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GEOLOGY AND WATER RESOURCES OF ESTANCIA VALLEY, NEW MEXICO

WITH NOTES ON GROUND-WATER CONDITIONS IN ADJACENT PARTS OF CENTRAL NEW MEXICO

BY

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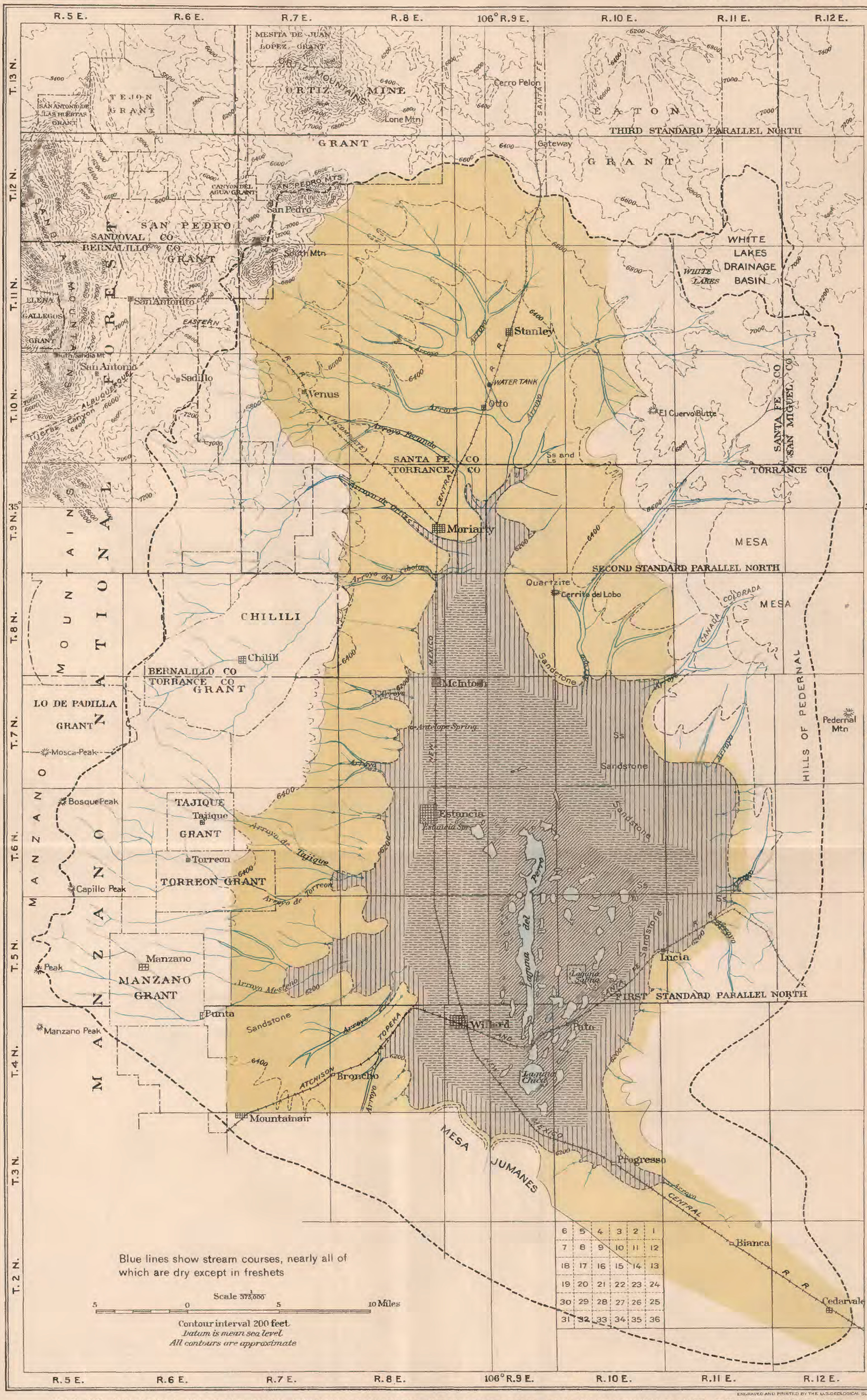

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MAP OF ESTANCIA VALLEY, NEW MEXICO, SHOWING PHYSIOGRAPHY AND PLEISTOCENE AND RECENT GEOLOGY

LEGEND

PHYSIOGRAPHIC PROVINCE		PRINCIPAL FORMATION AT THE SURFACE	
ANCIENT LAKE BED	Salt basins	Lake sediments and recently deposited clay with precipitates of salt left by evaporating waters *Boundaries are taken from the township plats of the General Land Office*	
	Clay hill area	Wind-blown clay	*Boundaries are approximate*
	Lake flat	Lake sediments	
	Littoral zone	Beach materials and alluvial deposits with sand dunes on the east side	
	Alluvial slope	Alluvial deposits	

GEOLOGY AND WATER RESOURCES OF ESTANCIA VALLEY, NEW MEXICO.

By Oscar E. Meinzer.

INTRODUCTION.

LOCATION AND AREA.

Estancia Valley lies near the geographic center of New Mexico, south of Santa Fe and east of Albuquerque. Its drainage basin forms a depression with no outlet, having a maximum extent of about 65 miles north and south and 40 miles east and west, and includes an area of about 2,000 square miles (fig. 1).

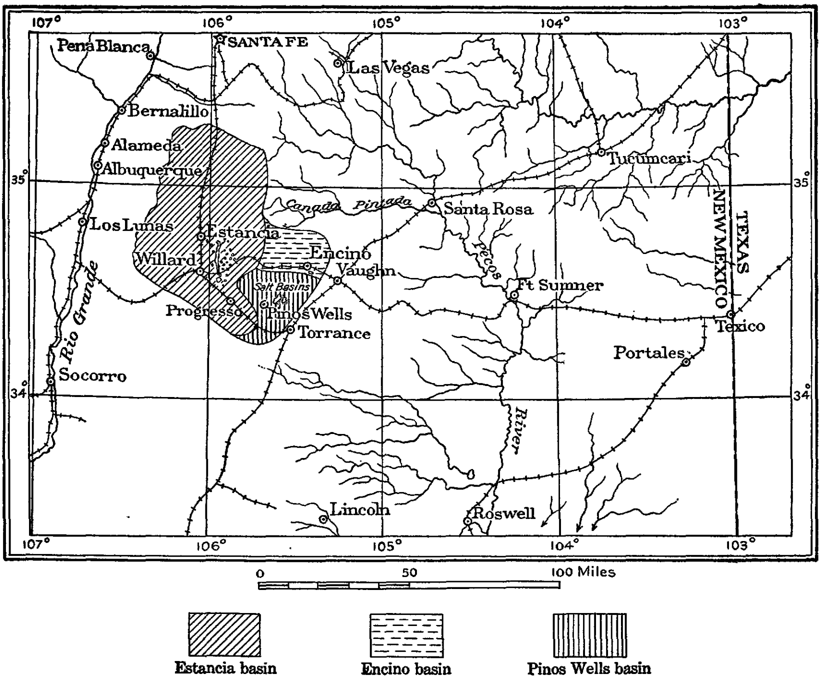


Figure 1.—Map showing location of Estancia, Encino, and Pinos Wells basins.

GEOGRAPHIC RELATIONS.

On the west Estancia Valley is separated from Rio Grande Valley by a mountain wall; on the east it is bordered by a maze of hills which divide it from the upland that slopes toward the Pecos Valley and from the Encino and Pinos Wells basins; on the north it rises gradually until it ends abruptly as a plateau overlooking the valley of Galisteo Creek, which flows westward into the Rio Grande; on the southwest it is terminated by a mesa; and on the southeast, where it is hemmed in between the mesa and the hills, it is separated by a low divide from the Pinos Wells Basin.

DEVELOPMENT.

This valley has long supported a sparse population. Nestled in the western foothills, remote from any city or railroad, the Mexican villages of Chilili, Tajique, Torreon, Manzano, and Punta de Agua have for generations led a peaceful but primitive existence, their inhabitants depending for a livelihood chiefly upon their flocks of sheep. Moreover, planted here and there upon the broad, level expanses of the valley proper are isolated establishments which have been the homes of independent and prosperous ranchers, most of whom are Mexicans.

But within the past decade a great change has taken place. Two railways have been built—the New Mexico Central Railroad, which traverses the entire length of the valley, and the "Belen cut-off" of the Atchison, Topeka & Santa Fe Railway, which crosses its southern part. Hundreds of homesteaders have come to take possession of the land, and eight villages have sprung up along the railways.

FIELD WORK.

Insufficient rainfall during recent years has caused crop failures and has created an urgent demand for an investigation of the feasibility of irrigating with ground water. In response to this demand, and for the purpose of classifying the land under the enlarged homestead act, an examination of the valley covering a period of six weeks was made by the writer in the summer of 1909. The time spent was not sufficient to make a complete investigation, hence attention was directed especially to the more practical phases of the problem. In August, 1910, several days were spent in the Encino and Pinos Wells basins.

PHYSIOGRAPHY.

MOUNTAINS, HILLS, AND MESAS.

West of the valley is the Manzano Range, which extends for 30 miles as an unbroken mountain wall and forms a sharp divide between the Estancia and Rio Grande basins. This range culminates in a

A. "GATEWAY" THROUGH DIKE NORTH OF ESTANCIA VALLEY.

See page 9.

B. CANYON IN MESA JUMANES.

See page 9.

series of peaks, the loftiest of which—such as Manzano Peak, Capillo Peak, and Mosca Peak—reach altitudes of more than 9,000 feet above sea level and more than 3,000 feet above the valley. The range supports a forest of large pine trees, most of which are included in the Manzano National Forest, and along its eastern base is a broad, irregular belt of foothills partly covered with smaller timber.

At the northwest corner of Estancia Valley are South Mountain and the San Pedro Mountains, two isolated masses which include a number of peaks that reach altitudes of more than 8,000 feet above sea level. Between South Mountain and the north end of the Manzano Range, a distance of nearly 15 miles, the moutain wall is interrupted, the divide between the Estancia and Rio Grande basins here being formed by a more or less hilly upland tract through which the not yet completed railway from Moriarty to Albuquerque finds a low pass.

North of the San Pedro Mountains is a still larger mountain mass, known as the Ortiz Mountains. North of the Manzano Range and separated from it by Tijeras Canyon is another lofty range, known as the Sandia Mountains. Both Ortiz and Sandia mountains lie entirely outside the Estancia Basin.

The valley is bordered on the northeast by a mesa whose margin is dissected into rugged and fantastic erosion forms. Cañada Colorada (Red Canyon), one of the largest gorges that has been carved out of this mesa, is picturesque and imposing. Farther south are the Hills of Pedernal, whose somber gray hue contrasts strongly with the vivid colors of the escarpment of the mesa and the Red Canyon. Back of these hills, outside of the Estancia drainage basin, stands Pedernal Mountain. The hills that inclose the valley on the southeast are lower and more subdued.

From the center of the valley northward the surface rises gently up to a point where the plain ends abruptly in an escarpment, so that, seen from the north, Estancia Valley is a mesa which forms the south boundary of the Galisteo Creek drainage basin. Here the tributaries of the creek are actively eroding and are thereby gradually shifting the divide southward. A short distance north is a huge igneous dike, which stands in prominent relief as a result of the denudation of the softer rocks through which it projects. This dike has evidently hindered the erosive attack on the north end of Estancia Valley. The gap in the dike through which the drainage passes has long been utilized as an approach to Estancia Valley, and the New Mexico Central Railroad now enters through this "Gateway." (See Pl. II, *A*.)

On the southwest the valley is terminated abruptly by the Mesa Jumanes, whose escarpment, 500 feet high, forms an imposing physiographic feature (Pls. II, *B*; III, *B*). Between the Mesa Jumanes and the Manzano Range is a pass through which the Atchison, Topeka & Santa Fe Railway finds an exit westward.

To the southeast the valley becomes constricted between the Mesa Jumanes, which forms its southwestern flank, and the hills which border it on the northeast. This constricted belt extends a considerable distance and eventually opens into the Pinos Wells Basin. The New Mexico Central Railroad passes through it and leaves the Estancia drainage basin at probably the lowest point on the basin's rim.

ALLUVIAL SLOPES AND ARROYOS.

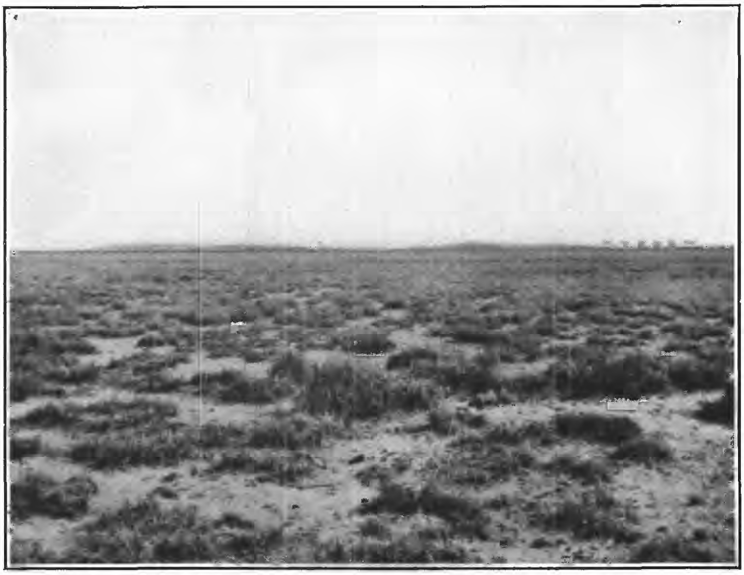
A gently sloping plain, formed by sediments washed out from the mountains, extends from the mountainous border toward the flat center. The gradient of this plain is not great, but is sufficient to be perceptible, and in general it decreases toward the center of the valley. Over wide tracts the surface is exceedingly even, but, taken as a whole, the evenness is broken by many irregularities, most of which can be grouped into two classes—rock hills and arroyos.

At a number of localities isolated masses of hard rock project prominently above the smooth plain, which surrounds them almost as a sea surrounds a rocky island. One of the most conspicuous of these masses is the unique butte known as Cerrito del Lobo.

The arroyos, or "draws," constitute an important feature of this part of the valley. Most of them have their origin in canyons that debouch from the mountainous border, whence they traverse the sloping plain, all converging toward the center of the valley. They have no great tendency to join each other, but many of them continue in straight and nearly parallel courses for long distances. In general they are deepest near the mountains, where the largest may be bordered by impressive cliffs nearly or quite a hundred feet in height, and become shallower toward the basin until ultimately they disappear upon the central flat. Most of them are broad, several being more than a mile wide. Their flat bottoms are rarely trenched by gullies except in the upper courses, for they are stream channels rather than valleys through which stream channels meander. Generally speaking, they carry no permanent streams, but form avenues for the escape of storm waters, and are built on a scale commensurate with the volume of the torrential floods which they must periodically accommodate. These floods usually disappear before they reach the central flat, and in disappearing they leave the sediment with which they were laden. Thus the arroyo bottoms are at present being built up rather than cut down.

ANCIENT LAKE BED.

The central portion of the valley is for the most part flat (Pl. III, *A*), and there is good evidence that it was once the bed of a lake, a fact which has been noted by Keyes in a brief paper on "Ephemeral



A. LAKE FLAT.

See page 10.

B. MESA JUMANES, SHOWING LANDSLIDING.

See page 13.

Lakes,"[1] in which he states that "the Sandoval bolson, south of Santa Fe, contains traces of a comparatively recent lake of considerable size." At the margin of this ancient lake bed are beach ridges and other shore features, which, although not obtrusive, are distinct, and occur on all sides at the same vertical horizon. (See Pls. IV, *B;* V, *A* and *B;* XIII, *C.*) The belt within which shore features exist (which will be designated the "littoral zone") forms the inner boundary of the "alluvial slopes" and the outer boundary of the "lake flat." In Plate I the littoral zone and the lake flat are represented as occupying about 180 square miles each, but it should be understood that the boundary between these two areas is very arbitrarily drawn. For the sake of convenience, though at the sacrifice of logical arrangement, the shore features are described under the heading "Geology."

SALT BASINS AND CLAY HILLS.

Although most of the central area of the valley is flat, one portion, forming a region of considerable extent (roughly estimated as 85 square miles), contains irregular clay hills associated with sharply bordered depressions containing salty mud flats, the whole forming a strange labyrinth (Pls. VI, IX, and X), the full discussion of which will be found under the heading "Geology."

GEOLOGY.

ROCK FORMATIONS.

METAMORPHIC AND IGNEOUS ROCKS.

Manzano Range.—The core of the Manzano Range consists of a complex of schists and quartzites, with associated masses of granite and other igneous formations. These rocks are supposed to have been brought to their present elevated position by a grand faulting movement near the close of the Cretaceous period. Because of their resistant character and nearly vertical dip they form sharp ridges and peaks.

