, therefore, taken as the danger limit.

The action of soluble matter within a soil upon the growth of plants is very complex and to a great extent not well understood. It is a fact of common note that a *little* alkali makes crops grow better. There is danger in this little alkali, however, for if the amount increases ever so little beyond the point where plants grow better, there is noted a decrease in production and the productivity of these soils may be considered dependent upon the per cent of alkali present. The fact has been noted that with 0.25 per cent of alkali in the top foot of soil the crop production is decreased. This decrease becomes more and more marked until the plants refuse to grow. The limit of growth may be considered 0.50 per cent. Occasional cases have been noted elsewhere where crops would live with more alkali present, but in the Pecos Valley, soils, with one-half of 1 per cent alkali, are entirely unproductive.

Plants of different species are able to withstand different amounts of alkali, and the resistance of the same plant to alkali varies in different stages of its growth. In the Roswell area afalfa was found sickly and dying with a little over 0.40 per cent alkali in the soil, while in other stages of its growth isolated plants have been found growing in a soil containing more than 0.75 per cent alkali. Young apple trees showed signs of distress with a little over 0.30 per cent, while sugar beets grew with something over 0.50 per cent.

The action of soluble matter upon plant growth varies with the osmotic pressure of the solution in the plant tissues. This fact has been experimentally demonstrated by Slosson and Buffum of the Wyoming Experiment Station. Since the osmotic pressure varies with the concentration of the solution, the mere statement of the total percentage of salt within a soil determined chemically does not give a true idea of the osmotic pressure of a solution. The percentages as given in this report and in all reports of the Division of Soils are based upon the dry weight of the soil and are the amount of alkali dissolved by the water when the soil is saturated.

The method for salt determinations as used in the field work of the Division of Soils has been described in previous publications, but a short sketch of the method will be given here for the intelligent consideration of the results.

Samples of soil are collected with a 1½-inch soil auger with an extension handle long enough to bore 20 feet. The samples are usually taken in 1-foot sections and the alkali determined in each foot of depth. The soil as collected is thoroughly mixed upon a clean piece of oilcloth. A portion of the mixed sample is saturated with distilled water and packed in a hard-rubber cell of a capacity of about 50 c. c. with two metal sides. The electrical resistance of this saturated soil is taken by a Wheatstone bridge. The temperature is then taken by inserting a thermometer in the soil in the cell. This constitutes the field work. In the laboratory a number of typical samples of the alkali in the soil are analyzed and a solution of salt corresponding in relative composition to the average of these analyses is made. By varying dilutions of this solution the per cent of salt is ascertained for each 5 or 10 ohms difference in resistance. The per cent of water of saturation for each type of soil is then determined by saturating the soils in the same manner as done in the field and making gravimetric moisture determinations. Then by determining the weight of the wet soil the cell will hold, the number of cubic centimeters of the soil moisture in the cell filled with saturated soil may be calculated. Knowing the number of cubic centimeters of soil moisture contained in the cell full of saturated soil, the cell factor, or the figure by which the resistance of that amount of solution must be multiplied in order to give the specific resistance, can be found from the known constants of the cell. The resistance obtained in the field is multiplied by the figure 0.55 to correct for the resistance offered by the insoluble, nonconducting particles of soil and the result multiplied by the cell factor, giving the specific electrical resistance of the solution around the soil grains. The per cent of salt corresponding to the specific resistance is determined from the solution made up from the chemical analyses of the field samples. This percentage, multiplied by the per cent of water in the saturated soil, gives the per cent of alkali in the dry soil.

In the field work borings are taken at frequent intervals and the salt content determined for each foot of depth. These percentages are plotted on base maps and lines drawn separating the three conditions of the soil respecting alkali. These three conditions are shown in the alkali map by different colors.

The maps as presented may be taken as an indication of the condition of the soil during June, 1899. For the construction of the maps the salt content of the soil to a depth of 5 feet was considered.

The area of Pecos loam is seen to be colored to indicate between 0.25 and 0.50 per cent alkali. This soil at every point examined within the area of the map was found to contain more than 0.25 per cent of alkali within the upper 5 feet. The porosity of this soil, however, would enable most of this salt to be immediately washed out upon the application of irrigation water, as has been seen in a number of places where small tracts of this upland soil were cultivated around Roswell.

The areas on the salt map showing from 0.25 to 0.5 per cent of salt are susceptible of a much greater range of conditions than are indicated by the range in salt content to the depth of 5 feet. Crops may make a moderate growth on any or all parts of this class of land, and there are places near the lower limit, undoubtedly, where the conditions are excellent at the present time, because the salts are so distributed that only small amounts are contained in the first and second foot, while a sufficient amount occurs below this to bring the average up to 0.25 per cent or more.

This condition, while giving excellent results at present, is dangerous, because the salts are liable to move toward the surface unless good underdrainage is provided.

As we approach the upper limit on this class of land the other extreme may be found to exist, i. e., an accumulation of salts at the surface in sufficient amount to kill all crops, and yet the quantity of salts be sufficiently small in the lower depths to bring the average for 5 feet below 0.5 per cent.

The Problems of the Roswell Area.

It has been shown under the discussion of the soils that the accumulation of the alkali salts in the surface of the soil is in all cases due to lack of drainage. The salts which are present now near the surface were once buried at such a depth as to be of little or no damage to plants, and this translocation has been brought about by irrigation. The water supply is good; therefore the salt must originally have come from the soil. Much of the land has already suffered from accumulations of salt, so there are two important problems before the farmer: First, the prevention of further damage from seepage water and alkali salts; second, the reclamation of the lands already damaged or abandoned.

Roswell is situated in a large grazing country, and the principal industry is cattle and sheep raising. The agriculture is largely supplementary to the range. Alfalfa is the principal crop. There is, however, a growing tendency toward fruit raising on the part of some of the farmers. The local demand for fruit is great enough at present to use all of the fruit produced, but there is danger of overstocking the local market, and thus necessitating the shipment to distant markets.

Situated as it is, there is no question but that cattle and sheep will prove the most profitable industry toward which the farmers may turn. The success of the Roswell community is to be attributed to their realization of this fact. Since alfalfa offers the most ready forage crop, the soil should be in the best condition for its growth. One of the most essential conditions of a soil in an alfalfa field is good drainage. Alfalfa roots penetrate deep into the subsoil, and as soon as standing water is encountered their roots cease to grow. If drainage keeps the level of standing water down, the success of the crop is insured. Drainage also removes and insures no further damage from alkali.

THE HAGERMAN AREA.

GEOLOGY AND TOPOGRAPHY.

The Hagerman area, or Northern Canal system, lies about the center of the basin formed by the ancient obstructions in the Pecos River about Seven Rivers. The Roswell area lies near the northern end of the same basin. This basin, cut out of the Red Beds or Permian strata, is more or less filled with sediment derived from these rocks. The Red Beds contain crystals of gypsum scattered throughout their sands and gravels, and, interstratified with the beds of sand and clay, heavy, massive saccharoidal gypsum. It is to the solution and redeposition of this gypsum that the gypsum of the soils of the Roswell area is mainly due, though this gypsum in the soils may in part be from mechanical sedimentation.

The Hagerman area lies along the terraces cut by the Pecos River in the sediments of the old lake. The action of the Pecos has been aided by the streams entering from the west, notably by the Felix and Penasco. The terraces are very imperfect, the land sloping from the edge of the river channel gradually upward to the west. On the east side the Pecos is bounded by high bluffs.

SOILS.