The east side.—On the east side of the central and southern portions of the valley igneous and metamorphic rocks are also exposed. Pedernal Mountain, which lies in the northeast part of T. 7 N., R. 12 E., consists of flint-like quartzite in which considerable schistosity has been developed. The Hills of Pedernal lie west of this mountain and form a belt several miles long (chiefly in T. 7 N.) consisting of low but rugged peaks that rise abruptly above the level table-land that borders them on the north and the undulating upland on the south. Like Pedernal Mountain, they consist mainly of quartzite. They have been described as formed "by an uplift of quartz-bearing rock, the metamorphism produced by this intru-

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[1] Keyes, C. R., Ephemeral lakes: Am. Jour. Sci., 4th ser., vol. 16, 1903, p. 377.

sion being evidenced by a broad band of hornblende schist along the western base of the hills."[1] They appear to belong to the same formation as the schists and quartzites in the Manzano Range and probably have similar structural relations to the contiguous rocks.

Cerrito del Lobo, the previously mentioned isolated butte in the eastern part of the valley, is an outlier of the same quartzite formation. Across it, with a north-south trend, runs a breccia zone that has been weathered more rapidly than the quartzite through which it passes, thus giving the butte a bilobate profile that can be seen miles away. This bilobate feature also characterizes some of the Hills of Pedernal.

South of the Hills of Pedernal the eastern wall of the basin is formed by a broad, undulating upland, which is for the most part grass-covered, but in which red granite is exposed at numerous points and schist and quartzite are found. These rocks have also been encountered in wells.

The northwest side.—South Mountain and the San Pedro Mountains, as well as the Ortiz and other mountains to the north, consist of cores of igneous rock supposed to be laccoliths formed by great intrusions of lava near the close of the Cretaceous period.[2] The dike through which the "Gateway" passes (Pl. II, *A*) is a member of this great intrusive system.

CARBONIFEROUS ROCKS.

Outcrops on the west side.—A formation consisting of thick beds of massive gray limestone with a few relatively unimportant layers of sandstone and shale extends eastward from the metamorphic and igneous rocks of the Manzano Range, forming a rugged foothill belt. In general, it dips gently away from the mountains and passes beneath younger strata. In Abo Canyon, which cuts across the low southern end of the Manzano Range, west of Mountainair, G. B. Richardson, who in 1905 made a reconnaissance along the line of the Belen cut-off, observed a thickness of about 500 feet, mostly of massive limestone, containing abundant Carboniferous fossils at some horizons. The formation is also well exposed in the canyons back of the village of Manzano and elsewhere.

Red beds several hundred feet thick, consisting chiefly of fine-grained sandstone with some shale, occur farther east and evidently lie above the limestone. They were observed by Richardson in the vicinity of Abo Canyon in a north-south escarpment and are exposed farther north in a similar position and for several miles form the south bluff of Arroyo Mesteño (Manzano Draw).

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[1] Johnson, D. W., Notes of a geological reconnaissance in eastern Valencia County, N. Mex.: Am. Geologist, vol. 29, 1902, p. 87.

[2] Johnson, D. W., Geology of the Cerrillos Hills, N. Mex.: School of Mines Quart., vol. 24, 1903, pp. 463-471.

South of Willard (SE. ¼ sec. 31, T. 4 N., R. 9 E.) the escarpment of Mesa Jumanes shows the following succession of essentially horizontal strata:

Section in escarpment of Mesa Jumanes.

	Feet.
Limestone, dark gray	50
Sandstone, gray, or buff, friable	300
Sandstone, etc., red	10
Gypsum	100
Talus.	

There is good evidence that this series lies stratigraphically above the red beds exposed along Arroyo Mesteño and elsewhere. Its age is fixed by several species of upper Carboniferous fossils found by Richardson in the capping limestone.[1]

Mesa Jumanes is in places bordered by chaotic heaps of talus that appear to have been formed by landslides that probably resulted from the basal position of the thick bed of soft gypsum (Pl. III, *B*).

Well sections on the west side.[2]—The following data concerning wells bear on the occurrence of the above-described series in the western part of Estancia Valley:

Section of railway well at Mountainair.

[Surface elevation: 6,486 feet above sea level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, clay, etc	20	20
Clay and gravel	20	40
Lime and dry gravel	30	70
Red rock (i. e., hard red clay)	110	180
Blue-gray shale	20	200
Red rock (hard clay)	83	283
Blue-gray shale rock (water at 295 feet)	27	310
Red clay and small dry gravel	20	330

Section of Atchison, Topeka & Santa Fe Railway well at Willard.

[Surface elevation: 6,100 feet above sea level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Light-red clay and gravel	35	35
Coarse gravel, etc., containing water	17	52
Light-red clay and gravel	78	130
Coarse gravel, etc., containing water	22	152
(?)	81	233
Sand, gravel, etc	79	312
Red sand rock, entered	128	440

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[1] Lee, Willis T., and Girty, G. H., The Manzano group of the Rio Grande valley, New Mexico: Bull. U. S. Geol. Survey No. 389, 1909, p. 21.

[2] Sections furnished by Atchison, Topeka & Santa Fe Railway Co.

In the test well recently sunk 4 miles east of Estancia (SW. ¼ sec. 10, T. 6 N., R. 9 E.) a formation described by the driller as "red hematite iron ore" was found between the depths of 225 and 525 feet, and red sandstone between 577 and 707 feet.

In the well of H. C. Williams, 2½ miles south of Estancia (NE. ¼ sec. 26, T. 6 N., R. 8 E.), soft gray sandstone was encountered between the depths of 233 and 303 feet, below which is red clay that was entered about 15 feet.

Between Mountainair and Arroyo Mesteño several wells penetrate dense red sandstone, while red shale is reported in numerous wells on the west side almost to the north end of the valley.

Outcrops and well sections on east side.—A similar series of gypsum, red and buff sandstones, red shale, and gray limestones exists on the east side of the valley, and light-colored sandstone occurs in a succession of low outcropping ridges north of Lucia for 15 miles.

North of the Hills of Pedernal the east wall of the basin is formed by relatively level table-land, which is terminated on the southwest by an escarpment that appears, for at least a part of its extent, to follow a fault line. The formations that underlie the table-land are exposed in this escarpment and also in Cañada Colorada (Red Canyon) and a number of smaller canyons. Wherever they were observed, they lie nearly horizontal and consist of beds that bear a general resemblance to the Carboniferous formations on the west side. In the vicinity of Cañada Colorada there is a basal hard, gray limestone, overlain by a brownish red or chocolate-colored massive limy formation, upon which rests a second hard, gray limestone, somewhat over 50 feet of strata belonging to the three formations being here exposed. Above the second limestone a thickness of considerably more than 100 feet of sandstone is exposed, while the cap rock, at the top of the cliff, consists of less than 5 feet of indurated gray limestone. The sandstone, which is prevailingly light yellow, is rather soft and weathers into fantastic, castellated forms. It shows abundant cross-bedding and ripple marks. Farther northeast is a series of soft red shale and sandstone, which is white at the top owing to the presence of limy material. This series is at least 100 feet thick and appears to rest on the cap rock that outcrops at the top of the escarpment.

Immediately southwest of the escarpment and dipping sharply away from it is a series of rocks consisting of gypsum, red beds, and sandstone, somewhat resembling the series that outcrops in Mesa Jumanes. Between the escarpment and the valley proper is an upland belt in which there are numerous exposures of limestone, sandstone, and other formations. These strata generally slope toward the valley, but their dip differs greatly in different localities and in some places takes the opposite direction. In certain localities (as in secs. 26 and 27, T. 11 N., R. 10 E.) the dip differs greatly within short distances, and fracturing and slicken-sided surfaces (as in SE. ¼ sec. 35, T. 10 N., R. 9 E.) also show that violent deformation has taken place in this region.

At Lucia the following section is reported by the Atchison, Topeka & Santa Fe Railway Co.:

Section of railway well at Lucia.

[Surface elevation, 6,177 feet above sea level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Loose gravel	20	20
Cemented gravel	(?)	(?)
(?)	(?)	100
Red sand	10	110
Coarse gravel	10	120
Lime gravel (water)	5	125
Hard white sandrock	5	130
Gray lime	5	135
Red clay	10	145
Lime and clay	5	150
Gray lime	14	164
Red clay	26	190
Gray lime	15	205
Lime and clay	15	220
Gray lime	10	230
Lime and clay	15	245
Red clay (water)	15	260
Fine red sand	25	285
Red clay	30	315
Gray lime (water in vein)	5	320
Dark-gray limestone	25	345
Black shale, entered	5	350

Immediately west of Lucia the railway cuts through light-colored sandstone, which also outcrops in this vicinity. In drilling the well of E. Moulton, in Lucia, this bed of sandstone was found between the depths of 16 and about 75 feet, below which was encountered a bed, about 15 feet thick, of soft white material (possibly gypsum), and then red clay and sand, in which the well ends. J. E. Pauley, a driller, reports other wells in the region north of Lucia which pass through light-colored sandstone and enter red clay and sand.

CRETACEOUS ROCKS.

In the region north of Estancia Valley there is exposed a thick series of Cretaceous strata, chiefly shale and sandstone, to which geologists have given considerable attention. It is represented in the areas bordering South Mountain and the San Pedro Mountains and in the north rim of Estancia Valley. It no doubt occurs beneath the north part of the valley, but there is no proof that it extends far south, for the section of the test well 4 miles east of Estancia and other well sections here given indicate that it is absent in at least much of the southern part of the valley.

VALLEY FILL.

AGE AND CHARACTER.

The hard rock floor of Estancia Valley is covered by deposits that may be grouped under the general term "valley fill." Nearly all these sediments originally came from the highlands that border the valley and are the product of thousands of years of weathering and denudation. The erosive processes which have carved the canyons and given form to the serrate peaks have at the same time supplied the material that has accumulated in the lowlands as the valley fill.

These sediments derived from the mountains were chiefly washed by storm waters into the valley, where they lodged to form the deposits of the alluvial slopes, or were carried into the ancient lake, to settle quietly on its bottom or to be worked over by the waves. Some of these sediments have more recently been picked up and driven about by the wind. The deposits of salt in the salt basins are also of recent formation. The valley fill can therefore be classified as follows:

4. Precipitates from solution: Salt and gypsum beds.
3. Wind deposits: Clay hills and sand dunes.
2. Lake deposits: Stratified sediments and beach materials.
1. Alluvial deposits.

All these deposits are geologically young. In general, the oldest are the alluvial deposits, the next in age the lake deposits, and the youngest the wind deposits and salt beds.

The age of the lake deposits is the most definitely fixed, for without doubt this lake was synchronous with Lake Bonneville, in Utah, and other ancient lakes of the arid West, which are unanimously and with good reason correlated with the cold, humid glacial period. The lake deposits may therefore be considered Pleistocene in age. The stratified sediments and beach materials are of about the same age, for at the time that the coarser materials along the beach were continually being handled and rehandled by the waves finer sediments were settling quietly in areas more remote from the shore.

The alluvial deposits have a much wider range in age. Part of them are coeval with the lake deposits, part are more recent; some, indeed, are very recent, but there is evidence that most of them were laid down in their present position before the advent of the lake, and hence belong chiefly to the late Tertiary or early Pleistocene.

The wind deposits come within the late Pleistocene and Recent periods, for the dune sand was chiefly supplied by the lake and the clay deposits were all formed since the lake dried up. The sand has, on the whole, been buffeted about by the wind longer than the clay.

WORK OF THE STREAMS.

DISTRIBUTION OF THE ALLUVIAL DEPOSITS.

The bulk of the valley fill consists of alluvial deposits; that is, of materials laid down by the streams and not rehandled by any other agency. Such deposits underlie the broad belt comprising the alluvial slopes (Pl. I), are interbedded and intermingled with lake deposits in the littoral zone, as can be seen in many natural and artificial exposures, and probably occur at no great depths below the lake sediments in the lake flat and clay hill area. Their relation to the lake deposits can, however, be best understood after those deposits have been described.

The alluvial material is much thicker in some localities than in others. If the interpretations of the well sections are correct, the total thickness of the valley fill is 312 feet at Willard, 225 feet in the test wells 4 miles east of Estancia, and 233 feet in H. C. Williams's well south of Estancia. L. Knight's deep well (in the NE. ¼ sec. 1, T. 5 N., R. 8 E.) was carried to a depth of 240 feet without encountering rock. In many parts of the valley, however, especially on its east and west margins, the alluvium is much thinner and rock crops out.

ORIGIN OF THE ALLUVIAL DEPOSITS.

The alluvial deposits were laid down by streams which were probably intermittent and exceedingly irregular in their flow, depending then, as now, chiefly on the sudden and capricious visitations of heavy local storms. The work of these streams was correspondingly capricious and variable; at one place they eroded, only to deposit a little farther on the load which they thus picked up; at one place they left behind coarse gravel, and at another they laid down only fine silt. The same locality was at different times subjected to all these conditions and, moreover, by the frequent changing of the courses of the streams, was at one time an arroyo and at another an interstream area. It is therefore not surprising that the alluvial deposits consist of heterogeneous beds which have little continuity or regularity, and that two wells in the same locality should have quite different sections.

CHARACTER OF THE ALLUVIAL DEPOSITS.

Most of the alluvial material consists of clay, with which are associated pebbles and bowlders of different sizes and composition. In general the pebbles and bowlders decrease both in size and abundance from the mountain borders, where bowlder beds with little or no clay may occur, toward the central portion of the valley, where clay virtually free from pebbles may be found. But though coarse materials form a larger proportion of the mass in the regions near the mountain than in the interior, yet well sections furnish abundant proof that beds of clean gravel and sand occur in the very heart of the valley. The composition of the pebbles depends on the kind of rocks that constitute the uplands and the resistance of these rocks to weathering and wear. On the whole pebbles of limestone are by far the most numerous, because this rock is well represented in the uplands, especially on the west, and is also resistant in character.

The alluvial deposits present two or three types which differ in color, cementation, and position. The type most commonly encountered near the surface has a pink hue. It is only slightly indurated, but contains so much cementing material that wells sunk into it require no curb. Pink deposits are shown at the north end of the valley, where they have been exposed by erosion on the tributaries of Galisteo Creek. The igneous bowlders and the direction of the cross-bedding in this locality show that the deposits were derived from higher ground to the north, which has since been eroded away.

Deposits of a second type have a dull gray color and are cemented into a conglomerate, which is locally known as "concrete." Their gray color is due to the large amount of calcium carbonate and other cementing material they contain and also to the greater abundance in them of dark gray limestone pebbles. Gray conglomerate crops out in the cliff on the McIntosh ranch, in the region west of Willard, and elsewhere, and is also found in many wells at levels below the pink alluvium.

Deposits of a third type may be discriminated in which the cementing process has gone so far that the formation has lost the appearance of alluvium and has become a sort of massive concretionary limestone, or caliche. Limestone of this type lies near the surface over a large area in the vicinity of Cedarvale, at the southern extremity of the valley, and in the region south of Otto, where it forms a ridge through which the railway cuts (sec. 30, T. 10 N., R. 9 E.).

WORK OF THE LAKE.

SIZE OF THE LAKE.

At its period of greatest extension the lake that occupied the central portion of the valley was about 35 miles long and 23 miles wide and had an area of about 450 square miles. Its maximum depth at this period was almost 150 feet, and its shore line, which nearly coincides with the 6,200-foot contour, was about 150 miles long. If this lake were now in existence the villages of Estancia and Willard would be 100 feet under water; McIntosh and Progresso would also be submerged; Moriarty and Lucia would virtually be lake ports; and Stanley, Mountainair, and Cedarvale would be inland towns. The higher ground which surrounded the lake has been explored every-where, but no outlet channel has been found, and it is therefore certain that the lake had no outlet and that its water was salt.

The theory of the existence of an ancient lake in the valley is based on the presence of shore features and lake sediments.

SHORE FEATURES.

Sea cliffs, terraces, beaches, beach ridges, spits, and bars are found within the littoral zone on all sides of the lake flat, at altitudes between 6,100 and 6,200 feet above sea level.

CLIFFS AND TERRACES.

A distinct sea cliff occurs southwest of Lucia (about NW. ¼, sec. 11, T. 4 N., R. 10 E.), and another cliff marks the exposed end of the land that projects eastward between Arroyo de Torreon and Arroyo Mesteño (sec. 9, T. 5 N., R. 8 E.). Wave erosion is well shown in many places, notably on the sandstone outcrops southwest of Dunbar's ranch (T. 6 N., R. 10 E.).

The prominent escarpment northwest of Willard coincides with the shore line, but whether it was formed by the lake is uncertain. There is also, perhaps, ground for doubt as to the origin of the cliff at the McIntosh ranch, directly northwest of the village of McIntosh, and of the cliff immediately northwest of Antelope Springs. (See Pl. V, *B*.) Both of these coincide with the shore line, and the McIntosh cliff at least has been scoured by water and strewn with beach materials.