The soils of the Hagerman district correspond very nearly to the soils of the Roswell area. On the lowest lands lying close to the Pecos River dune sands and sandy loams form the predominating soil types. These are usually well drained from their nearness to the river channel, though occasionally, even when apparently in the most favorable conditions, these lands are found wet and in need of drainage. On the level lands immediately around Hagerman, the soil is heavy and corresponds very nearly to the Roswell loam. Around this are areas of gypsum soil, which is exposed in drains to the south of Hagerman. The discussion of the cultivation of this gypsum land will be deferred until it is considered under the Carlsbad area, where it is more typically developed.

Upon the uplands of the Hagerman area and above the canal the Pecos loam, similar to the upland soil at Roswell, is typically developed. This area of soil is a continuation of the Roswell area. A soil map has not been drawn of the Hagerman area, as a short time only was spent in reconnoissance of the soils. The great similarity of this district to the Roswell and Carlsbad soils, however, will enable the conclusions drawn from them to be readily applied to the Hagerman conditions.

THE WATER SUPPLY.

The Northern Canal heads in a dam across the Hondo River directly east of Roswell. This dam collects and directs into the canal the unused and waste water from the Berendo and North Spring rivers, also from the Hondo in times of flowing in that stream above Roswell. A great deal of seepage and drainage water is collected, which, together with the salt from the Berendo water, renders the Northern Canal water salty. At the point where the Northern Canal crosses the South Spring River a second diverting dam collects the water of that stream. This also contains quantities of seepage and drainage water. The average condition of the Northern Canal water is shown by the following analysis by Prof. E. M. Skeats, of Carlsbad, N. Mex.

	Parts per 100,000.
$NaCl$	65
$CaCO_3$	17
$CaSO_4$	51
$MgSO_4$	25
K_2SO_4 / Na_2SO_4	23
Silica, alumina, and iron	2
Water of crystallization	19
Total solids	202

Of these salts calcium carbonate, calcium sulphate, the silicon, iron, and alumina compounds, with much of the water of crystallization, amounting in all to 89 parts, may be disregarded, since upon the evaporation of the water these compounds crystallize out and do not collect in the soil in sufficient quantity to be of harm to vegetation. Thus the harmful salts of the water are present in the proportion of 113 parts of salt to 100,000 of water.

UNDERGROUND WATER.

The wells above the canal are from 60 to 100 feet deep, with water at about 60 feet. The water in all of these wells is good, containing about

35 parts of soluble matter per 100,000. Of the land below the canal, part of it has already become so wet that underdrainage is necessary. Around the town of Hagerman water is found in places as near the surface as 3 feet. During the four years during which irrigation has been practiced the entire character of the vegetation around Hagerman has been changed from grama and other prairie grasses to salt grass. The change has been brought about almost entirely by underground seepage waters and alkali.

ALKALI OF THE SOILS.

The condition of the soils of the Hagerman area correspond exactly to the conditions existing at Roswell. The cause of the present conditions, however, includes one factor which was noted as unimportant in the Roswell area; that is, the amount of alkali in the irrigation water. The application of each acre-foot of Northern Canal water adds 3,000 pounds of salts to the soil. Such salts, if allowed to accumulate by evaporation of the water, would soon so impregnate the soil with alkali that crops would not grow. Allowing 2½ acre-feet per year, in two years 15,000 pounds of soluble matter would have accumulated, or enough to prevent profitable cultivation, provided all of the salt was retained by the surface foot of soil. This rapid accumulation may easily be prevented by washing the accumulated salts from the previous irrigation down into underground drainage. Another successful method is to grow soil-shading crops which prevent the rapid evaporation from the surface of the soil, so that less water is needed in irrigation. Cultivation offers the most effective method of preventing evaporation from the soil's surface, and this should be carefully followed out in the growth of all crops which allow cultivation.

PROBLEMS OF THE DISTRICT.

The problems of the Hagerman district are very similar in character to the problems of the Roswell district. The accumulation of alkali salts must be prevented, and the excess already present must be removed. The leakage from canals and laterals, particularly in the case of water containing alkali salts, is one of the most potent sources of trouble. The loss from the canal in running through the sandy and gravelly soils is great. In the case of the main canal 1 cubic foot per second is lost for every mile. This water, seeping under the ground, gradually fills up the subsoil until capillary force lifts the water to the surface, where it evaporates leaving the alkali.

CARLSBAD AREA.

GEOLOGY.

The Carlsbad area lies entirely in Eddy County, New Mexico, along both sides of the Pecos River. The irrigation district lies in a basin cut off on the north by a canyon, through which the Pecos runs, and on the south by canyons and rough country from below the Black River to the Texas line. This basin is undoubtedly the site of an ancient lake, bounded on the west by the foothills of the Guadalupe Mountains, on the east by the scarp of the Staked Plains. The entrance to and exit from this basin were through narrow gorges cut in the hard carboniferous rock of the foothills. The sediments form the present soils of the district, modified to a great degree by the Pecos and the drifting action of the wind. The elevation of the country, or more likely the cutting away of the dam below Black River, placed the Pecos in position to commence the removal of the lake sediments. The river has begun the cutting and has already worn down to its hard rock over part of the district, and has commenced meandering in its bed, forming broad and treacherous sand bars. At other points in its course the Pecos has worn down to the conglomerate which lies at the base of the lake sediments.

The water supply of the Carlsbad area is derived entirely from the Pecos River. The original plans for irrigation contemplated taking the water direct from the river with a storage reservoir 6 miles above Carlsbad, with a capacity of 7,000 acre-feet. The situation of the dam is in a canyon with limestone walls, offering a natural abutment for the ends of the dam. This storage reservoir proving inadequate, a second reservoir was constructed 17 miles above Carlsbad, near Seven Rivers. This dam forms a lake 8 miles long and of an average width of 1¾ miles, with a storage capacity of 140,000 acre-feet.

SOILS.

Map 4 accompanying this report shows the soils of the Carlsbad area. Four distinct types of agricultural soil have been recognized and named, each type being different in its relation to irrigation waters and alkali and to vegetation. These types are as follows:

1. Pecos sands.
2. Pecos sandy loams.
3. Pecos conglomerate soil.
4. Gypsum loam or "yeso."

THE PECOS SANDS.

Along the Pecos River, filling up the tortuous bends of its course, are areas of sands blown about by the winds. The characteristic vegetation of mesquite, yucca, and canaigre in a great measure prevent the drifting of these sand dunes. The mesquite forms small dunes around its roots, and as the dunes build up the mesquite extends its roots, keeping on top of the dunes. In this way dunes 8 to 10 feet high are formed with mesquite growing on the top. This dune sand is composed of rounded grains of quartz with smaller quantities of gypsum and limestone. The texture of the dune sand is shown in the following table:

Mechanical analysis of dune sand.

Diameter.	Conventional names.	4064. Carlsbad, 2 miles NW., 0 to 6 inches.
Millimeter.		*Per cent.*
2 to 1	Gravel	0.00
1 to 0.5	Coarse sand	.00
0.5 to .25	Medium sand	.22
.25 to .1	Fine sand	70.25
.1 to .05	Very fine sand	21.50
.05 to .01	Silt	2.70
.01 to .005	Fine silt	.43
.005 to .0001	Clay	4.22
Loss at 110° C		.43
Loss on ignition		.35

This type of sandy soil is from its texture well adapted to truck farming and root crops. Melons, potatoes, and small fruit grow well on this soil. It forms the soil of La Huerta, that part of Carlsbad north of the Pecos River and immediately adjoining the town. There are narrow strips of this soil found along the river as far south as the area was examined. Such a soil is not apt to be rich in plant food, but in the forcing of fruit and early vegetables this is not so necessary as ease of cultivation.

The virgin Pecos sand contains very little alkali. Examinations were made at points all over the area of the portion mapped out, and in no case was natural accumulation of alkali found. The alkali profile, in Figure 2*a*, shows the per cent of alkali in two typical soils, one never irrigated and the other irrigated. It will be seen that the irrigated soil on the average carries a little more alkali than the virgin soil.