There are many terraces, more or less distinct and more or less intimately associated with beach ridges. Those in the vicinity of the cliff between Arroyo de Torreon and Arroyo Mesteño and those on the south margin of Arroyo de Torreon, near its mouth, will serve as examples, but others equally distinct occur in many localities.

BEACH RIDGES.

North and northeast of Lucia several prominent beach ridges (as in SE. ¼ sec. 4, T. 5 N., R. 11 E.) persist for considerable distances. They also extend, somewhat obscured by drifting sand, parallel to the east shore in T. 6 N., R. 11 E.; T. 7 N., R. 10 E.; T. 8 N., R. 9 E.; and between Lucia and Progresso. They are found in the embayment of Arroyo Mesteño (as in sec. 21, T. 5 N., R. 8 E.), and extend from the mouth of this arroyo to the mouth of Arroyo de Torreon. North of Arroyo de Torreon they occur almost continuously nearly to the north end of the lake (for example, in sec. 21, T. 6 N., R. 8 E., and sec. 23, T. 8 N., R. 8 E.). In short, beach ridges, large and small, are abundant throughout the littoral zone on both sides of the lake flat. They are, however, interrupted by the mouths of the arroyos, and are so generally absent at the north end (north of Arroyo del Cibolo, or Buffalo Draw) that the position of the shore line there is uncertain.

SPITS.

North of Lucia there are two large spits. The one farthest north, shown in Plate IV, *B*, is a definite gravelly ridge several rods in total width and about 10 feet high. It extends northeastward from the north end of a low sandstone ridge over a flat plain for a distance of about 1½ miles and terminates abruptly. It was evidently formed by currents which swept northward along the west side of the ridge and thence northeastward into an open sea. The south spit is similar in character and origin. Several smaller spits were observed in other localities.

BARS.

Perhaps the most typical features of the ancient lake bed are the bars built across the mouths of the arroyos. Most of these bars are interrupted by narrow gaps cut by storm waters discharged through the arroyos, but in several small ravines no such gaps have been cut and the natural dams remain unimpaired.

The largest bar is found at the east end of the great eastern embayment. It is about 15 feet high, trends approximately S. 30° E., and persists for several miles unbroken except at the gap which forms the outlet of the arroyo. (See Pl. XIII, *C*.)

Another prominent feature of this type is the remarkably wide embankment thrown across the mouth of the large arroyo south of the railroad west of Willard (T. 4 N., R. 8 E.). On the upstream side it ends abruptly with a steep bank like a normal bar or beach ridge, but on the lakeward side it extends for an indefinite distance, eventually merging with the lake flat. The gap which forms the outlet of the arroyo is a ravine approximately 20 feet deep, 20 feet wide at the bottom, and half a mile long.

Across the flat expanse of the first large arroyo northwest of the railway are thrown a series of three or more bars, all of which have gaps near their southeast ends. They occur near the mouth of the arroyo, north of the township line (sec. 33, T. 5 N., R. 8 E.).

Another notable bar is in the eastern embayment (sec. 34, T. 6 N., R. 11 E.), and another lies southwest of Antelope Spring, shutting in a ravine that runs east and west between sec. 22 and sec. 27 in T. 7 N., R. 8 E. Plate V, *A*, is a view of this bar from the south and shows the small gap at its south end. Just south of the Arroyo de Torreon is still another bar built across the mouth of a small ravine also having a gap at the south end.

Most of the gaps are post-lacustrine drainage channels like the one in the large bar first described. Some of the gaps, however, are probably places where the bars were never completed. A gap would be formed where a spit projected from one side of an arroyo nearly, but not quite, to the other. The gap in the bar last mentioned may be

A. WIND-DEPOSITED CLAY.

See page 25.

B. SPIT NORTH OF LUCIA.

See page 20.

A. GAP IN BAR NEAR ANTELOPE SPRING.

See page 20.

B. CLIFF FORMING ANCIENT SHORE LINE NEAR ANTELOPE SPRING.

See page 19.

of this kind. Such a gap would serve as an outlet for the drainage and might be deepened and widened by erosion.

A few of the bars built athwart the mouths of small ravines are not broken by gaps. Northwest of Willard (sec. 34, T. 5 N., R. 8 E.) such a bar impounds the storm waters, forming a small lake after heavy rains (Pl. I). Another such bar lies east of McIntosh, near the southeast corner of T. 8 N., R. 9 E. Here a small ravine is obstructed by a high embankment that suggests an artificial dam or a railway fill.

ESTUARIES.

The bars prove that the broad flat-bottomed arroyos were in existence at the time the lake was present. How far up these arroyos were submerged can be inferred only from the topography. During the highest stages of the lake the water must have extended into many of them for considerable distances, forming numerous bays which resembled estuaries. When the lake receded, the water was drained from the arroyos and, except for the rocky islands that appeared in the east, the shore line became much more regular. The flatness of the arroyo bottoms may in part be due to sedimentation during the lake epoch. The gaps in the bars and the gullies that here and there indent the valley sides are practically the only marks of stream erosion made in the lower courses of the arroyos since the departure of the lake.

STAGES INDICATED BY SHORE LINES.

The littoral zone, within which lie the terraces, beach ridges, and other shore features, ranges in width from less than a mile to several miles, but is commonly between 1 and 2 miles wide. Its vertical range is about 100 feet, for it lies between 6,100 and 6,200 feet above sea level. The most prominent features occupy an intermediate position in the zone. The lowest are generally small but distinct; the highest are vague and elusive. As one goes out toward the alluvial slopes from the level and monotonous lake flat the eye is prepared to catch the slightest irregularity, and the first small terraces and ridges invariably force themselves upon the attention. These are quickly followed by much larger features, which may at first appear to mark the ultimate extension of the lake. Upon going farther, however, it becomes evident that the outermost shore line has not yet been reached, for other beaches, which are much smaller and more vaguely defined, come into view. Still farther back all signs of wave work are lacking, and it is manifest that the boundary of the lake has been crossed.

The various shore features were not formed at the same time, but record levels at which the lake stood at different times. The level of a lake with no outlet is constantly fluctuating, for it is a function of rainfall on the one hand and of evaporation on the other, both of which are varying factors. Thus, when Lake Sevier, in Utah, was explored in 1872 it covered an area of about 188 square miles, but in 1880 it had so nearly dried up that one could walk across its beds;[1] and still more recently, in spite of the increasing amount of water diverted for irrigation from Sevier River, which is its sole tributary, it has refilled until it is again a lake of considerable size. Similar fluctuations have taken place in the level of Great Salt Lake within the relatively brief period in which records have been kept.

Yet even lakes which have no outlet are likely to remain at approximately one level long enough to impress distinct shore lines upon the sides of the basins that contain them. Thus, Lake Sevier has built at its north end a beach ridge comparable in size to the beach ridges of the ancient lake here described.

Lake Estancia, no doubt, had many fluctuations, the general history of which could perhaps be ascertained by a minute study of shore lines and by the correlation of lake deposits. The cursory examination that was made indicates that the lake stood at its highest level for only a brief time; that it remained a much longer time at somewhat lower levels, which did not, however, greatly diminish the water area; and that it finally shrank to lower and lower levels until it became too small and too shallow to form shore features that can at present be discerned. In the vicinity of Estancia the innermost shore line observed passes through the western part of the village and east of Estancia Spring.

SIZE OF LAKE AND SIZE OF SHORE FEATURES.

Shore features are the work of waves and currents, and these are produced by the wind. But in order to produce large waves the water must be so deep that the waves will not be dissipated by friction on the bottom, and it must spread uninterruptedly over a large area, so that the winds will have a long sweep. Thus, in storms of the same magnitude, the waves on a large lake will be enormous when compared with those on a pond, but small when compared with the mighty swell of the ocean. If other things had been equal the shore features would be largest at the outermost shore line and would be progressively smaller inward. To the extent that this is not true it must be inferred that the time during which the lake stood at the different levels was not equal. When the lake stood at the level necessary to produce the most pronounced shore features it had shrunk but slightly from its maximum size. When it became smaller it built smaller shore features, and finally it became so constricted and shallow that little wave work was done.

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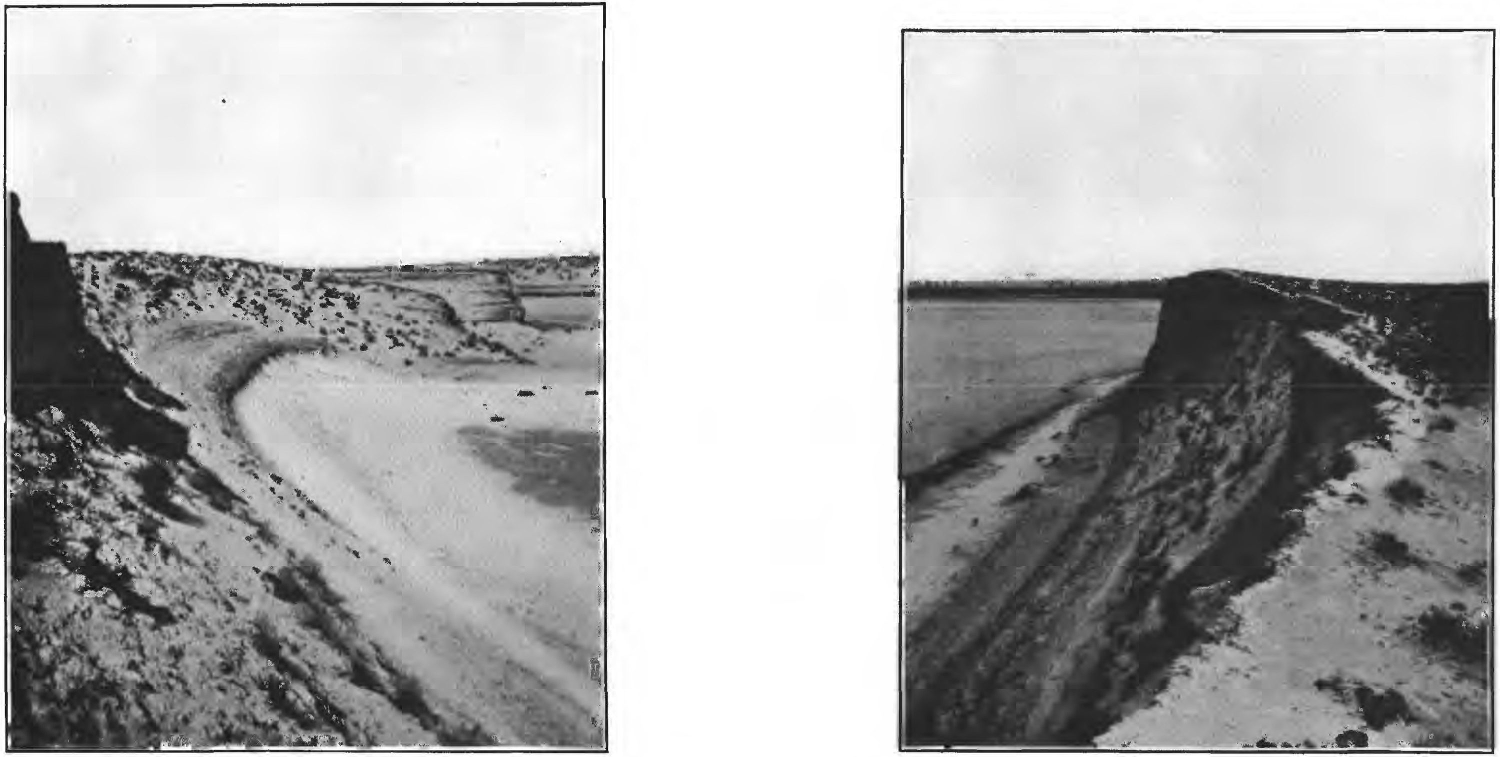
[1] Gilbert, G. K., Lake Bonneville: Mon. U. S. Geol. Survey, vol. 1, 1890, p. 224 et seq.



A. B

CLIFF SURROUNDING A SALT BASIN.

Showing lake sediments overlain by wind-deposited clay. See page 23.

Broadly considered, the shore features in Estancia Valley are commensurate with the size of the ancient lake. They are tiny in contrast with those of the much larger ancient Lake Bonneville, but they compare in size with those of the smaller Lake Sevier.

EFFECT OF PREVAILING WINDS.

A decision as to which side of the lake shows the most vigorous wave work depends somewhat on the interpretation of the cliffs that extend along the west coast. The terraces, beach ridges, spits, and bars are perhaps best displayed on the west side, between Arroyo del Cibolo (Buffalo Draw) and Arroyo Mesteño (Manzano Draw), but this superior distinctness is due partly to the fact that many of the features on the east side, although perhaps larger, have their character obscured by drifting sand. Some of the most conspicuous features are found in the eastern embayment, where, no doubt, large waves were formed by the free sweep of the west winds, but features perhaps equally prominent are found along the southwestern coast. Shore features are not of impressive size at the south end of the lake and are almost undiscernable at the north end.

On the west side there is little sand, but on the east side sand occurs in large quantities—a difference probably due, in part, to the prevalence of westerly storm winds.

LAKE DEPOSITS.

BEACH MATERIAL.

Most of the material constituting the beaches, beach ridges, spits, and bars is gravel. The pebbles are water worn and many of them are covered with a gray coat of lime. The best exposures of beach material are found in the gaps that have been cut through the bars.

STRATIFIED SEDIMENTS.

Except for the salt basins and clay hills, the area within the shore zone is flat (Pl. III, *A*); but the salt basins (Pl. I) are excavated to depths of 10 to 20 feet in the material of this plain, and their sides are generally steep and thus expose the strata to good advantage. Wells have also been dug and are usually left uncased, showing the materials through which they extend. Moreover, many cellars and dugouts have been made, most of which likewise remain unlined. Ample opportunity is therefore afforded to examine the formation which immediately underlies the plain. This formation is totally different from that which underlies the alluvial slopes. It is perfectly stratified, consisting of innumerable thin layers lying one upon another, each layer traceable for an indefinite distance. It is precisely the kind of deposit which would be formed at the quiet bottom of a large body of standing water and which could be formed in no other manner. It was observed in many exposures, natural and artificial, and in widely separated localities. It is practically coextensive with the lake flat and clay hills area and can be seen wherever there is a salt basin, a dug well, a cellar, or any other excavation. It is shown in Plate VI, *A* and *B*, Plate VII, *A*, and Plate VIII, *A*; but none of these pictures do full justice to the delicate lamination displayed in fresh cuts. Clay or shale constitutes the bulk of the material, but layers of sand were also noted, and beds of grit and fine gravel were observed near the outer margin of the lake flat.

The following is a generalized section of the strata in a large open well on the farm of L. Knight, NE. sec. 1, T. 5 N., R. 8 E. (Pl. VIII, *A*). The lake beds appear to begin at the depth of 3 feet 8 inches.

Section in shallow open well of L. Knight.

	Thickness.		Depth.	
	Ft.	*in.*	*Ft.*	*in.*
Soil	0	6	0	6
Dark reddish gray clay	1	0	1	6
Soil belt	0	2	1	8
Dark reddish gray clay, including a few pebbles	2	0	3	8
White and yellow, fine, earthy sand, interbedded with thin strata of fine gravel	4	0	7	8
White shale, including crystals, and interbedded with thin strata of sand	4	0	11	8
Yellow, red, and gray sand, very fine	2	6	14	2

A contrast with this section is presented by a section more remote from the shore—the cliff of the salt basin in sec. 21, T. 5 N., R. 10 E. (Pls. VI, *A* and *B*, and X, *A*, and fig. 2), in which the lake sediments consist almost exclusively of laminæ of clay or shale, considerably impregnated with lime and gypsum. In some of the basins strata of fine sand were observed, but clay or shale greatly predominates in the interior area in which the salt basins are found. Borings made for soil samples also show a graduation toward finer sediments with increasing distance from the shore.

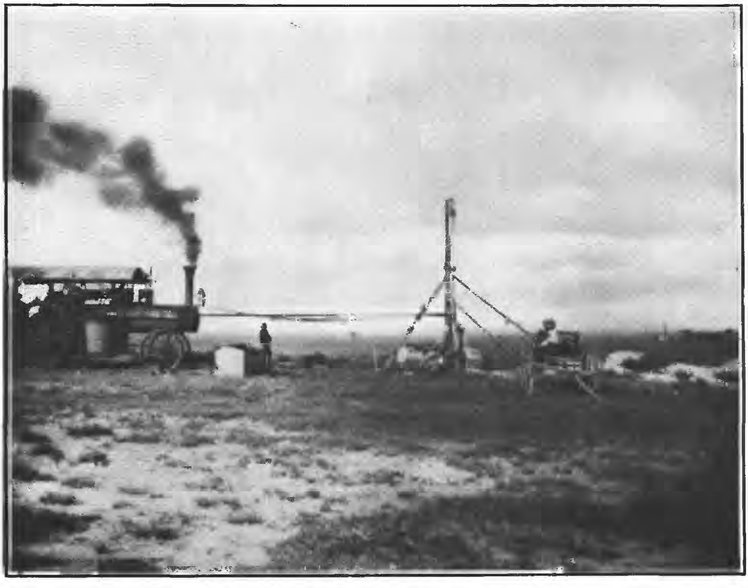
Numerous crystals, most of them of gypsum, are included in the clay or shale strata. These crystals are generally small, but in some localities large selenite crystals were found.