THE PECOS SANDY LOAM.

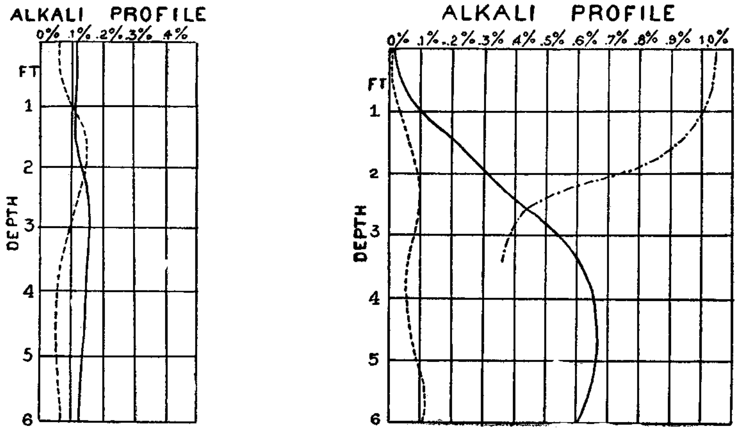
This is the most important type of soil in the Carlsbad area and covers the greater part of the irrigable land under the Southern Canal. This loam is very similar in character and texture to the Pecos sandy loam at Roswell.

The accompanying table shows the average texture of the soil.

Mechanical analyses of Pecos sandy loam soils.

Diameter.	Conventional names.	4067. ½ mile S. Otis, N. Mex., 0 to 12 inches.	4068. 1½ miles S. Otis, N. Mex., 0 to 12 inches.
Millimeters.		*Per cent.*	*Per cent.*
2 to 1	Gravel	0.00	0.00
1 to 0.5	Coarse sand	Trace.	Trace.
0.5 to .25	Medium sand	1.32	1.65
25 to .1	Fine sand	10.20	12
.1 to .05	Very fine sand	36.30	41.45
.05 to .01	Silt	19.10	10.27
.01 to .050	Fine silt	3	10.45
.005 to .0001	Clay	18.65	18.72
Salts dissolved in 1½ liters of water, used in mechanical analyses		4	2
Loss at 110° C		2.60	2.67
Loss on ignition		4.70	2.45

The mechanical analyses of 4067 and 4068 represent typical soil from the Pecos sandy loam. These soils in the field appear much lighter in texture than the mechanical analysis would indicate. A microscopical examination of the soils was made to see the cause of this. Under the microscope a great many particles were found to consist of little conglomerates of clay cemented by lime. These particles upon shaking in the mechanical analysis gradually disintegrated, forming a soil which contained 32 per cent of clay. Since a mechanical analysis made in



a. In Pecos sand.
.... Before irrigation.
—— After irrigation.

b. In Pecos sandy loam.
—— Original soil.
...... Irrigated soil.
—·—·— subirrigated soil.

FIG. 2.—Diagram showing salt content to depth of 6 feet.

this way did not represent true field conditions analyses were made with only enough shaking with water to wash off the loose clayey particles. Also in soils containing gypsum and lime, the water used for the mechanical analysis dissolved a quantity of the gypsum and lime. This amount is indicated in the table as soluble in water, but must not be taken to represent the per cent of alkali salts.

In the field the breaking down of the particles is observed in spots continuously wet, and even with a normal amount of moisture the soils have become a little heavier by this disintegration. In some parts of the area this disintegration of the soil has gone on since irrigation commenced, and now we have irrigated soils which are heavier than nonirrigated soils situated under the same conditions.

The alkali profile given in figure 2*b* shows the per cent of alkali salt in the soil under three conditions: (1) The virgin soil; (2) the soil after irrigation, where drainage is good; and (3) the soil where irrigated when the drainage is poor or when subirrigated. The texture profile on the soil map shows the soil to be composed of nearly all (93 per cent) sand to a depth of 6 feet. Situated as these sands are, along the banks of the river, the drainage is normally good and the salt, which originally is found in the subsoil, is readily leached out and

SAND DUNES WITH CHARACTERISTIC VEGETATION OF MESQUITE AND CANAIGRE, NEAR CARLSBAD, N. MEX.

These sand dunes when leveled down and put under irrigation make good truck land.

carried away. Where this drainage is defective the evaporation from the surface is sufficient to rapidly concentrate the soil solutions and the alkali salts accumulate at the surface. Such a state of affairs is found along the foot of the gravel bluffs, in secs. 8, 9, 10, 14, and 15, of T. 22 S., R. 27 E. (See map 5.) Here the water in seeping out from the conglomerate bluffs has swamped an area of land and the rapid evaporation of the water is swiftly producing an alkali flat.

The Pecos sandy loam contains about 20 per cent of carbonate of lime. So much lime is objectionable to a great many plants, but fortunately the class of plants grown in the Pecos Valley are tolerant of lime. The humus content of the soil is low, as is true of many of the arid climate soils. Since the humus is the principal element of nitrogen, this element is perhaps the element most needed in the Pecos Valley soils.

The plowing under of alfalfa is found to be of great benefit to sugar beets, due to the addition of the nitrogenous organic matter of the alfalfa. The practice of plowing under alfalfa has not been general, since the cost of seeding and starting alfalfa is heavy. The first year's crop is not sufficient to pay for the cost of planting. There are other leguminous crops which, without doubt, could be grown in the valley, and could be turned under with profit.

The question of fertilizing, either with green manures or chemical fertilizers, is one which farmers of the West are very loath to consider. Western soils are usually rich soils, but in some districts even the virgin soils are poor. Particularly is this true of soils in the true arid regions, where the native vegetation is scanty and the humus content of the soils very low. The yield of sugar beets per acre upon the Pecos loam averages less than 5 tons per acre. This low yield is due partly to lack of proper plant food within the soil. No experiments, so far as known, have been conducted on the effect of fertilizers other than alfalfa upon the growth of beets or other crops. This defect in the soil is realized by the farmers at present, and improvement in their methods of handling the soils is looked for in the near future.

PECOS CONGLOMERATE SOIL.

Underlying the Pecos sandy loam throughout the area examined is found a bed of gravel or conglomerate. This conglomerate is exposed over many points in the area, and whenever so exposed its disintegration gives rise to a gravelly soil. This loose material is usually 2 feet deep, underlaid by gravel or conglomerate. The table following illustrates the texture of the soil. No. 4069 contained 19.3 and 4070 contained 26.1 per cent of coarse gravel.

Mechanical analysis of Pecos conglomerate soil.

Diameter.	Conventional name.	4069.	4070.
Millimeters.			
2 to 1	Fine gravel	Trace.	Trace.
1 to 0.05	Coarse sand	1.20	1.11
0.05 to .25	Medium sand	1.80	1.97
.25 to .1	Fine sand	12.51	12.88
.1 to .05	Very fine sand	45.77	39.81
.05 to .01	Silt	12.91	17.66
.01 to .005	Fine silt	3.43	3.46
.005 to .0001	Clay	17.22	18.22
Loss at 110° C		2.21	2.37
Loss on ignition		2.99	4.08

Presenting as it does such a large percentage of gravel, this soil is difficult to cultivate. Water readily leaches through it, and its irrigation would require large heads of water to cover short distances. Very little of this gravelly land has been cultivated. The area is seen to be large, and as land becomes scarcer and more valuable there will no doubt be a demand for this gravelly soil.