As to the thickness of the lake sediments little is definitely known, but the available evidence indicates that they are relatively thin and are underlain at no great depth by alluvial deposits. The principal evidence concerning their thickness is found in the beds of gravel (alluvial deposits) encountered in drilling on the lake flat, and in the transition in many wells from sediments of grayish hue (lake sediments) near the surface to red clay (alluvial deposits) at greater depths.

The beds penetrated by the railway well at Willard, as shown in the section given above (p. 13), appear to be alluvial rather than lake deposits. The beds below 32 feet in the deep wells of L. Knight (NE. ¼ sec. 1, T. 5 N., R. 8 E.), given in the following section as reported by the owner, also appear to be alluvial.

A. LAKE SEDIMENTS OVERLAIN BY WIND-DEPOSITED CLAY.

See page 23.

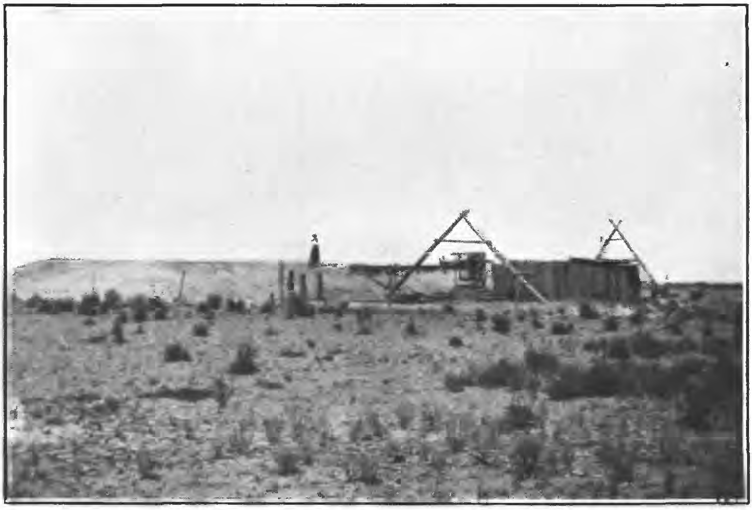


B. TESTING A WELL IN ESTANCIA.

See page 43.

A. OPEN WELL IN LAKE SEDIMENTS.

See page 24.



B. PUMPING PLANT AND RESERVOIR.

See page 54.

Section in deep wells of L. Knight.

	Thickness.	Depth.
	Feet.	*Feet.*
Sand and clay, chiefly dark-colored (in part given above)	30	30
Sticky blue mud	2	32
Gravel	8	40
White chalky material	20	60
Red clay, intermixed with white sand and gravel	30	90
Chiefly red clay with some grit	145	235
Clean gravel	5	240

WORK OF THE WIND.

SAND DUNES.

On the east side of the valley are great masses of wind-blown sand, the largest accumulations having collected east of McIntosh, in the west central part of T. 6 N., R. 11 E. and in an adjacent area to the west, and in certain localities north and south of Progresso. Much of this sand is heaped into fresh dunes and is at present being handled by the winds. Its occurrence on the east side of the valley is due in part to a difference in the derivative rocks, but in part also to the prevailing westerly storm winds at the time the lake existed and more recently. The preponderance of sand along the east shore is characteristic of other lakes, both ancient and modern. Moreover, of the materials excavated from the salt basins the sand was generally carried farther than the clay.

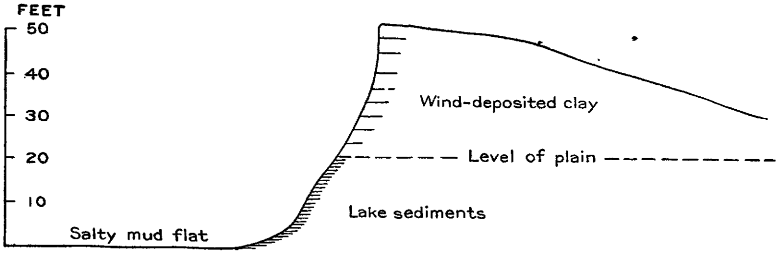


FIGURE 2.—Section of cliff surrounding salt basin.

SALT BASINS AND CLAY HILLS.

The salt basins in Estancia Valley are not remnants of the ancient lake—not merely low spots in which the surplus water collects until it is dissipated by evaporation—but are distinct basins sunk below the level of the plain by which they are surrounded, and as a rule are bordered by definite, nearly vertical walls. (See figs. 2 and 3.) Their flat bottoms practically coincide with the ground-water level and consist of mud covered with crusts of salt (Pl. VI, *A* and *B*), although after rains they may be submerged in water (Pl. IX, *B*). The floor of one basin

(Laguna Salina, secs. 29 and 30, T. 5 N., R. 10 E.) is covered with salt sufficiently thick and pure to be commercially valuable (Pl. IX, *A*).

Altogether there are several score of salt basins, with a total area estimated at 13,500 acres. Among these, Laguna del Perro assumes relatively gigantic proportions, for it is about 12 miles long and covers an area nearly equal to the combined area of all the other basins.

The clay hills in the valley are closely associated with the salt basins. Within the area in which they exist there are many level tracts which are essentially a part of the original plain (Pl. X, *B*). The highest clay hills project more than 100 feet above the plain on which they rest, but most of them are perhaps less than 50 feet high. Typically they form huge embankments that more or less completely encircle the salt basins (Pl. X, *A*). This form is so common that a traveler approaching a hill or ridge confidently expects to find a salt basin on the other side. In some places the ridge lies close to the basin and walls it in with a steep cliff (Pl. VI); in others it stands back a short distance, a ledge or terrace intervening between the ridge and the basin. (See Pl. IX and fig. 3.) As a rule the highest ridges are on the east sides of the basins, and the west sides of many basins are entirely open.

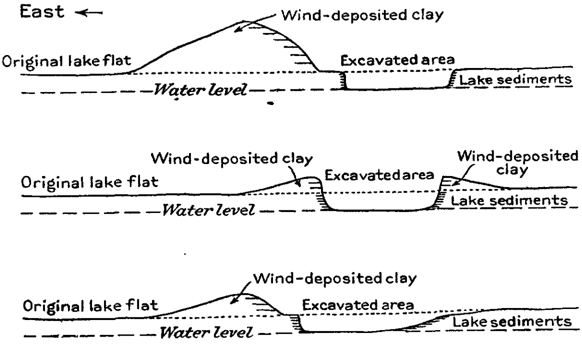


FIGURE 3.—Diagrammatic sections of salt basins and clay hills.

These hills and ridges are composed of pale yellowish gray, fine-grained, pulverulent dust or clay, and contain no pebbles or grit. The clay shows indistinct stratification and occasional cross bedding. Its structure is shown in Plate IV, *A*.

Both basins and hills are the work of wind. D. W. Johnson has described these features and has recognized the eolian character of the hills by calling them "dunes of white adobe soil."[1] Keyes refers to "shallow lake basins hollowed out of the plains-floor by the wind," and cities "Laguna del Perro and other lakelets of the Estancia plains" as typical.[2] It is difficult to conceive any other mode of origin. The material excavated from the basins was heaped up to form the hills. The work of excavation proceeded to the ground-

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[1] Johnson, D. W., Notes of a geological reconnaissance in eastern Valencia County, New Mexico; Am. Geologist, vol. 29, 1902, p. 82.

[2] Keyes, C. R., Geologic processes and geographic products of the arid region: Bull. Geol. Soc. America, vol. 19, 1908, p. 574, and Pl. 41.

A. LAGUNA SALINA.

Showing its white incrustation of salt. See page 25.

B. A SALT BASIN WHOSE FLOOR IS TEMPORARILY COVERED WITH WATER.

See page 25.

A. CLAY RIDGE BORDERING A SALT BASIN.

See page 25.

B. TYPICAL CLAY-HILL TOPOGRAPHY.

See page 25.

water level but could be carried no deeper, and hence the flat, miry, alkaline floors of the basins. The material and structure of the hills corroborates the theory of their eolian origin, the material, as far as observed, being thoroughly assorted and containing nothing coarser than the wind could handle. Southwest winds have prevailed in this region and hence the hills are best developed on the east and north sides of the basins, as is well shown in figure 4. The wind is still active and the effects of its recent erosive work can be seen on exposed parts of the basin walls.

The highest clay hills lie within the vertical range in which shore features are found and consist of material that would yield very readily to wave action, yet not the slightest indication of a shore line is recorded on their flanks, so they have evidently been formed since the lake disappeared. When the lake had dried up deflatation from the dry surface began. As the water level sank the basins were eroded deeper, and, conversely, to a certain extent the presence of the basins tended to lower the water level still more.

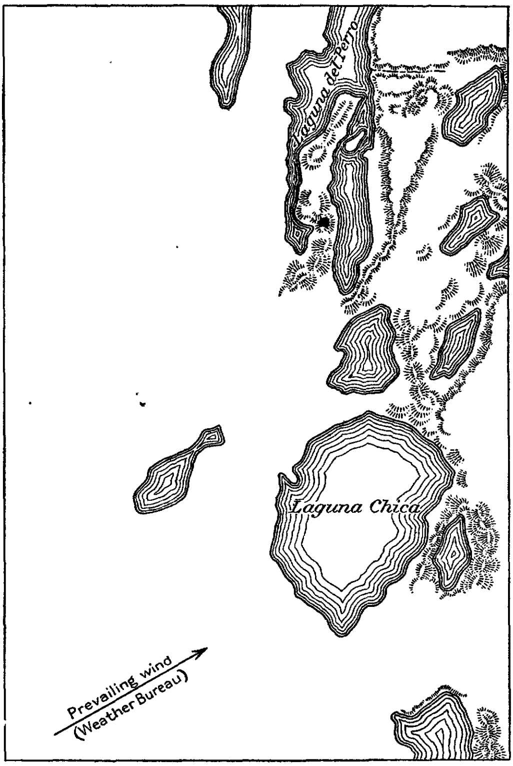

FIGURE 4.—Map showing the relation of topographic features to prevailing direction of wind. (Eastern portion of township plat, T. 4 N., R. 9 E., surveyed by Duane Wheeler.)

Attention has already been directed to the small amount of post-lacustrine stream erosion in the valley proper, in contrast to which the work of the wind is surprisingly great and impressive. Indeed, the most conspicuous and effective stream work has been done on the wind-built hills.

SOILS.

RED LOAMY SOILS.

The most widely distributed soil in the valley consists of red clay intermingled with varying quantities of silt, grit, and gravel. It is seen in typical character in the alluvial slopes and arroyos, but it also occurs throughout much of the littoral zone and is found far up in the foothills. It is essentially the product of the weathering of the rocks in the surrounding highlands, whence it has been washed out into its present position in the manner already described. In general this soil is very fertile, as is demonstrated by the large crops that it produces when climatic conditions are not unfavorable, and its fertility is due largely to its content of soluble substances which serve as plant food. These soluble substances have been produced by the weathering of the rocks and have not been leached out from the soil by percolating waters to so great an extent as in more humid regions.

SANDY SOILS.

Sandy soils are found chiefly on the east side of the valley. They range from clean pale-yellow dune sand, which is worthless for agriculture, to red earthy sand and red sandy loam, which may be very productive. Sandy soils, like clay and loam soils, have been deprived of less of their soluble constituents in arid than in humid regions.

ALKALI SOILS.

It has just been stated that most of the soil in Estancia Valley, as in arid and semiarid regions generally, is very fertile because of the soluble substances which it contains. But if certain soluble substances, commonly known as alkalies, exist in soils in quantities too large, they are injurious to plant life; hence very fertile soils grade readily into alkali soils; and, moreover, soils which at first are very productive may, after a period of irrigation and cultivation, become harmfully alkaline. On this point Milton Whitney,[1] Chief of the Bureau of Soils, United States Department of Agriculture, makes the following statement:

> This accumulation explains the wonderful fertility of the lands generally in the arid regions the world over, but it is also a constant menace because of the large amount of soluble salts which is liable to accumulate locally as the result of irrigation or as a result of other natural conditions not well understood, until they are a menace and often a destructive agency for the very lands which were formerly held in such esteem.

The different kinds of alkali and their effects upon vegetation can best be explained by a further quotation from Whitney, as follows:

> The alkali soils of the West are of two principal classes. The alkaline carbonates or black alkali (usually sodium carbonate) is the worst form, actually dissolving the organic materials of the soil and corroding and killing the germinating seed or roots of plants; the white alkalies, the most common of which are sodium sulphate (Glauber's salt), sodium chloride (common salt), magnesium sulphate, and magnesium chloride, are not in themselves poisonous to plants, nor do they attack the substance of the plant roots, but are injurious when, owing to their presence in excessive amounts, they prevent the plants from taking up their needed food and water supply.
>
> The amount of soluble salts which plants can stand depends upon the character of the salt, the character of the soil, and the kind of plant. Hilgard states that few

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[1] Alkali lands: Farmers' Bull. No. 88, U. S. Dept. Agr., 1899, p. 7.

> plants can stand as much as 0.1 of 1 per cent of sodium carbonate; of sodium chloride plants can stand about 0.25 of 1 per cent, and of sodium sulphate 0.45 to 0.50 of 1 per cent. Plants can stand less salts in sandy lands than on heavy clay or gumbo lands. It is a well-known fact that crops also differ in their ability to stand salts, and many crops will grow well upon soils on which others will not live.
>
> Investigations at Billings, Mont., showed that when the concentration of the salts in active solution in the soil moisture is as great as 1 per cent the limit of most cultivated plants is reached. Further concentration kills all our ordinary agricultural crops. It was found, furthermore, that plants could just exist with 0.45 of 1 per cent of the soluble salts present, and this is taken as the limit of plant production.

A later statement by C. W. Dorsey, of the Bureau of Soils, is as follows:[1]

> Of the different classes of alkali, sodium carbonate, or black alkali, is considered the most injurious. Laboratory experiments have shown that magnesium chloride and sulphate are equally, if not more, injurious than sodium carbonate. After these salts comes sodium chloride (ordinary salt), and, last, sodium sulphate. When present in soils to the exclusion of other salts, 0.05 per cent of sodium carbonate presents about the upper limit of concentration for common crops. One-half of 1 per cent of sodium chloride is commonly regarded as the endurance limit of crops and 1 per cent of sodium sulphate. Sodium sulphate, then, is the least injurious and sodium carbonate the most injurious of the salts usually constituting the greater part of alkali under ordinary field conditions, while sodium chloride occupies a middle position.

Gypsum (calcium sulphate) acts as an antidote for black alkali by reacting with it to form calcium carbonate, which is harmless, and sodium sulphate, a less injurious white alkali. A soil that contains a large amount of gypsum would therefore not be expected to contain much black alkali, although it may contain some.[2]

In Estancia Valley the shallow water belt (Pl. XI), the ancient lake bed (Pl. I), the area of highly mineralized waters (Pl. XI), and the area in which the most alkaline soils are found, all coincide approximately with one another because all are results of the same general causal conditions. The rain water that falls on the highland borders migrates toward the lowest area, where it accumulates until it is disposed of by evaporation. Whether it here stands slightly below the general surface of the ground, as at present, or a short distance above the surface, as in the Pleistocene period when the lake existed, is merely an incident in the general circulation. The important facts in this connection are that in its migration it dissolves and carries along the soluble constituents which it encounters in the rocks and soil, and that on its evaporation these soluble constituents are left behind, thus becoming concentrated in the lowest portion of the valley. The crusts of alkali which cover the salt basins are visible illustrations of the process that has impregnated with alkali the soil of the low area.

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[1] Reclamation of alkali soils: Bull. Bureau of Soils No. 34, U. S. Dept. Agr., 1906, p. 10.

[2] Cameron, F. K., Application of the theory of solution to the study of soils: Field operations, Div. of Soils, 1899, U. S. Dept. Agr., 1900, pp. 152 et seq. Hilgard, E. W., Soils, Macmillan Co., New York, 1906, pp. 449 et seq., 457, 458.

Samples of soil collected at five points within the lake flat along a line extending 6 miles eastward from Estancia (see the map, Pl. XI) were analyzed by the United States Bureau of Soils, with the following results:

Analyses of soils in Estancia Valley.

Location.	Depth within which the material was obtained. *Feet.*	Soluble solids (alkalies); per cent of total material.	Predominating salts in the order named.
Estancia, NW. ¼ sec. 12, T. 6 N., R. 8 E., at the intersection of the railway with the section line.	1	0.2	Chlorides and bicarbonates.
	2	.3	Do.
	3	.8	Sulphates and chlorides.
	4	1.0	Do.
	5	1.2	Do.
	6	1.0	Do.
T. J. Moore, northeast corner of SW. ¼ sec. 5, T. 6 N., R. 9 E.	1	.1	Do.
	2	1.4	Chlorides and sulphates.
	3	1.3	Sulphates and bicarbonates.
	4	1.5	Do.
	5	2.1	Sulphates and chlorides.
	6	1.6	Do.
Southwest corner of sec. 4, T. 6 N., R. 9 E.	1	.6	Do.
	2	.7	Chlorides and sulphates.
	3	3.7	Sulphates and chlorides.
	4	3.9	Do.
	5	3.7	Do.
	6	3.5	Do.
N. Williams, southwest corner of SE. ¼ sec. 3, T. 6 N., R. 9 E.	1	2.5	Do.
	2	2.7	Do.
	3	2.9	Do.
	4	2.7	Do.
	5	2.9	Do.
	6	3.5	Do.
H. N. Summers, southeast corner of SW. ¼ sec. 1, T. 6 N., R. 9 E.	1	1.6	Do.
	2	2.8	Do.
	3	3.7	Do.
	4	4.5	Do.
	5	3.6	Do.
	6	4.5	Do.

In respect to these analyses J. A. Bonsteel, in charge of soil surveys, writes:

> It is apparent to the student of soils and soil conditions in the Basin region that these soils are very heavily loaded with alkali salts, comparing more directly with those of old desiccated lake basins than with any of the agricultural lands now occupied in the United States. You will also notice the continual appearance of chlorides in practically all of the samples. From this I judge that the soil samples were taken from a decidedly alkaline tract, probably a desiccated lake bed, and where only the most efficient tile underdrainage would render the majority of these soils capable of producing any economic vegetation.

CLIMATE.

RAINFALL.

The following tables give the monthly and annual precipitation in Estancia Valley as recorded by the United States Weather Bureau. They cover a period that is too short to serve as a reliable basis for estimating the average monthly and yearly precipitation, but they are, nevertheless, exceedingly instructive.

Precipitation in Estancia Valley, in inches, 1903-1909.

Estancia.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1904	......	......	......	......	......	......	......	......	......	......	0.10	0.75	....
1905	1.00	0.94	0.38	2.68	0.01	1.13	......	1.07	1.16	......	......	......	....
1906	.08	.33	.69	1.37	.03	.00	4.41	1.73	1.49	2.17	1.33	1.13	14.76
1907	.40	.21	.00	1.97	1.22	.90	.56	4.71	......	1.94	2.11	......	....
1908	.20	Tr.	......	......	......	......	4.46	......	......	......	......	......	....
1909	......	......	......	......	......	1.00	.99	1.30	1.25	1.36	.10	.78	....

Mountainair.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1903	0.60	5.39	0.46	0.43	0.06	2.96	0.52	1.71	0.36	Tr.	0.00	0.52	13.01
1904	.10	Tr.	.14	.14	.57	2.38	1.11	2.45	2.66	0.98	.03	.34	10.90
1905	.72	1.64	1.09	3.66	.32	1.11	2.47	1.60	3.12	.31	3.74	3.04	22.82
1906	.40	1.11	.28	......	......	......	......	......	1.43	1.96	1.49	2.84	....
1907	1.38	.31	.06	2.68	4.24	.12	1.19	4.88	1.99	3.45	2.22	.34	22.86
1908	.60	.51	.36	3.00	.61	.66	4.78	2.50	.78	.77	1.73	.37	16.57
1909	.18	.80	4.92	.22	.18	.06	2.31	2.53	1.90	1.61	Tr.	1.79	16.50
Average	.57	1.40	1.04	1.69	1.00	1.21	2.06	2.61	1.75	1.30	1.32	1.32	17.11

Otto.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1909	0.45	0.25	0.40	0.36	0.29	0.37	1.27	2.00	2.47	0.54	0.20	0.25	8.85

Estancia Valley clearly belongs to the semiarid belt, its rainfall being deficient in quantity and irregular in distribution. Much more rain falls in some years than in others, much more falls in some months than in others of the same season, and much more falls during a certain month in one year than during the same month in other years. A large share of the rain comes in heavy downpours of short duration, covering limited areas and occurring at irregular and often at long intervals. The heaviest precipitation is in July and August. There is frequently a deficiency in the winter and spring months.

During the summer the great cyclonic storms which regularly pass eastward across the continent have relatively little effect in this region, but the showers are generally produced by ascensional currents resulting from the daily heating of the atmosphere. Nearly every afternoon the temperature rises, the barometric pressure decreases, and the weather becomes threatening. Most of the storms blow over with a few stray raindrops, but occasionally one bursts with fury and the rain descends in torrents.[1]

The above tables cover too brief a period and are too incomplete to afford a basis for definite conclusions, but they indicate more rainfall at Mountainair than at Estancia. Of the 37 months in which records are available for both stations 27 months show greater rainfall in Mountainair and only 10 months show greater rainfall in

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[1] Henry, A. J., Climatology of the United States: Bull. U. S. Weather Bureau Q, 1906, pp. 50, 888-889.

Estancia. Moreover, in these 37 months 58.53 inches fell in Mountainair and only 41.90 inches fell in Estancia. This difference is graphically shown in figure 5.

EVAPORATION.

The term "annual evaporation" is used to mean the total thickness of the layer of water that would be removed by evaporation from the surface of a lake or other body of water continuously exposed to the atmosphere for one year. It is as important a factor of climate as is rainfall. It varies inversely with the relative humidity of the atmosphere and directly with temperature and wind velocity. At Albuquerque the average evaporation for two years (1900 and 1903) was 82.9 inches;[1] at Amarillo, Tex., it was reported to be 55.4 inches.[2] In Estancia Valley it is probably less than at Albuquerque and more than at Amarillo.

TEMPERATURE.

The following table gives the meager data at present available as to the mean

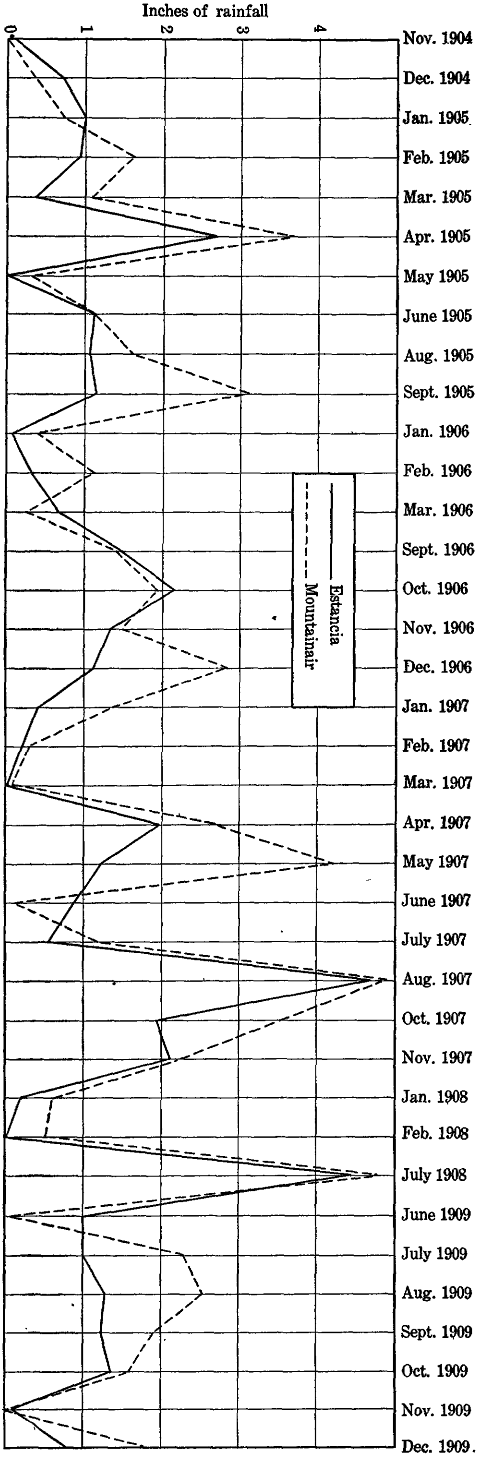

FIGURE 5.—Diagram showing relative amounts of rainfall at Estancia and Mountainair during months in which observations were made at both places.

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[1] Lee, W. T., Water resources of the Rio Grande Valley in New Mexico: Water-Supply Paper U. S. Geol. Survey No. 188, 1907, p. 31.

[2] Johnson, W. D., The High Plains and their utilization: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 4, 1901, p. 677.

annual temperature, the highest and lowest temperatures, and the dates of latest frosts in the spring and earliest frosts in the fall:

Temperatures in Estancia Valley, 1903–1909, in degrees Fahrenheit.

Years.	Mean annual.		Highest.		Lowest.		Last killing frost in spring.		First killing frost in fall.	
	Estancia.	Mountainair.	Estancia.	Mountainair.	Estancia.	Mountainair.	Estancia.	Mountainair.	Estancia.	Mountainair.
1903	....	49.4	....	95	....	−12	....	May 25[a]	....	Sept. 17
1904	....	50.3	....	74	....	− 3	....	May 9[a]	....	Sept. 8[a]
1905	....	[b]49.1	94	96	− 6	−13	Apr. 23[a]	May 12[a]	Sept. 15	Sept. 30
1906	50.2	....	95	92	−16	− 2	May 8	....	Oct. 6	Oct. 14
1907	....	[c]52.4	95	95	7	− 2	June 12[a]	May 29[a]	Sept. 25[a]	Oct. 9[a]
1908	....	51.0	94	95	7	7	....	May 13	....	Sept. 27
1909	....	....	....	....	....	....	....	May 15[a]	....	....

[a] Minimum temperature of 32° or lower.
[b] Interpolated.
[c] Obtained by averaging the monthly means.

The following statement by A. J. Henry,[1] of the United States Weather Bureau, in regard to New Mexico in general, applies for this region:

> The daily variation of temperature is very great. * * * Owing to the dryness of the air, the extremes of temperature are not such potent factors in the comfort of animal life as the degrees registered by the thermometer would indicate. It is a noteworthy fact that 100° in the shade here is not so oppressive as a temperature of 85° in a humid climate. Sunstrokes are unknown in New Mexico. In a somewhat corresponding degree the cold of winter is felt less. Spring advances slowly, development being retarded by the cold nights as well as by the lack of moisture. * * * May, June, July, and August are characterized by extremes of heat during the middle of the day, but the nights are cool.

WIND.

Late winter and early spring are characterized by high winds which make outdoor life unpleasant, but destructive winds are rare. Later in the year there is less wind and the climate is generally very agreeable.

The following table, which gives data as to the prevailing direction of the wind, is introduced especially because of its bearing on the wind theory of the formation of the clay hills and the location of the sand dunes:

Prevailing direction of wind in Estancia Valley.

Summarized by years, 1903–1909.

	1903	1904	1905	1906	1907	1908	1909
Estancia	....	....	SW.	W.	....	....	....
Mountainair	SW.	SW.	SW.	SW.	SW.	SW.	SW.

Summarized by months for 1907.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Estancia	....	....	W.	....	....	SW.	SW.	....	....	....	NW.	....
Mountainair	SW.	SW.	SW.	SW.	SW.	SW.	SW.	SW.	SW.	SW.	SW.	SW.

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[1] Henry, A. J., Climatology of the United States: Bull. U. S. Weather Bureau, Q., 1906, p. 888

The next table gives the average wind velocity for one year at four points in the general region to which Estancia Valley belongs. It is presented because of its bearing on the data given on page 59 in regard to the pumping capacity of windmills.

Average wind velocity in the Southwest in 1907, in miles per hour.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
El Paso, Tex.	8.1	10.4	10.4	13.2	12.5	11.0	9.8	8.0	7.0	8.8	7.9	9.4
Mesilla Park	5.8	6.9	8.5	10.7	10.4	8.1	8.4	7.5	6.1	......	5.5	6.6
Roswell	6.1	6.7	7.7	7.6	7.2	6.0	5.2	4.5	5.0	4.6	4.6	7.1
Santa Fe	7.2	8.2	8.6	8.0	7.8	7.2	6.7	7.3	7.3	7.6	7.7	9.5

RELATION OF CLIMATE TO AGRICULTURE.

The mean annual rainfall, taken by itself, gives very incomplete information as to the adaptability of the region to agriculture, for the distribution of the rainfall, the rate of evaporation, and other factors are vital elements of the problem. The preponderance of precipitation in the summer over the winter season is obviously favorable to agriculture, but the deficiency of rainfall in the spring, its general irregularity, and the fact that much of it comes in short heavy showers are unfavorable, as are also the low humidity of the atmosphere and the strong spring winds, both of which intensify evaporation.

WATER.

SOURCE AND DISPOSAL.

If the mean annual precipitation for the entire Estancia Basin is assumed to be 15 inches, the amount of water that falls on the basin as rain or snow in an average year is approximately 1,600,000 acre-feet. If it is further assumed that within recent years the quantity of ground water has neither materially increased nor decreased, it follows that the same amount is, on the average, withdrawn each year from the Estancia Basin. This withdrawal is accomplished by evaporation into the atmosphere and by seepage through underground passages to lower points outside of the basin. No water leaves the basin in surface streams.

EVAPORATION FROM THE SURFACE.

Much of the water that falls as rain or snow returns to the atmosphere by being evaporated, either directly from the surface or after it has soaked a short distance into the ground, from which it is again withdrawn by vegetation or by capillary action in the soil. The proportion of moisture thus disposed of is greatest for the lightest showers and least for the heaviest and most persistent rains.

MOUNTAIN SPRINGS AND STREAMS.

Some of the moisture that falls on the mountains seeps into the pores and crevices of the rocks, but reappears at lower levels, where it issues in springs that give rise to brooks or rivulets, most of which disappear long before they reach the valley, the water being dissipated both by evaporation and by seepage into the ground. Springs and streams of this type in the canyons and foothills of the Manzano Range have determined the location of the old Mexican settlements of Chilili, Tajique, Torreon, Manzano, and Punta de Agua.

FLOODS.

In the entire basin there are no permanent streams except the tiny ones just mentioned, but there are many wide stream channels, or arroyos, which are normally dry, but which during heavy storms carry much water. The water of most of these floods is lost in the arroyos, but that of a few of the largest reaches the central flat and there soaks into the earth. Probably these floods furnish most of the ground water in the valley fill.

UNDERFLOW.

Though the valley includes no important permanent surface stream it contains a great body of ground water which, below a certain depth, fills every pore, crack, and crevice. From time to time this great body of water receives contributions from portions of the rainfall that escape evaporation. It is not, however, a stationary mass, for it moves constantly, though very slowly, away from the upland border and toward the low central portion of the basin.

OVERFILLING OF UNDERGROUND RESERVOIR.

If the ground water is constantly augmented by contributions from the rainfall, and if this newly acquired water moves constantly toward the center of the valley, it would be expected that in the central region the pores and crevices of the ground above the bed rock would in time all become filled and the underground reservoir would overflow. This is essentially what takes place, the surplus being returned to the surface or brought so near to the surface that it can be reached by evaporation. The surplus is disposed of in three ways—by overflow from valley springs, by evaporation from the salt basins, and by evaporation in other areas in which the ground water rises near enough to the surface to come within the reach of the atmosphere through capillarity. In each of the three ways the ultimate disposal of the water is by return to the atmosphere through the process of evaporation.

There are several valley springs, two of the largest and best known of which are Estancia Spring, in the village of Estancia, and Antelope Spring, several miles north (Pl. I)—both important watering places in the old days before the advent of the agriculturist. From general observations it seems safe to say that their combined yield does not exceed several hundred acre-feet per year—an amount which is insignificant when compared with the total quantity of water that falls upon the Estancia Basin each year as rain or snow.

Where the ground water lies sufficiently near the surface, it is withdrawn in the same manner and by the same process that kerosene is withdrawn through the wick of a burning lamp, the soil serving as the wick. The moisture at the top of the soil is constantly being removed by evaporation just as the kerosene at the top of the wick is removed by burning, and new moisture is drawn up through the pores of the soil just as kerosene is drawn up through the pores of the wick. In both cases the liquid is lifted by capillarity.