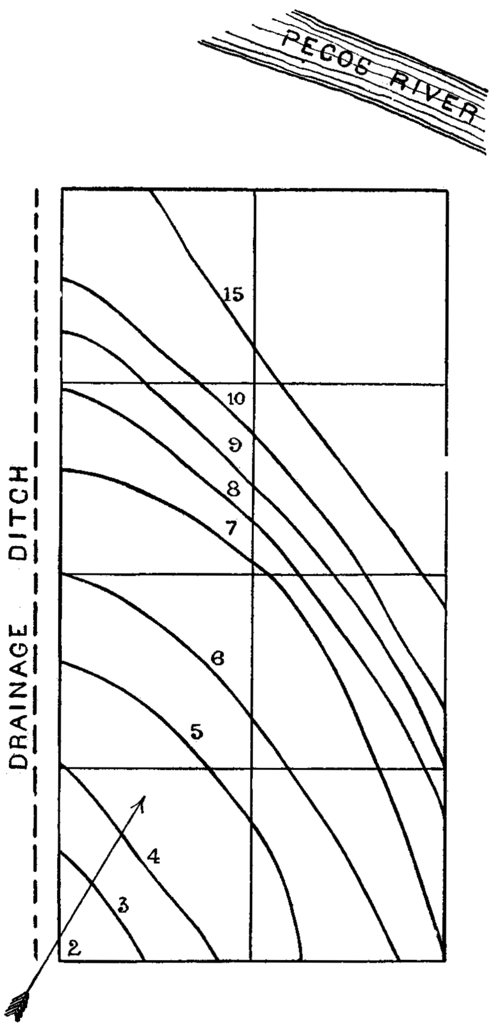
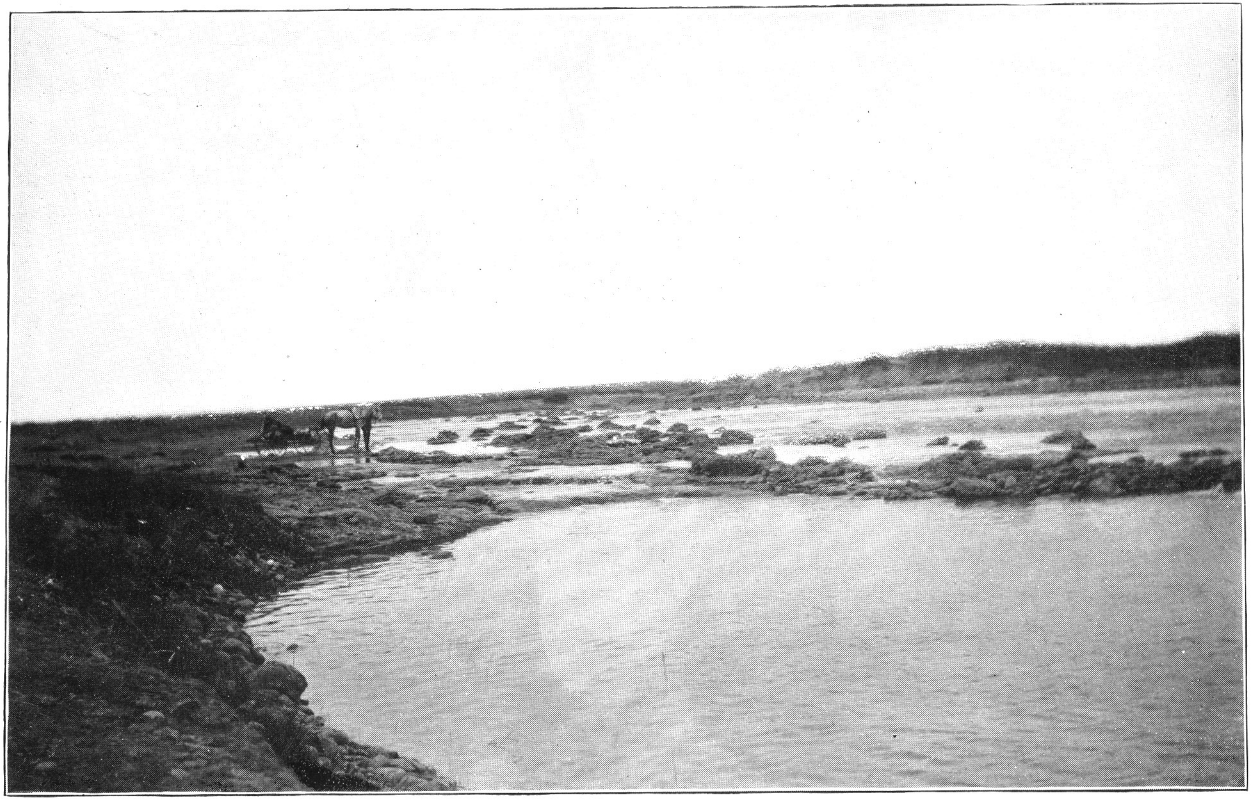


FIG. 3.—Diagram of orchard showing depth to standing water.

The ready penetration of the water in this soil makes low-lying areas of it uncertain, for water seeping up from below through the conglomerate soon swamps the overlying soil.

The canal over part of its course runs through the conglomerate. At these points quantities of water seep out of the bed and through the conglomerate to appear lower down. The alkali flats in several sections have been formed in this way from the seepage water out of the conglomerate bluff into the sandy soils along the river bottoms.

This permeability of the conglomerate offers one of the great sources of danger from seepage water. Though it offers a ready natural underdrainage for part of the upland, it is in the same way a great source of damage to the low-lying lands. Draws and flats adjacent to



Conglomerate in Pecos River Bed.

This layer of conglomerate extends under nearly all of the soils of the Carlsbad area, affording good drainage to some soils and being an element of danger to others differently located.

the hills of conglomerate receive as seepage water the drainage from the upper lands.

Figure 3 shows the depth to standing water in an orchard near Carlsbad being injured by seepage water and alkali coming from under the conglomerate. The arrow shows the direction of the underground drainage toward the Pecos River. The surface of the orchard is nearly level and about 20 feet above the river. This shows the influence of the good drainage along the river bank, in lowering the level of the standing water.

Figure 4 shows the soluble salt content of the surface foot in the orchard and the influence of the good drainage along the Pecos River. The relation of these lines to the drainage lines in figure 3 is very apparent.

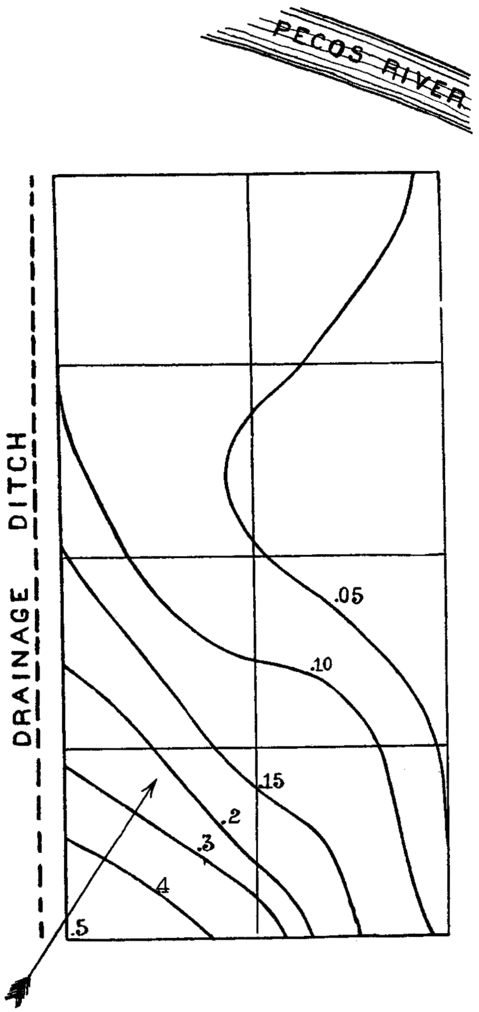


FIG. 4.—Diagram of orchard showing soluble salt content of surface foot.

GYPSUM LOAM OR "YESO."