There is a limit to the height that water can be lifted by capillarity, but this limit is not the same for different soils. It can be lifted higher through clay or fine silt, which has small pores, than through sand, which has larger pores. Hilgard states that the maximum height of capillary rise thus far observed is 10.17 feet.[1] C. H. Lee concludes that in the area he has investigated in Owens Valley, Cal., no appreciable evaporation occurs from soil where the depth to water exceeds 8 or 9 feet.[2] For most soils, capillarity is probably not effective except where the water stands considerably nearer the surface than 10 feet.

The rate at which water is raised by capillary action depends on the character of the soil and the height that the water is lifted. It is more rapid in sandy soil than in clay soil, and more rapid where the water is near the surface than where it is several feet below the surface. In an experiment made at Deerfield, Kans., in 1905, Slichter[3] found that the evaporation during the period from August 6 to September 3 was as follows: From open water, 10.90 inches; from cultivated soil with 1 foot to water, 4.88 inches; from uncultivated soil with 1 foot to water, 5.83 inches; from soil with 2 feet to water, 2.23 inches; from soil with 3 feet to water, 0.80 inch. The soil was sandy loam. Lee[2] concluded from his experiments in Owens Valley that where the water level is not more than 3 feet nor less than 1 foot below the surface, a depth of evaporation of about 80 per cent of that from an exposed water surface can be expected.

The salt basins of Estancia Valley are a part of the time miry or covered with water, and are probably in general near enough the water

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[1] Hilgard, E. W., Soils: MacMillan Co., N. Y., 1906, p. 203.

[2] Precipitation, run-off, and evaporation in the Owens Valley: Monthly Weather Review Weather Bureau, U. S. Dept. Agr., vol. 38, No. 1, Jan., 1910, p. 127.

[3] Slichter, C. S., The underflow in Arkansas Valley in western Kansas: Water-Supply Paper U. S. Geol Survey No. 153, 1906, p. 44.

level to permit evaporation from the ground water. If their total area is taken as 13,500 acres and the annual evaporation from open water is taken as 72 inches, then the amount of water that would be removed from their surface each year if they were continually covered with water is 81,000 acre-feet, or about 5 per cent of the total precipitation in the Estancia Basin. Where the water level is very near the surface evaporation may take place even more rapidly than from open water, but since in certain places and certain seasons it is probably some distance below the surface the actual average rate of evaporation is probably much less than for open water. Moreover, much of the evaporating potentiality is consumed in removing surface water which runs in from the clay hills during heavy showers.

Evaporation of ground water is also taking place in some localities outside of salt basins, and it seems probable that the amount of water withdrawn in these localities is quantitatively important. Near the McGillivray well, in Estancia, where the water is only 5 feet below the surface, incrustations of salt were observed, although similar incrustations were not evident in the soil of the same locality where the depth to ground water is greater, this being true of the red soil that lies at a higher level to the west and also, to a certain extent, of the "ashy" soil that lies at a lower level to the east. Similar conditions were observed elsewhere along the shallow-water belt on the west side of the valley. East of Moriarty there are also areas of very shallow water in which crusts of salt have formed at the surface such as are not generally found in the central part of the valley. The explanation seems to be that where the ground water lies at a shallow level it is drawn to the surface and evaporated, leaving its content of salt. The total area outside of the salt basins having a depth to water of less than 10 feet is perhaps as great as the area of the salt basins themselves.

LEAKAGE OF THE BASIN.

As has been repeatedly indicated, the rock formations which border the valley and underlie the valley fill constitute a relatively impervious basin in which the water collects. But this basin is perched high above most of the surrounding territory and if it is not entirely waterproof serious loss may occur. The extensive outcrop of more or less porous rock formations east of the Manzano Range produces a condition favorable for the absorption by these formations of water that falls upon the outcrop or crosses it in coming from the mountains. To the extent that this absorbed water finds passages of escape through porous strata or fissures formed by deformation or in other ways, to that extent the water of the basin is lost. It is possible that such escape occurs through the nearly horizontal strata to the south, through the north end, or through the fissures and porous strata to the east. The conditions here involved are so complex and obscure that it is impossible to form an estimate of the amount of this leakage, but it may be a large factor.

SUMMARY.

The foregoing analysis of the disposal of the water that falls on the Estancia drainage basin is summarized in the following table. The analysis is not exhaustive, but is sufficiently complete for practical purposes.

Disposal of precipitation in the Estancia Basin.

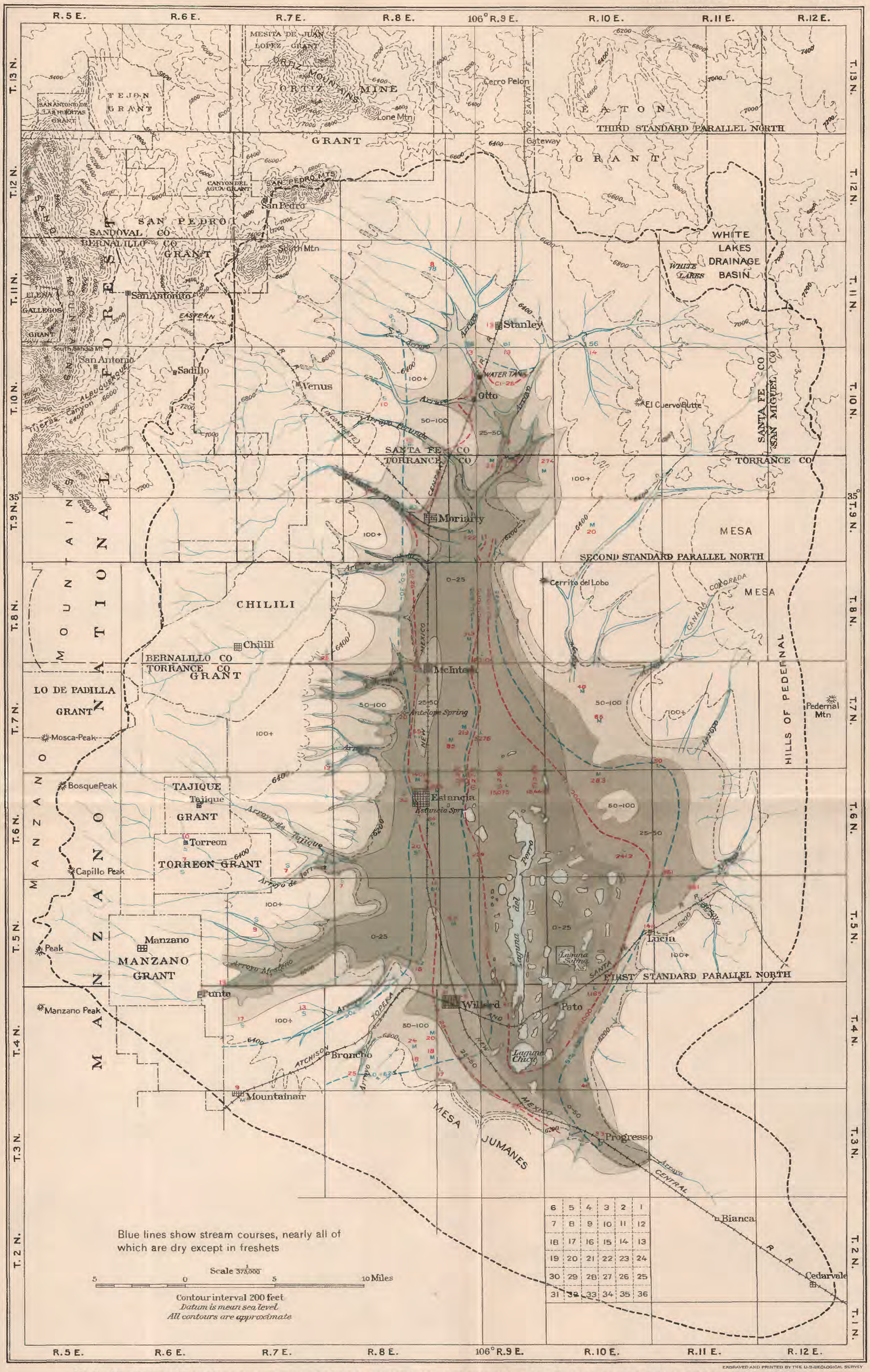
Process.			Quantitative importance.
Evaporation.	Before reaching the ground water.	Before soaking into the ground.	Great, but indefinitely known.
		After soaking into the ground. Withdrawn by vegetation, capillarity of the soil, etc.	
	After seeping into the rocks, from which it is returned through mountain springs.		Small.
	After reaching the ground water in the valley fill.	Returned through valley springs.	Small.
		Returned by rising in salt basins.	Appreciable.
		Returned by approaching near the surface in other localities.	Probably appreciable, but indefinitely known.
Seepage.	Entering into the pores and crevices of the rocks and escaping from the basin.		Indefinitely known. Possibly great.

HEAD.

GROUND-WATER TABLE.

METHODS OF INVESTIGATION.

Below a certain level the earth is saturated, every pore and crevice being filled with water. This level is known as the ground-water level or ground-water table. To ascertain its position relative to the surface throughout the valley the depth to water was measured in about 200 wells and was reported by owners, drillers, or other reliable persons for many more. The measurements were made with a stout cord, which was marked at intervals of 3 feet. This allowed much more rapid work than the use of a steel tape, and the error due to the elasticity of the cord was less than 1 per cent. A more serious error, or rather ambiguity, arose from the fact that the ground is



MAP OF ESTANCIA VALLEY, NEW MEXICO, SHOWING DEPTH TO AND QUALITY OF THE GROUND WATERS

LEGEND

Swatch	Explanation
▨	Salt basins Water near surface
0-25	Depth to water less than 25 feet
25-50	Depth to water between 25 and 50 feet
50-100	Depth to water between 50 and 100 feet
100+	Depth to water over 100 feet
Cl-25, 65	Contents of chlorine in parts per million
30, 50	Contents of sulphate radicle in parts per million

Parts per million of sulphate radicle determined by the turbidimeter method

Swatch	Explanation
S	Less than 30
M	Between 100 and 625
L	More than 625
⊙27%	Point where samples of soil were taken, and percentage of alkali in the upper 6 feet

generally graded up around a well, making it uncertain as to what level should be taken as the natural land surface, to which all measurements were referred. The element of error is of no practical importance in the determination of the general position of the ground-water table, but it must be taken into account if future measurements are made for the purpose of detecting changes in the water level. The general results are shown on the map, forming Plate XI, and more specific data are given in the table on page 67.

RELATION OF GROUND-WATER TABLE TO THE SURFACE.

Over an area of about 240 square miles (including the salt basins) the ground water stands within 25 feet of the surface, over an area of about 210 square miles it stands between 25 and 50 feet below the surface, and over an area of about 250 square miles it stands between 50 and 100 feet below the surface. Thus, over a total area of about 450 square miles it is less than 50 feet below the surface, and over a total area of at least 700 square miles it is less than 100 feet below the surface. The shallow-water area covers the low central plain and extends far up the large arroyos, especially Arroyo Mesteño. The map, Plate XI, indicates the general boundaries of the areas of different depths to water as nearly as these could be ascertained, but numerous small areas in the foothills in which water is locally found at depths of less than 100 feet are not shown.

SHALLOW-WATER BELT ON THE WEST SIDE.

About a mile west of the New Mexico Central Railroad and extending nearly due north and south for a number of miles is a narrow belt in which the ground water is very near the surface. This belt runs along the base of the cliff on the McIntosh ranch (SE. ¼ sec. 35, T. 8 N., R. 8 E.), whence it extends northward to the east side of sec. 23 and perhaps beyond. It passes southward through Antelope Spring; thence through secs. 23, 26, and 35 in T. 7 N., R. 8 E., to secs. 2 and 11 in T. 6 N., R. 8 E., and to Estancia Spring; thence to secs. 26 and 35 in the same township and through secs. 2, 3, 10, 11, and 15 in the next township south, beyond which it was not traced. Along this line, wherever data were obtainable, the ground water was found near the surface, at depths in most places of less than 10 feet and in some places of less than 5 feet. It can not be asserted, however, from the data available, that there are no interruptions in this shallow-water belt.

It is not closely related to the topography, for the surface rises toward the west and gradually descends toward the east, yet in both directions the depth to water increases. Thus, on the McIntosh ranch the water is virtually at the surface, but less than half a mile east and at a level about 25 feet lower it is 30 feet below the surface;

at Antelope Spring it is at the surface, but 1 mile east and at a considerably lower level it is 35 feet below the surface; on sec. 2, T. 6 N., R. 8 E., it is only 8 feet below the surface, but a short distance east and at a lower level it is 20 feet below; in the west part of Estancia it is practically at the surface, but in the east part, which is lower, it is 15 or 20 feet below; at a point 1½ miles west of the railway, along the line between townships 5 and 6, it is only 4 feet below the surface, but at a considerably lower point half a mile east of the railway it is 22 feet below; in the SW. ¼ sec. 14, T. 5 N., R. 8 E., it is only 14 feet below the surface, but 1 mile farther east and on ground perhaps 15 or 20 feet lower it is 32 feet below. In some localities it would be possible, though perhaps not practicable, to draw the ground water from the shallow belt by gravity through a tunnel or siphon out to the surface farther east. Indeed, such a scheme is being attempted by H. C. Williams on sec. 26, T. 6 N., R. 8 E.

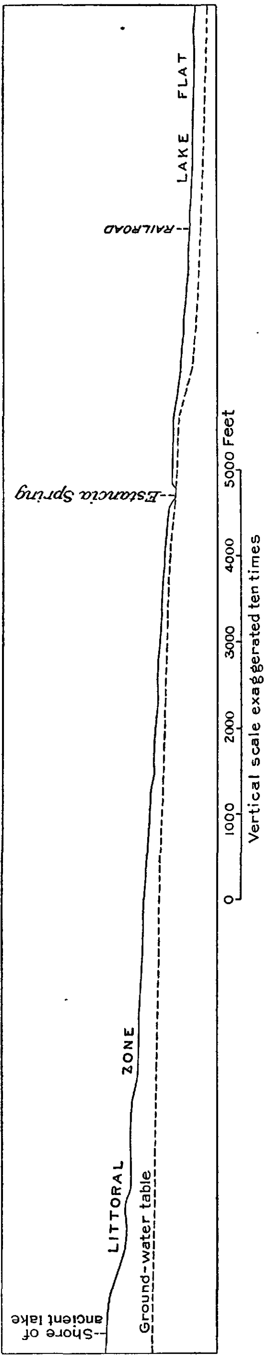


FIGURE 6.—Section through Estancia village showing the relation of the shallow water belt to the surface.

This shallow-water belt is shown on the map, Plate XI, and in figure 6 it is shown in a cross section passing through the village of Estancia, the only locality in which wells have been sunk close enough to each other to make such a section possible. The cause of this abrupt change in the ground-water level is not evident. At Antelope Spring and McIntosh ranch it might be correlated with the cliff immediately west, but such an explanation will not hold farther south. Neither underground structure, concentric arrangement of beach materials, nor the existence of the salt basins appear to furnish an adequate explanation.

INFLUENCE OF THE SALT BASINS.

Although the ground-water table is nowhere at any great depth throughout the low central portion of the valley, it does not approximate as closely to the surface as it would if the salt basins were absent. Moreover, these depressions are perhaps chiefly responsible for the scarcity of springs and seeps in this region.

RELATION OF GROUND-WATER TABLE TO UNDERFLOW.

The ground-water table is not level, but slopes toward the center of the valley, although, in general, this slope is less steep than that of the land surface. An approximate idea of the amount of slope, or the "hydraulic gradient," can be deduced from the map, Plate XI, but it will be only approximate, because the topographic contours are based largely on aneroid readings and are therefore only approximately correct. In the following table somewhat more accurate data are given for several stations whose altitudes were determined by railway levels:

Slope of ground-water table in Estancia Valley.

Station.	Altitude of surface above sea level.	Depth to water.	Altitude of ground-water table above sea level.[a]	Difference in altitude of ground-water table.	Distance from preceding station.	Hydraulic gradient, or slope of ground-water table.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Miles.*	*Ft. per mile.*
Stanley	[b]6,317	[c]115	6,202			
Moriarty	[b]6,204	40	6,164	38(?)	11.5	3.3(?)
McIntosh	[b]6,136	30	6,106	58	8.5	6.8
Estancia	[b]6,093	15	6,078	28	7	4.0
Willard	6,090	35	6,055	23	12	1.9
3 miles east of Willard	[d]6,055	10	6,045	10	3	3.3
Progresso	[b]6,167	35	6,132	87	8	10.9
Cedarvale	[d]6,425	174	6,251	119	15	8.0
Mountainair	6,487	[e]210	6,277			
Broncho	6,312	175	6,137	140	6	23.3
Willard	6,090	35	6,055	82	7	11.7
3 miles east of Willard	[d]6,055	10	6,045	10	3	3.3
Pato	6,085	25	6,060	15	3	5.0
Lucia	6,187	[e]40	6,147	87	7.5	11.6
Venus	[f]6,555	180(?)	6,375(?)			
Moriarty	[b]6,204	40	6,164	211(?)	10.5	21.0(?)

[a] In the deep wells the artesian head is given.
[b] Gannett's Dictionary of Altitudes.
[c] Approximate. Data somewhat conflicting.
[d] Estimated.
[e] Reported by A. T. & S. F. Ry. Co.
[f] Elevation relative to Moriarty, according to railway survey.

It has already been explained that the ground water is not stationary, but is constantly, though very slowly, moving toward the low central part of the valley. If no new supplies were received at the borders and none were removed in the center of the valley the ground water would in time find its level and come to rest. Other things being equal, the steeper the slope the more rapid is the motion of the ground water. On this basis a generous supply and vigorous underflow are indicated from the western and northwestern mountains, but a meager supply and sluggish underflow from the north end.

RELATION OF GROUND-WATER TABLE TO SUPPLY AND DISPOSAL.

It has been seen that there is an equilibrium between the supply of water from the rainfall that is annually added to the underground store and the amount annually removed from this store by evaporation and seepage. Fluctuations in the ground-water level, whereby the amount of evaporation is regulated, tend to maintain this balance through changing climatic conditions. If the rainfall should decrease and thereby diminish the annual increment to the underground store, then, by the excess of loss over gain, the ground-water level would be lowered. This in turn would decrease the flow of the springs and the evaporation from the salt basins and other shallow-water areas. Ultimately a level would be reached at which the loss would no longer be greater than the gain. A similar adjustment would take place if the rainfall remained the same while the evaporating power of the atmosphere increased. If, on the other hand, the amount of rainfall should increase or the evaporating power decrease, or, as is more probable, if both these changes should take place at the same time, then the ground-water level would rise, new springs would burst forth, the salt basins would fill and even perhaps overflow, and capillary action would become effective over a larger area, until at last loss and gain would again balance.

There are constant fluctuations in the water level as rainy and dry seasons alternate and rainy and dry years or periods of years succeed each other. In some wells fluctutations of several feet within the past few years were reported. Thus the boundaries of the areas having specified depths to water, shown in Plate XI, are not stationary, but expand after humid periods and again contract after periods of drought. In Pleistocene times, when throughout the continent the climate became notably humid, the water level in Estancia Valley rose greatly and equilibrium between increment and disposal was not established until a large lake had accumulated, exposing hundreds of square miles of water surface to continuous and unrestricted evaporation.

ARTESIAN CONDITIONS.

IN THE VALLEY FILL.

If a well is drilled to some depth below the point where water is first encountered and this shallow water is cased out, the water from greater depths generally rises in the well at least to the level of the shallow water and in many places a few feet higher, but no well was found in Estancia Valley in which the artesian pressure from the deeper horizons of the valley fill is sufficient to lift the water above the surface of the ground, although in the shallow-water belt on the west side of the valley it is possible to secure flows by drifting or tunneling. In closed basins of the type to which Estancia Valley belongs flows are frequently obtained from wells drilled in the valley fill of the low central areas. The relatively unfavorable condition in Estancia Valley in regard to flows, as also in regard to springs and seeps, suggests that there is a relative dearth of ground water. It is, however, doubtful whether such an inference is justified, since the salt basins introduce an unusual feature which may be wholly responsible for the unfavorable conditions. Moreover, the slope of the sides is not as steep as in many basins that have flowing wells.

IN THE ROCK FORMATIONS.

The sedimentary rocks on the west side of the valley dip eastward from the mountains toward the valley, and to some extent the rocks on the east side also dip toward the valley. Moreover, in some of the rock wells on the west slope the water rises under considerable pressure. In the railway wells at Mountainair, for example, water from a depth of 295 feet is reported to rise 85 feet, which brings it to about 6,277 feet above sea level and about 200 feet above the center of the valley. These conditions gave rise to a hope that artesian wells could be obtained in the valley by drilling into the rock formations.

Accordingly several test wells have been sunk. The deepest one, located 4 miles east of Estancia (SW. ¼ sec. 10, T. 6 N., R. 9 E.), in the heart of the valley, passes through more than 400 feet of red shale and sandstone, as has already been stated, and ends in "hard gray rock" at a depth of nearly 800 feet. The results have not been favorable. At several horizons the water rose slightly above the surface, but no flow of any practical consequence was obtained.

RECOVERY OF WATER.

In the foregoing pages it has been shown that the ground water constantly receives new supplies on the high land and that it migrates slowly but constantly toward the valley, where the excess is disposed of by evaporation. On its way a small amount is at present intercepted and pumped to the surface. The extent to which the water can be recovered by human agencies for human use is a matter of great practical importance. Two phases of this question will here be considered, the yield of wells and the total amount of water available.

YIELD OF WELLS IN THE VALLEY FILL.

A large amount of miscellaneous information in regard to the yield of wells was collected, but unfortunately the bulk of this information is of little value because few wells have been sunk deep enough to reach the strongest water horizons and most of the pumping tests have not exceeded a few gallons per minute. A few rather conclusive tests were reported, however, and through the generous assistance of R. B. Cochran, of Estancia, several others were made in the course of this investigation.

Throughout most of the valley there is no difficulty in procuring ample supplies for domestic purposes and for the use of stock, but there are a few localities where even this amount of water is hard to obtain. Near the north end of the valley no wells were seen, and, owing to the northern exposure of the deposits that here underlie the valley, the prospects of procuring water except at considerable depths are not encouraging. In general the yield of wells appears to be better on the west side than on the east side of the valley.

At Willard the Atchison, Topeka & Santa Fe Railway Co. drilled a number of wells. The deepest one entered red sandstone at 312 feet and was continued in this rock to 440 feet, at which depth the drilling was stopped. Within the first 312 feet numerous beds of coarse gravel supplied water freely. Fourteen 8-inch wells were sunk at intervals of about 120 feet to depths of approximately 200 feet. An air lift was applied to 12 of these wells simultaneously for 10 days and nights, practically without stopping. During this period each well yielded 110 gallons per minute, and the water level was temporarily lowered 3 feet.[1] The water is used extensively on locomotive engines and for other purposes, train loads being shipped to points more than 50 miles east. Altogether, the consumption from these wells amounts to about 350,000 gallons per day, or 400 acre-feet per year.

The irrigation well of E. A. Von de Veld, SE. ¼ sec. 21, T. 5 N., R. 8 E., is 8 feet in diameter and 35 feet deep, with water level about 23 feet below the surface. This well will furnish about 80 gallons per minute, but the yield can no doubt be much increased by sinking deeper. The well of the Willard Mercantile Co., in the village of Willard, which is 5½ feet in diameter and 48 feet deep and in which the water level is 42 feet below the surface, has been tested at 40 gallons per minute.

The open well of L. Knight, NE. ¼ sec. 1, T. 5 N., R. 8 E., is about 45 feet long and 9 feet wide, and extends to a bed of gravel that is 32 feet below the surface and 10 feet below the water level. It yields about 90 gallons per minute. Several wells have also been drilled to greater depths, and, though they have not yet been tested, the beds of water-bearing gravel that they penetrated give promise of more generous yield.

The well of R. N. Reagan, SW. ¼ sec. 2, T. 6 N., R. 8 E., is a dug hole, 6 feet by 4 feet, to a depth of 31 feet, below which it is an uncased 12-inch drilled hole that goes to 115 feet beneath the surface. The section consists chiefly of gravelly clay to a depth of 60 feet, below which "concrete" is reported. The water level is 16 feet below the surface, and downward from this level more or less seepage is received, although the strongest water horizons are reported to be at 60 feet

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[1] The data in regard to the test were given by John Knowles, who has charge of pumping tests and construction for the railway company.

and at the bottom. When completed this well was reported to have been pumped at more than 100 gallons per minute, which rate of pumping lowered the water level about 16 feet, but when tested in the summer of 1909 it yielded scarcely 40 gallons per minute with the same lowering of the water level. The well of Mr. Hawkins, sec. 14, T. 6 N., R. 8 E., is also reported to have been tested at about 100 gallons per minute.

On the premises of Mrs. Angus McGillivray, in Estancia, two test wells were put down—a 6-inch well to a depth of 37 feet and a 10-inch well to a depth of 233 feet ending in hard rock. According to the driller, the largest supply of water was found at a depth of 33 feet where the drill entered a 4-foot bed of gravel, from which the water rose to a point 5 feet below the surface. With a suction pipe extending 16 feet below the water level, the 6-inch well was successfully pumped at a rate approximating 200 gallons per minute.

In the test wells 4 miles east of Estancia the most water was found, according to J. L. Mayo, the driller, in a bed of gravel at a depth of about 215 feet, but pumping 15 gallons per minute from this source is said to have lowered the water level in the well considerably. The well of Oscar Hadley, 3 miles north and 4 miles east of Estancia, which is 94 feet deep, is reported to have been tested at about 20 gallons per minute without lowering the water perceptibly. The well of B. W. Honnold, SE. ¼ sec. 21, T. 7 N., R. 9 E., which is 140 feet deep, is reported to have been tested at 18 gallons; the 6-inch well of P. M. Rutherford, SW. ¼ sec. 27 in the same township, which is 104 feet deep, at 40 gallons; and the well of Mr. Campbell, about 5 miles northeast of Estancia, at 40 gallons. Several other tests of this kind were reported. On a number of the old ranches water has in the past been pumped from wells with steam engines.

Many wells, especially the dug wells on the alluvial slopes, end in clay from which the water seeps. Many others, in particular the cased wells in the central portion of the valley, end in fine sand, which, though yielding more freely than the clay, likewise gives up its water with difficulty and tends to fill the well whenever rapid pumping is attempted. Neither material can be relied upon to furnish water in abundance. For successful wells yielding large supplies it is in general necessary to find beds of gravel, and the coarser and cleaner the gravel the more successful will be the wells. Under "Geology," page 17, it was explained that the beds of gravel have little continuity or regularity, and that a bed encountered in one well may be entirely absent in another not far distant.

YIELD OF WELLS IN THE ROCK FORMATIONS.

Many wells, especially those near the mountains, end in rock. On the east side the water-bearing rock consists chiefly of sandstone, but on the west side limestone is more abundant. The yield of these wells is ordinarily adequate for culinary purposes and for the use of stock, but such tests as have been made do not promise large supplies. At Mountainair one 8-inch railroad well yields 18 gallons per minute, and another railroad well only 14 gallons, while the 6-inch town-site well yields 28 gallons per minute. Each of the wells is more than 300 feet deep and in each the stated rate of pumping lowers the water level approximately 100 feet. In the test wells east of Estancia little water was found after rock was encountered. At the box factory, in the north part of Estancia, a well 6 inches in diameter and 120 feet deep was pumped at the rate of 18 gallons per minute, the water being lowered about 35 feet. The well of H. C. Williams, NE. ¼ sec. 26, T. 6 N., R. 8 E., is perhaps the best rock well that was reported. Below the depth of 233 feet it is said to pass through 70 feet of soft sandstone, and pumping at the rate of 40 gallons per minute is reported to have lowered the water in the well only 12 feet. In the last two wells mentioned there is some doubt as to whether the water comes from rock strata.

AVAILABLE QUANTITY OF GROUND WATER.

The rate at which wells yield water is a question of vital importance in determining the feasibility of recovering ground water on a large scale, but, contrary to the general supposition, it gives little information as to the total quantity available. This quantity is not inexhaustible, as is so freely assumed. So far as large pumping operations, such as would be required for extensive irrigation, are concerned its limits are sharply drawn. The amount of ground water obtainable can not be determined by pumping a few hundred gallons per minute from a well for a short period, for the same reason that the quantity of water in a lake can not be determined by applying to it the same pump; and to proceed on the theory that an unlimited amount of ground water is available for irrigation is as unwise as to plan an irrigation project without reference to the flow of the stream upon which it depends. The essential difference is that the flow of the stream can be readily and accurately measured, but no such precise methods can be applied to ground water, and therefore much more caution must be used in carrying out a project that depends upon ground water.

Some idea of the total quantity of water that is stored underground can be obtained by considering the sections of wells that have been drilled. The average thickness of the water-bearing beds can be multiplied by the total area over which they occur, and this product by the percentage of pore space in the material comprising these beds. But such an estimate will give little information that is of practical value because withdrawals in excess of the new contributions will lower the water level, increase the cost of pumping, and eventually lead to disaster. Estimates of possible annual recovery by man must therefore be based on the annual increment or on the surplus annually disposed of by nature, and not on the total quantity now stored in the earth.

Unfortunately the quantity of water that is annually available in Estancia Valley can not be accurately predicted. From the discussion under the heading "Source and disposal" (p. 34), it appears that the surplus now disposed of by nature through evaporation from the salt basins and other areas of shallow water is a substantial quantity, probably amounting to many thousands of acre-feet each year. Perhaps most of this surplus could be intercepted in wells and pumped to the surface, but it can hardly be hoped that more than this surplus is annually available.

QUALITY.

SOLIDS DISSOLVED IN WATER.

The rocks which lie near the surface are exposed to weathering agencies that disintegrate and decompose them, thereby forming certain mineral compounds that are more or less soluble in water. The water which falls as rain contains little or no dissolved mineral matter, but when it enters the ground and percolates through the earth it gradually takes into solution those soluble substances with which it comes in contact, and consequently ground water always contains dissolved mineral matter. So long as this matter remains in solution it is invisible, but when the water is evaporated, as in a tea kettle or steam boiler or on the surface of the salt basins in Estancia Valley, it is left behind and forms a crust or scale. Ground waters differ greatly in the total amount of substances they contain in solution and in the proportions of the different kinds of substances. When, by evaporation of the water or some other cause, these substances are thrown out of solution, they form mineral salts, such as calcium carbonate (limestone), calcium sulphate (gypsum), sodium carbonate (black alkali), sodium sulphate (Glauber's salt), and sodium chloride (common salt).

METHODS OF INVESTIGATION.

During the progress of the field work 84 samples of water were collected and examined for their content of the carbonates, bicarbonates, sulphates, and chlorides. They were chosen from those wells or other sources which would aid most in interpreting the quality of the ground water for the entire region. They were obtained from all parts of the valley, but were taken in largest numbers in the central area, where the mineral content varies greatly within short distances and where its consideration is important in connection with irrigation.

The assays were made in the field by means of the apparatus and methods described in Water-Supply Paper No. 151. In order to have some check upon the work, and also to have a basis for judging the relative amounts of calcium, magnesium, sodium, and potassium, a single sample was sent to Prof. J. R. Bailey, of the University of Texas, for complete analysis in the laboratory. This sample was taken from the well of H. N. Summers, 6 miles east of Estancia, in the region where it was especially desirable to know the relative amounts of the bases in the deeper waters. The following table gives the complete analysis, and, for purposes of comparison, the field assay of a sample taken from the same well on the same day:

Analysis and field assay of water from well of H. N. Summers, 6 miles east of Estancia.

Ions.	Parts per million.	
	Sample assayed in the field.	Sample analyzed in the laboratory.
Total solids		1,956
Silica (SiO_2)		19
Iron (Fe)		.05
Aluminum (Al)		Trace.
Calcium (Ca)		200
Magnesium (Mg)		114
Sodium (Na)		274
Potassium (K)		3.8
Carbonate radicle (CO_3)	.0	.0
Bicarbonate radicle (HCO_3)	243	306
Sulphate radicle (SO_4)	553	755
Chlorine (Cl)	393	390
Temporary hardness as $CaCO_3$		251
Free carbon dioxide (CO_2)		8.8

The field determination agrees closely with the laboratory analysis in the content of chlorine, but there are considerable discrepancies in the bicarbonate and sulphate determinations. The bicarbonate determination is a simple volumetric process with a definite end point, and the assays probably gave results that are fairly accurate relative to each other. Despite these discrepancies, the field assays are of value, especially in throwing light on the problem of the utility of the water for irrigation, a problem in which it is desirable to have tests from as many localities as possible, but in which great precision is not required.

In the table on page 71 are given the results of the 84 field assays and also of 19 tests of water from railway wells, furnished by the Atchison, Topeka & Santa Fe Railway Co.

CHLORINE.

In general the chlorine content of these waters is proportionate to the amount of common salt that would be deposited by their evaporation. The ground waters of Estancia Valley differ widely in this respect, the samples analyzed ranging from 7 parts to 16,442 parts per million in the amount of chlorine that they contain. In the central portion of the valley, where the amount of chlorine decreases with the depth, only tests of shallow water are shown on the map, the analyses of samples from deeper cased wells not being used for this purpose.