The soil map shows a large irregular-shaped area of gypsum soil north of Black River and another area south of Black River, around Malaga. This gypsum or "yeso," as the native Mexicans term it, possesses marked peculiarities which merit a careful study.

The material is composed of nearly pure gypsum in a granular form. When dry it is hard and compact, but upon wetting it absorbs water about as readily as a lump of sugar and breaks down into a soft mass which is very pervious to water.

Mechanical analyses of this material are very indefinite because the particles are so soft that they break up by agitation with water. The area mapped as gypsum soil does not everywhere have the gypsum on the immediate surface, but in nearly all places is covered with a thin layer of loam, derived from the decomposition of the gypsum or deposition by wind and water of other material. This loam varies in thickness from a fraction of an inch to 3 feet in depth.

The composition of the gypsum loam is shown in the accompanying table:

Mechanical analyses of gypsum loam soils.

Diameter.	Conventional names.	4071.	4074.
Millimeters.		*Per cent.*	*Per cent.*
2 to 1	Gravel	....	....
1 to 0.5	Coarse sand	Trace.	....
0.5 to .25	Medium sand	2.20	2.58
.25 to .1	Fine sand	9.42	14.25
.1 to .05	Very fine sand	38.47	37.13
.05 to .01	Silt	12.67	13.95
.01 to .005	Fine silt	10.87	8.88
.005 to .0001	Clay	19.70	15.46
Salts dissolved in $1\frac{1}{2}$ liters of water used in mechanical analyses		1.90	2.34
Loss at 110° C.		3.03	2.80
Loss on ignition		3.41	3.27

The most important physical property of the gypsum is its capillary power. When compared with another soil this property of the gypsum is remarkable. Wet spots have been observed in a field where on boring water could not be found within 6 feet of the surface.

A tube filled with the gypsum soil was placed with its lower end in water and the height to which the water rose was determined every day. The following table shows the results of the experiment:

Time.	Pecos gypsum, height in inches.	Pecos dune sand, height in inches.	Time.	Pecos gypsum, height in inches.	Pecos dune sand, height in inches.
15 minutes	$1\frac{1}{2}$	$6\frac{1}{2}$	6 days	$37\frac{1}{2}$	....
45 minutes	$2\frac{1}{4}$	$11\frac{1}{2}$	7 days	40	....
1 hour	3	13	8 days	$42\frac{1}{4}$	....
2 hours	5	14	9 days	$44\frac{1}{4}$	....
6 hours	$9\frac{1}{2}$	17	10 days	$46\frac{1}{2}$	....
24 hours	$17\frac{1}{2}$	$18\frac{1}{4}$	13 days	$50\frac{1}{2}$	....
2 days	24	$19\frac{1}{2}$	14 days	52	....
3 days	$27\frac{3}{4}$	$20\frac{1}{2}$	15 days	53	....
4 days	32	$20\frac{1}{2}$	25 days	58	21

At the time the top of the tube was wet the water was slowly rising, and no doubt would have risen several inches higher. This great capillarity is of special importance and must be fully considered before reclamation by irrigation. The surface of the soil is kept moist all the time and the rapid evaporation from the surface causes the deposition of the alkali salts. It is undoubtedly this physical property which renders the cultivation of the gypsum soils so difficult in the Pecos Valley. The New Mexico Experiment Station has shown that, in itself, the gypsum is not harmful to plant growth, but in districts where water contains alkali salts the cultivation of the gypsum can not be recommended.

One of the most serious difficulties in the way of reclamation of gypsum lands would be their proper drainage. Canals, ditches, and laterals when passing through the gypsum are found to lose quantities of water by seepage, both lateral and downward. Cavities and underground channels are dissolved out in the gypsum, which makes it very

A Gypsum Soil without the usual Covering of Loam, near Florence, N. Mex.

This material looks like white alkali, but is quite free from this except where affected by seepage water.

difficult to drain the soil. Open drains have been seen in which the water would flow in from one side, directly across the drain, and out into the subsoil on the other side. The great depth from which water is raised by the gypsum would necessitate the placing of the drains deeper than usual. Open drains can not be used, for the gypsum erodes so easily that the drains are not easily controlled. The irrigation laterals on the gypsum area, if run on a steep grade, cut deep trenches and fill up the subsoil with the water which seeps from their sides and bottoms. Plate VI shows such a lateral, which has cut a trench in places 10 feet deep in the gypsum. The virgin gypsum carries small quantities of alkali salts in nearly all places examined, but at no point was an accumulation of alkali salts encountered. A very different state of affairs is seen after the gypsum has been irrigated. The top of the soil soon becomes crusted over and the growth of agricultural plants prevented. Even where not cultivated, but in the vicinity of ditches and irrigated fields, the subirrigation of the gypsum is so great as in a few years to destroy all vegetation which can not withstand quantities of alkali.

From our present knowledge of the subject, the cultivation of pure gypsum soils is to be discouraged in the Pecos Valley.

The Water Supply of the Carslsbad District.

The irrigation water of the Carlsbad district is obtained by storage of the Pecos water. It has been shown that the normal flow of the river is all from springs situated along its middle and lower courses in New Mexico. This water contains more or less alkali in solution all of the time, and in standing in reservoirs the evaporation from the surface serves further to concentrate the water. The evaporation in Lake McMillan has been found to be as much as 4½ inches per week, and, though authentic records are not at hand, the evaporation from a water surface is estimated to be about 10 feet of water per year. This great evaporation from the surface of a large reservoir is a very important item in the engineering of a storage system for the southwest. Estimates by the engineer of the Southern Canal system at Carlsbad during the summer of 1899 showed that during several weeks of May and June the evaporation from the large reservoir exceeded the inflow from the Pecos by as much as 25 cubic feet per second. The inflow from the Pecos is at a minimum during the winter and early spring, and the evaporation during this time continues to concentrate the water, so that when the water is first needed for young, tender plants, such as sugar beets, it is in its worst condition. The first floods, which occur generally in May or June, bring down large quantities of salt which have accumulated in the salt drains of the upper Pecos. These floods seldom improve the condition of the water. Later floods furnish the purest water of the season, and it is upon these floods of pure water that the farmer should depend, if possible.

From analyses by Prof. E. M. Skeats, of Carlsbad, the condition of the water has been found to vary from 510 parts soluble matter in 100,000 parts of water found in the first floods, to 243 parts found in the later floods, with an average of 310 parts. Professor Skeats gives the following as the average composition of the soluble matter in the Pecos water:

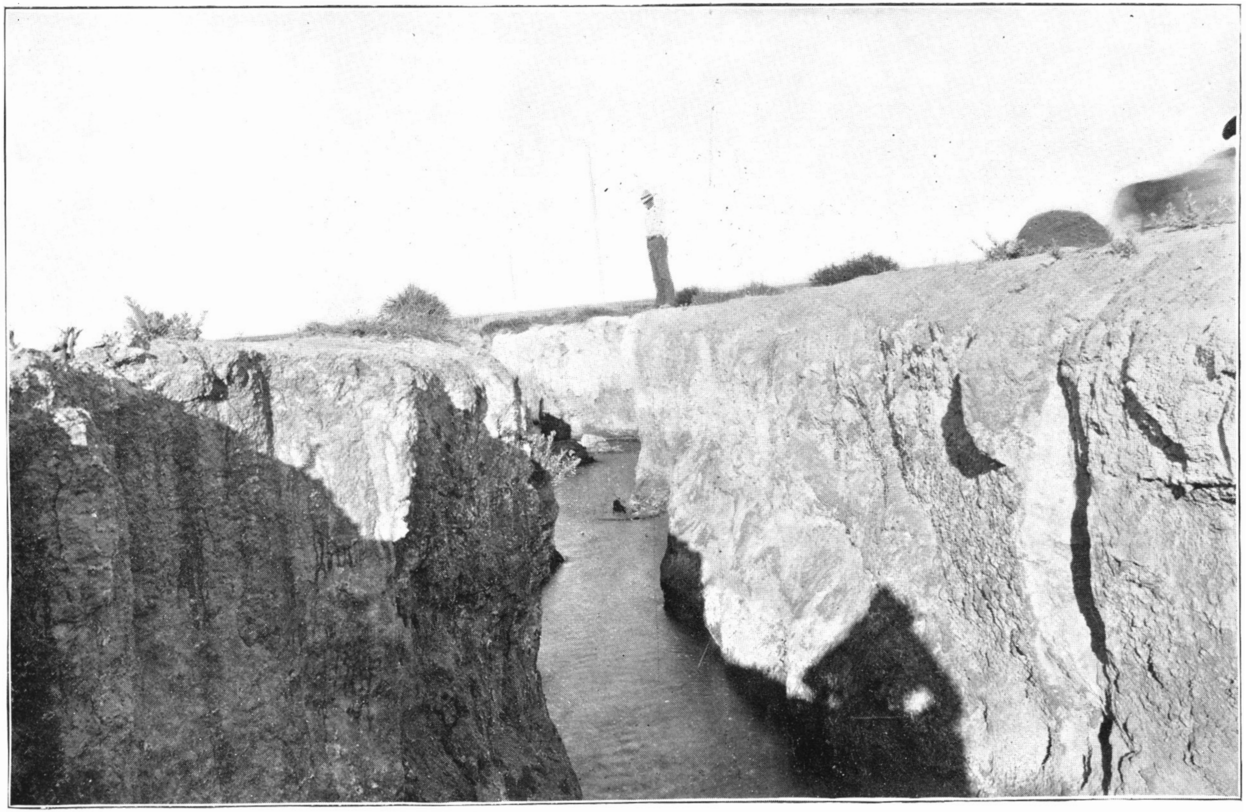
	Parts per 100,000.
$NaCl$	98
$CaCO_3$	11
$CaSO_4$	130
$MgSO_4$	49
K_2SO_4	5
Silica, alumina, and iron	2
Water of crystallization, etc	15
Total salts	310

Of this it will be seen that 152 parts per 100,000 are salts likely to accumulate in the soil solutions and injure plants. The application of 2½ acre-feet of water would add 10,000 pounds of soluble salts to the soil, and, since 15,000 pounds can be taken as the maximum amount allowable in the surface foot of the soil, 1½ years only would be required so to fill the soil with alkali that agriculture would be unprofitable. This salt, however, is not all deposited in the surface foot, but is distributed in the soil as deep as the water penetrates, and if enough water is added to wet down to the level of standing water part of the salt left from the evaporation of the previous irrigation is washed away.

During June, 1899, a sample of the water from the main canal near Carlsbad was taken. A chemical analysis of this sample was made by Dr. Frank K. Cameron, chemist of this division, with the following result:

	Parts per 100,000.
$CaSO_4$	161.64
$MgSO_4$	2.16
Na_2SO_4	59.98
$NaCl$	168.16
	391.94
Undissolved after evaporation	43.28
Total salts	435.22

The water at the time this sample was taken was said to be so concentrated as to injure young sugar-beet plants. The osmotic pressure of a solution is the determining factor in its action toward plants; the water at this time contained about one half as much salt in actual solution as could be endured by most plants. To this salt was added that already within the soil, so that the delicate rootlets were immersed



A LATERAL DITCH CUTTING DOWN INTO THE GYPSUM SOIL.

The gypsum is so soft and transmits seepage water so readily that it is to be avoided in irrigation work.

Seepage Stream from the Gypsum Area, flowing about 2 Cubic Feet per Second.

The loss from the canals flowing through the gypsum area is often enormous.

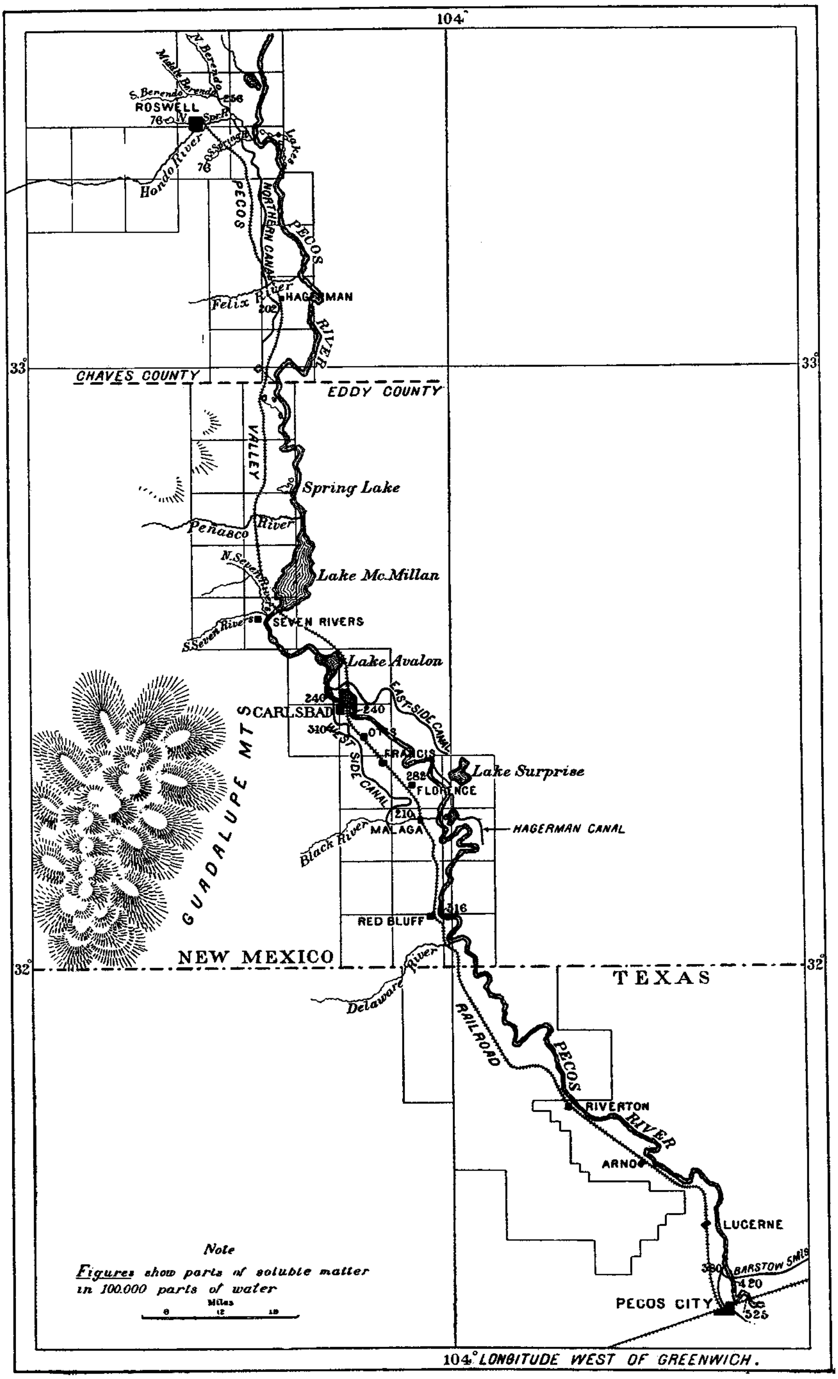


FIG. 5.—Sketch map of Pecos Valley, showing increase in salt content of water as it flows down the valley. (The figures show the salt content in parts per 100,000.)

in a solution almost as concentrated as they were able to stand. Under the intense heat of the sun of southern New Mexico this solution soon evaporates so much near the surface that it concentrates beyond the limit of plant growth. In the solution outside the rootlets the osmotic pressure becomes higher than the osmotic pressure inside the rootlets, and the plant dies of thirst though in the presence of plenty of moisture.

Figure 5 gives a graphic idea of the salt content of the water in different parts of the valley.

UNDERGROUND WATER.

One of the maps accompanying this report shows the depth to watér, measured from the surface of the ground. The map indicates by the shades the three conditions of the land: (*a*) Water more than 10 feet below the surface; (*b*) water between 3 and 10 feet; (*c*) water 3 feet or less.

The general condition of the vegetation throughout the area watered by the Southern Canal system is not healthy. Crops are more subject to disease than is the case under similar conditions in humid climates. Sugar beets are subject to a root-rot; fruit trees suffer from something similar, and even alfalfa has a disease which attacks the roots. This unhealthy condition can be attributed to the condition of the irrigation water. Plants with their roots immersed in a solution of the concentration of the irrigating water from the Southern Canal are weakened and the germs of disease, which seem to be present in all of the soil, are enabled to attack the plant, weakening it further. This root disease is difficult to deal with, since the application of sprays to the roots is an impossibility. Some benefit has been claimed from the application of copperas around the roots of the trees.

The depth of wells over the greater part of the district was at least 40 feet originally; at present water can be found over nearly the whole of the irrigated land at less than 20 feet. In some of the wells which were dug 40 feet eight years ago water stands now at a depth of 5 to 10 feet during the irrigating season. In the winter, after the water has been taken out of the canals and laterals, the water slowly lowers in the wells. As soon as the water is turned in the main canal the level in the wells begins to rise, even before the irrigation commences on the lands around the wells. That the loss from canals and laterals is the greatest source of seepage water in irrigation districts is a fact which is coming to be generally recognized. There is without doubt much seepage water from overirrigated land, but the loss from constantly running canals and laterals far exceeds this. The loss from the canals of the Carlsbad district, while not great when compared with the loss of canals of other districts, is great enough to cause serious damage. The canal in crossing the beds of gravel and conglomerate loses appreciably by seepage. The following measurements of loss in conglomerate will illustrate this point. In running through the conglomerate directly west of Carlsbad the canal loses 4 cubic feet of water per second in a distance of 1 mile. While this loss is not great when compared with some Colorado canals, as reported by Carpenter, yet the effect of this alkaline water has been seriously felt in the flat to the west of the town, immediately along the foot of the gravel hill. The underground water map shows an area in which water approaches to within 3 feet of the surface. The greater part of this water is the seepage from the canal, while part is due to the laterals in the town. The water has accumulated to such a degree and has become concentrated to such an extent by evaporation that the park trees and cottonwoods have suffered and many of them have died. A deep drain around the town would largely prevent this damage. Along the foot of the gravel bluffs, in secs. 8, 9, 10, 14, and 15, T. 22, R. 27 E., is another area in which water has seeped out from the gravel bluff, swamping the land. This water flows under the higher lands immediately south, and no doubt has its origin in the canal. Some of the seepage water comes from the irrigation on this upland, but this source seems inconsiderable when compared with the loss from the canal.

A third area of wet land on sec. 25, T. 22 S., R. 27 E. can also be attributed to seepage from the conglomerate. On the edge of this flat water originally stood 40 feet below the surface; while at present, during part of the irrigation season, it is unsafe to attempt to drive a horse along the roads through the flat.

The other areas, shown with water near the surface, are either in the area of gypsum soil or are immediately adjacent to the gypsum. The loss in canals and laterals in the gypsum is great. The measurements in the following table illustrate such loss:

Measurements of loss in canals and laterals by seepage in gypsum.

Lateral from gate 32 loses 1.64 cubic feet per second in 1¼ miles.
Lateral along south side sec. 12 loses 1.71 cubic feet per second in 1 mile.
Lateral from head gate 18 loses 0.89 cubic feet per second in ½ mile.
Main canal between gates 26 and 27 loses 2.62 cubic feet per second in 1½ miles.

All around the canal for a short distance below it the water stands near the surface, coming by direct seepage from the main canal. Along sections 31, 32, and 33 the canal loses 2.6 cubic feet of water in 1½ miles. This water has seeped out, forming ponds below the canal. A number of photographs illustrating the condition of the country and showing the ponds formed from seepage were secured.

One of the photographs shows a stream flowing approximately 2 cubic feet per second, which seeps from the canal. Attempts have been made to stop the seepage from this piece of canal, but so far without success. The canal company contemplates abandoning this piece of canal and running the water directly into Black River, from which it will be taken by a canal to supply the lands south of Black River.

ALKALI IN SOILS.

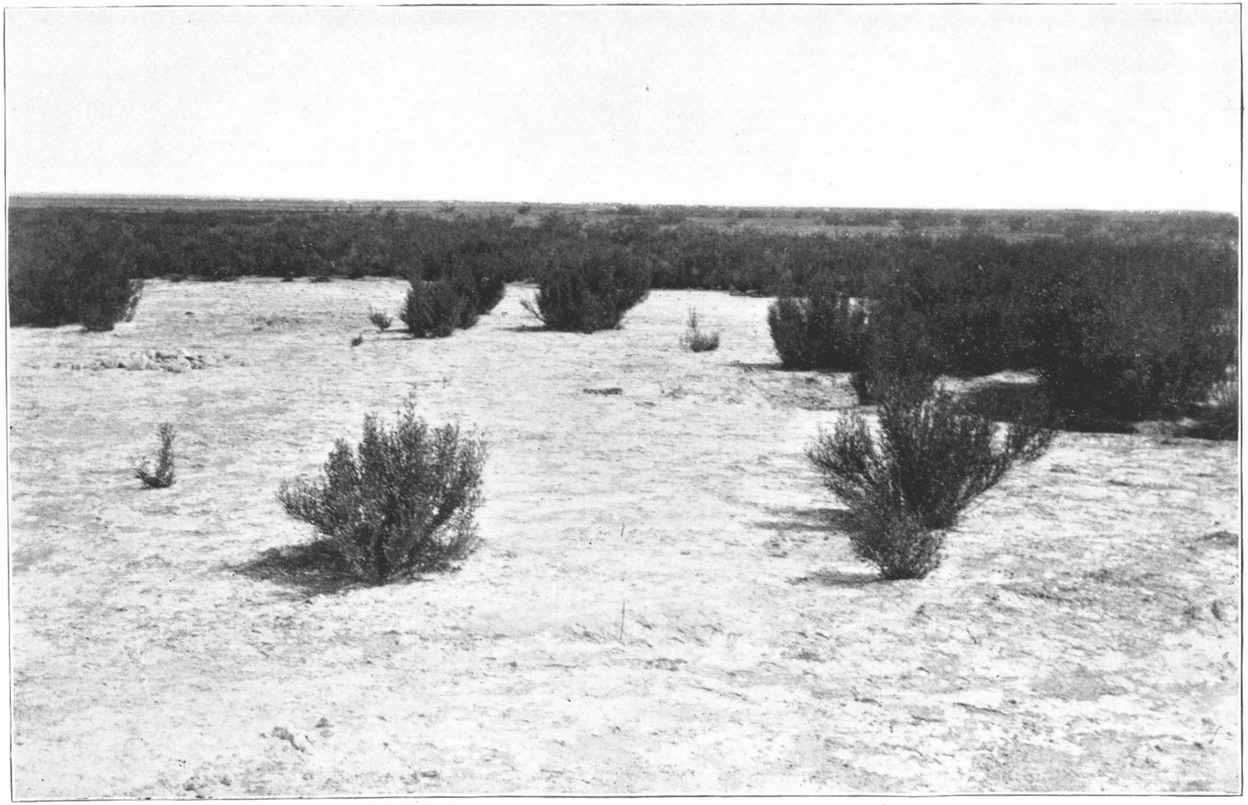
The alkali map accompanying this report shows three conditions of the soil: (*a*) Soil with less than 0.25 per cent of salt; (*b*) soil with from 0.25 to 0.50 per cent of salt; and (*c*) soil with more than 0.50 per cent of salt. The first represents land which is good; the second, land which contains sufficient alkali to damage crops, but not enough to prevent plant growth; and the third, land which already contains too much salt for crops. The alkali salts are entirely of the white kind—that is, containing no sodium carbonate. The following analyses, by Dr. Frank K. Cameron, were made on samples of crust collected by the members of the Division:

Number.	Locality.	$CaSO_4$.	$MgSO_4$.	Na_2SO_4.	$CaCl_2$.	$MgCl_2$.	NaCl.
4045	Six-mile dam	20.56	13.56	31	....	....	36.51
4046	Carlsbad, Pecos bank	3.62	39.92	35.73	....	....	20.33
4047	Carlsbad, Pecos bank	3.20	37.19	34.35	....	....	26.12
4048	West side Pecos, one-half mile south of Six-mile dam	11.29	25.76	5.67	....	....	56.61
4052	Carlsbad, one-half mile above	5.01	53.13	26.02	....	....	9.14
4054	Pecos bank, sec. 10, T. 22 S	11.68	54.94	4.60	....	....	28.75
4055	Southwest corner orchard, sec. 10, T. 22 S.	12.28	21.48	27.47	....	....	35.01
4056	Orchard, sec. 14, T. 22 S	7.06	24.52	32.47	....	....	38.14
	Alkali flat, sec. 14, T. 22 S	16.53	48.31	....	....	7.16	28.20
4053	Pecos bank, 100 yards above	23.45	29.14	28.26	....	....	19.14
4057	Mouth of Cass draw	6.33	18.50	33.06	....	....	42.11
4058	Sec. 14, T. 22 S	13.39	....	....	40.58	18.20	27.83
4061	Sec. 12, T. 23 S	46.44	7.52	26.46	....	....	19.57
4063	Delaware River bank	27.42	20.75	26.95	....	....	24.87

The soils were shown to contain originally only small quantities of alkali salts in their natural state, but at present there are areas containing great quantities of such salts. The presence of this alkali may, in nearly all cases, be attributed mainly to the salt which is contained in the irrigation water. The chemical composition compares nearly with the chemical composition of the salts contained in the waters. A comparison of the two maps, alkali map and underground water map, shows the relation between the seepage water and accumulations of alkali salts. In the area of gypsum soil the water is frequently below 6 feet, yet the capillarity is sufficient to bring the salt-laden water to the surface for evaporation.

PROBLEMS OF THE AREA.

This area of land, on which immense amounts of work and money have been spent in reclamation, presents a number of problems for serious consideration. There are two important problems which are in a measure peculiar to the Carlsbad district. These are the methods of irrigating with an alkali water and the cultivation of gypsum land. The character of the water is the most serious difficulty in the way of profitable irrigation. To develop a new supply of water would be an engineering problem difficult of solution. The use of the present supply is attended with possible loss of crops, especially where the most favorable conditions do not exist. The greater part of the area of Pecos sandy loam has good drainage at present, and the difficulties



ALKALI FLAT CAUSED BY SEEPAGE AND SUBIRRIGATION OF THE GYPSUM LAND.

Where the drainage is insufficient to carry the seepage water off these alkali flats are formed.

ALKALI FLAT FORMED BY SEEPAGE FROM CONGLOMERATE.

Most of the drainage in the Carlsbad area is due to the seepage through the gypsum and conglomerate.

encountered in these soils are at a minimum. Wherever the level of standing water is below 10 feet, there is no present need of drainage; but where (during its yearly fluctuations) the level of standing water approaches the surface of the ground as close as 3 feet, drainage must be installed. Moreover, the accumulation of alkali from the summer's irrigation should be removed by flooding and drainage during the late summer and autumn when the irrigation water is at its best.

BARSTOW AREA, TEXAS.

A brief examination was made of the conditions at Barstow, Texas. Here the water is taken out of the Pecos River by a diverting dam without storage. The water at this point contains more salt than the Pecos water at Carlsbad. Receiving, as it does, the drainage and seepage waters from the Carlsbad irrigated lands and being augmented by alkali springs along its banks, the water at Red Bluff, below the lower limit of irrigation in the Carlsbad district, carried in May, 1899, 320 parts of soluble matter per 100,000. The waters of the Pecos at the Barstow intake carried in June 390 parts of soluble matter per 100,000, and opposite Pecos City, below all irrigation, it carried 525 parts per 100,000.

The application of water of this character to the soil, if long continued, is sure to result in an accumulation of salts beyond the endurance of agricultural plants, unless good natural drainage is present or provision made for the escape of the salts by means of underground drains.

The soils are derived from the ancient lake basin sediments and are heavier in texture than the soils of the upper Pecos Valley. They originally contained greater quantities of alkali salts and, in fact, there are evidences of the accumulation of salts in beds at depths below the surface. The soil of much of this area is underlaid by gypsum. This in its turn introduces new complications which render irrigation farming in this district extremely difficult.

The most favorable conditions only can be relied upon to give profitable results in the irrigation of this district. The land has been under cultivation for about five years and, owing to excessive leakage from canals, seepage waters have accumulated to such an extent that much of the land has already been abandoned. All of the lands on the Pecos City side have been abandoned, and at present irrigation is confined to the Barstow or eastern side of the river.

The most promising field for such a district would be the cultivation of saltbushes and other plants resistant of alkali. Water from the Pecos, when the water is in its best condition, should be flooded over the land to wash away accumulated salts near the surface. This salt would have to be removed by good underdrainage, if intensive farming is contemplated.

A district lower down on the Pecos is reported to be entirely abandoned from the excess of alkali which the water and soil contained.

SUMMARY.

The foregoing pages have shown that the condition of the water in the Pecos River becomes more saline as one descends the river. This fact is well brought out in the sketch map of the Pecos Valley, fig. 5. On this map the parts of salt per 100,000 parts of water are shown by figures. The seriousness of the alkali problem varies in direct ratio to the salt content of the water. At Roswell the alkali is within the soil; the irrigation water is good. By washing the alkali from the soil with the pure water the alkali may be removed and the land thoroughly reclaimed. If once the alkali is removed by the soils being drained, there need be no further fear of damage from alkali. The water of the Berendos contains alkali in sufficient quantity to be harmful to lands, unless well drained. The use of this water has been almost entirely restricted to lands lying close to the deep-cut river channels, where natural drainage is good; therefore the damage from this water has been slight. The water of the Northern Canal contains 0.2 per cent of alkali, and care should be exercised in using it. The soils at Hagerman contain at present alkali, most of which has been derived from the evaporation of the Northern Canal water.

The water of the Carlsbad system contains on an average 0.31 per cent of alkali salts. The soils originally contained very little alkali, the greater part of that now present being due in all probability to the concentration of the irrigation water. The salt already accumulated must be removed by drainage, and all further accumulation must be prevented by washing out with fresh water during the winter or when the water is plentiful and fresh.

The soils of the Pecos Valley are deficient in organic matter and nitrogenous plant food. The growth and plowing under of leguminous crops is recommended, together with fertilizing with stable manure when such is attainable. In the southern part of the valley, where sugar beets form a money crop for the farmer, chemical fertilizers would be of value. Economy in the use of water and the prevention of leakage from canals or laterals will overcome much of the seepage, which at present is the principal cause of the alkali.

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During the short time spent at Barstow, Tex., Mr. G. E. Briggs, manager of the Pioneer Canal Company, assisted personally in the reconnoissance of that district.

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