The analyses plotted on the map show the following conditions: First, the water underlying the western slope (including nearly all of the western alluvial slope and most of the littoral zone) contains small quantities of common salt, the chlorine content being uniformly less than 25 parts per million; second, in this large area the amount of salt does not increase notably from the foothills toward the center; third, throughout an area in the center of the valley the chlorine content is very great, some of the shallow water being so salty that it can not be used for watering stock; fourth, between the first and the second areas there is a zone of fairly pure water which averages about 3 miles in width but has a tendency to extend some distance up the arroyos; and fifth, the water is somewhat higher in its content of salt on the east side of the valley than on the corresponding west slope. The transition from the fairly pure water of the intermediate zone to the strongly saline water in the central area is remarkably abrupt, so that on the west side, where there are many wells, it was possible to outline with considerable accuracy the limits of the area in which the water has more than 1,000 parts of chlorine. The abruptness of this transition is shown by assay No. 59 (J. B. Striplin) and assay No. 61 (J. W. Kooken), given in the table (p. 72). The first sample, coming from a well in the intermediate area, showed only 219 parts of chlorine; the second, taken from a well a quarter of a mile farther east, showed 5,276 parts.

In the central area the shallowest water is the most strongly saline, and the water from deeper sources is, as a rule, much better. However, no definite law of variation with depth could be established, and it is altogether probable that in some of the deeper wells a certain amount of shallow saline water is admitted by imperfect casing and mingles with the deep water that forms the principal supply. Within the area in which the shallow water contains more than 1,000 parts, 9 samples were taken from cased wells in which, as far as could be ascertained, the water came from more than 25 feet below the ground-water level. In these 9 samples the chlorine content ranged from 234 parts to 932 parts and averaged 595 parts, whereas 6 samples of shallow water within the same area ranged from 1,165 parts to 16,442 parts and averaged 7,063 parts, or more than 12 times as much as in the deeper waters. These relations are shown graphically in figure 7.

Finally, it is important to note that the deep waters in the central area are much saltier than the waters from the wells on the surrounding slopes. Thus, 34 samples were taken on the west side of the valley in the area of less than 25 parts per million, which includes nearly all of the extensive region lying west of the New Mexico Central Railroad. In these 34 widely distributed samples the chlorine content ranged from 7 to 25 parts and averaged 16 parts, a result which should be compared with the assays of the nine samples of deep waters in the central area in which the chlorine ranged from 234 to 932 parts and averaged 595 parts, or 37 times as much.

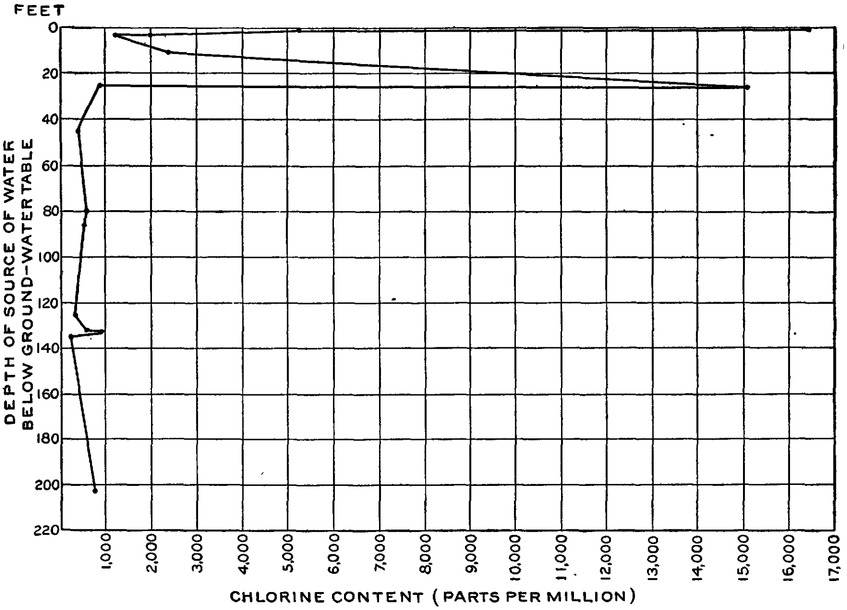

FIGURE 7.—Diagram showing decrease of chlorine with increase in depth of the waters of the central area of Estancia Valley.

CAUSE OF SALINITY.

The salinity of the water in the central area results from the process described under "Source and disposal." The ground water is constantly being replenished at the borders by rainfall; responding to the force of gravity, it constantly moves valleyward; and in the low central area the accumulating surplus is constantly coming to the surface and being disposed of by evaporation. In its migration through the earth it picks up a load of salt which it takes into solution, and when it evaporates it leaves this salt behind, thus adding to the salinity of the remaining water or to the amount of alkali in the soil.

But the precise reason for the existing conditions is not so evident. In most of the area in which the sheet of saline water occurs the ground-water level is too far below the surface for capillarity to be effective in drawing up ground water within the reach of evaporation. Thus, in the wells from which were taken the six samples that were tested, the depth to water ranges from 7 to 36 feet, while capillarity is probably not effective for depths of more than 5 feet and quite certainly not for depths of more than 10 feet. Moreover, the salts drawn up by capillary action would be deposited near the surface where evaporation would occur, and how they would be carried back to contribute to the salinity of the ground water is not obvious. It is also necessary to account for the salt content in the deeper waters at the center. The most reasonable hypothesis is that at various horizons in the valley fill of the central area there are beds impregnated with salt deposited by evaporating waters at the time they were formed, and that afterwards these beds became buried under new accumulations of valley fill. It is not unlikely that the shallow sheet of brine coincides approximately with a buried salt deposit laid down at the bottom of the ancient lake at a certain stage of its existence. This hypothesis would also explain the sharp boundary of the area.

SULPHATES.

The amount of the sulphate radicle in these waters is a measure of the sodium and calcium sulphates that they deposit on evaporation. The field apparatus can not well be used for determining less than 30 parts or more than 625 parts per million of this constituent,[1] but the waters in Estancia Valley range from less than this minimum to considerably more than this maximum. On the map (Pl. XI) the sulphate content is shown by blue figures, letters, and lines. Samples that contained less than 30 parts are represented by the letter "S," samples that contained between 100 and 625 parts are represented by the letter "M," and samples that contained more than 625 parts are represented by the letter "L." Only for those samples that come between 30 and 100 parts are the parts per million given in numbers, because it is only within this range that the field determinations have considerable accuracy. As with chlorine, the tests of samples from deeper cased wells are not plotted on the map.

With certain exceptions, the distribution of sulphates is analogous to that of chlorine, and the reasons for this distribution are no doubt in general the same. The western slope is underlain by water that has a small sulphate content, and in which there is no noticeable increase of sulphates toward the center, but the central area is

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[1] If water containing more than 625 parts is diluted with distilled water, its content of sulphate can be determined. This was done with the samples from Encino and Pinos Wells. See pp. 71 and 83.

underlain by water that is rich in sulphates, and between these two areas is a narrow intermediate zone. Then, too, the sulphate content is greater on the east side than on the corresponding west slope, and the deep water in the central area contains less sulphate than the shallow water in the same area, though much more than the water that underlies the west slope.

An important exception to the parallelism between the chloride and sulphate contents, however, is found in the southwestern part of the region, where the ground water contains a large amount of sulphates, but only small quantities of chlorides. This condition is well shown on the map (Pl. XI) by the radical divergence of the chloride and sulphate lines when they reach the south end of the valley. The large sulphate content is clearly due to the presence of gypsum in the derivative rocks, for in the escarpment of the Mesa Jumanes a bed of gypsum 100 feet thick is exposed. It will be observed that the effect of this gypsum bed does not extend far north, which is another indication that the principal ground-water supply comes from the western mountains.

CARBONATES AND BICARBONATES.

None of the samples that were tested showed an alkaline reaction with phenolphthalein, which fact shows the general absence in these waters of the carbonate radicle and hence of sodium carbonate, the injurious black alkali. This is not surprising, in view of the abundance of gypsum, which reacts with sodium carbonate and precipitates the carbonate radicle in the form of calcium carbonate. The phenolphthalein test does not prove the absence of sodium bicarbonate, but the abundance of gypsum does not favor its presence.

In the samples that were tested the bicarbonate radicle ranges from 97 to 873 parts per million, a much smaller range than that of the chloride and sulphate radicles. The chlorides and sulphates are much more readily soluble than the carbonates, which, together with the carbon dioxide present in the water, produce bicarbonates. Nevertheless, in the deposits on the west slope, except at the south end, chlorides and sulphates are so rare and carbonates (limestones and calcareous cement) so abundant that the water beneath the west slope contains much larger amounts of the bicarbonate radicle than of the chloride and sulphate radicles. But as the water percolates through the buried lake beds or other deposits in the central areas that are impregnated with salts, it redissolves large quantities of the soluble chlorides and sulphates, but only minor quantities of the carbonates, because it has already taken them up almost to the point of saturation; hence, in the central area the relative amounts of these ingredients are reversed, the total of bicarbonates being nearly the same, but the sulphates and chlorides having increased enormously.

BASES.

The principal bases, or positive radicles, are calcium, magnesium, sodium, and potassium. The relative amounts of these were not determined in the field, but the following inferences can be made. In the less highly mineralized water on the west slope, calcium and magnesium, derived from the carbonates, predominate greatly over sodium, while in the water near the south end, and to some extent also on the east side, the principal base is calcium derived from the sulphate; but in the central area large quantities of sodium chloride are taken up, thus increasing the content of sodium, so that in the strongly saline waters sodium is much more abundant than calcium or magnesium. Moreover, sodium sulphate is more soluble than calcium sulphate, which fact also tends to increase the relative amounts of sodium in the central area.

EFFECTS OF DISSOLVED SOLIDS.

Small amounts of the constituents commonly found in natural waters are not harmful to health. Chlorides are not objectionable in drinking water if only 50 to 100 parts are present, but amounts clearly preceptible to the taste render water unpalatable. Magnesic or sodic sulphated waters are laxative, and excessive magnesium or sodium content renders water unfit for man or beast. The worst form of alkali water—that containing alkaline carbonates—was not found in this region.

Calcium and magnesium render water hard and therefore poor for toilet and laundry uses. Bicarbonates and an equivalent quantity of calcium and magnesium are removed from water by boiling, but the calcium and magnesium in excess of this amount, such as would be present in gypsiferous waters, can not be precipitated by boiling. Sodium and potassium do not consume soap and therefore do not make water hard.

Calcium and magnesium compounds are the principal constituents of boiler scale. Sodium and potassium compounds do not form scale, but when they occur in large quantities they cause foaming and priming in boilers.

Water with relatively large amounts of most kinds of dissolved mineral matter is tolerated by plants. Among the common sodium salts the most injurious is sodium carbonate and the least injurious sodium sulphate; sodium chloride occupies an intermediate position. The effect of dissolved solids in irrigation water is more fully discussed under the next heading—"Irrigation."

IRRIGATION.

Much of the water that falls as rain or snow is lost or is of very small service in producing vegetation useful to man. If only a small part of this water that is now lost can be recovered and applied to growing crops it will greatly increase the agricultural product of the valley. Recovery is possible by storing storm water and by recovering ground water.

STORAGE OF STORM WATER.

The floods that from time to time come down the large arroyos and spread out over their extensive flat bottoms provide a sort of natural irrigation which makes these arroyos the most fertile and productive portions of the valley, and for this reason they bear such appropriate names as Arroyo Mesteño (Ranchers' Draw) and Arroyo Fecundo (Fertile Draw). The utility of this flood water could be increased if it were stored in reservoirs and applied in an economical manner at the time it is most needed. Only small beginnings in this direction have thus far been made, and without doubt further development would be found profitable, although there are handicaps in the scarcity of good reservoir sites and in the capricious nature of the floods.

UTILIZATION OF GROUND WATER.

PRESENT DEVELOPMENT.

At the time the valley was visited, in the summer of 1909, little had been accomplished in the way of irrigating with ground water, although a number of gardens and other small plats were being irrigated from this source by means of windmills, and somewhat more ambitious projects were being undertaken by S. Spore, L. Knight, E. A. Von de Veld, and H. C. Williams.

The plant of S. Spore is located 3 miles east of Estancia, on sec. 9, T. 6 N., R. 9 E. The water is provided by a large hole dug 23 feet below the surface, or about 15 feet below the water level, and one or more deeper drilled wells which discharge into the bottom of the dug hole. It is lifted by a chain and bucket elevator whose capacity is rated at 800 gallons per minute, the power being furnished by an 8-horsepower gasoline engine. The plant was not seen in operation. It was reported that considerable water had been developed, but that it is saline in character.

The plant of L. Knight is located 4 miles south of Estancia, on the NE. ¼ sec. 1, T. 5 N., R. 8 E. A hole, about 45 by 9 feet in size, has been dug 32 feet below the surface, or about 10 feet below the water level, and several deeper wells have been drilled. The yield of the dug well is about 90 gallons per minute; the drilled wells had not been tested. The water is lifted from the dug hole into an earth reservoir by means of a chain and bucket elevator propelled by a gasoline engine. The capacity of the elevator is rated at 250 gallons per minute and the engine at 4½ horsepower.

The plant of E. A. Von de Veld is located 7 miles northwest of Willard, in the SE. ¼ sec. 21, T. 5 N., R. 8 E. The water is obtained from a well 8 feet in diameter and 35 feet deep, which extends about 12 feet below the water level, and will yield about 80 gallons per minute. The water is lifted by a chain and bucket elevator propelled by a gasoline engine. The capacity of the elevator is rated at 160 gallons per minute.

The farm of H. C. Williams, 2½ miles south of Estancia, is in the shallow-water belt, and a ditch has here been dug for the purpose of leading the ground water out upon lower land by gravity. In the deep well the water rises to within 3½ feet of the surface. No pumping plant has been installed.

POSSIBILITIES OF FUTURE DEVELOPMENT.

The data already given seem to indicate that without seriously depleting the present supply, enough water can be withdrawn annually from the underground reservoir to increase materially the total production of the valley, but that, on the other hand the supply is not sufficient to irrigate more than a small part of the total acreage of arable land. If it is once proved that pumping for irrigation is feasible and profitable, the danger of overdevelopment will become imminent.

PROPER TYPE OF IRRIGATION SYSTEMS.

Irrigation with surface water has necessitated large cooperative projects, but the problem of irrigating with ground water, even on a large scale, is essentially different. In Estancia Valley each farmer should develop his own supply, install his own pumping plant, and construct his own reservoirs and system of distribution. This method of development will insure a maximum supply with a minimum lowering of the head, and will involve the least lift and the least loss in distribution. The only respect in which cooperation may be found profitable will be in the installation of a central power plant.

PROPER TYPES OF WELLS.

Where large supplies are required, as for irrigation, they can best be obtained by drilling in search of thick beds of clean, coarse gravel that will yield freely, sinking, if necessary, at least to the bottom of the valley fill. There are three reasons why deep-drilled wells are likely to yield much more water than shallow wells that stop a short distance below the ground-water level—first, the thickest and best beds of gravel may occur at any depth and the probabilities are, therefore, that they will not be found by shallow wells; second, of two similar beds the one at a considerable depth below the ground-water level will yield much more than the one only slightly below this level, because the water in the deeper bed is under much greater artesian pressure; third, if a deep well is properly finished with perforated casing, it can simultaneously receive supplies from all water-bearing beds that it penetrates.

If a single well will not yield enough, a group of wells can be drilled. A large pump can then be inserted at the bottom of a centrally located pit dug to the ground-water level or somewhat lower, and suction pipes from all the wells can be connected with it; or, if it is desired to use a chain-and-bucket elevator, the central pit can be sunk to a considerable depth below the ground-water level and the drilled wells can be connected by horizontal tunnels or pipes with the bottom of the pit, into which they will then discharge. Since the cost of pumping increases with the lift, it will be economy to have so many wells that the water in them will not be greatly lowered by pumping. In either system above described some expense will be involved in connecting the various wells.

For large supplies, beds of very fine sand should be cased out, because this sand yields its water slowly and causes trouble by rising in the wells. Screens can be employed to shut out the sand more or less effectually, but they are likely to become clogged in a short time and to require much attention. Difficulty with sand in wells can be reduced to a minimum by pumping slowly or by having a large number of wells so connected that water is drawn only at a slow rate from each.

Where no satisfactory water-bearing bed can be found and where the shallow water is not saline, it may be possible to develop valuable supplies from large dug wells or from systems of infiltration galleries, or it may be feasible to bring up the total yield by combining these with deep wells. If possible the maximum yield of the system of wells should be kept much greater than the capacity of the pumps, as this will reduce to a minimum the cost of lifting the water, the wear and tear of the machinery, and in some cases the deterioration of the wells.

GRAVITY INFILTRATION DITCHES.

The fact that it is possible to lead water by gravity from the shallow-water belt on the west side out upon lower ground to the east makes this scheme for irrigating appear very attractive, but it is not believed that enough water can be recovered in this way to justify the necessary expense of construction. The same money will be better invested in wells and a pumping plant with which a larger, more reliable, and more elastic supply can be obtained. Prof. Slichter discusses ditches of this type and makes the following concluding statements:[1]

> It should be noted that very few infiltration or underflow canals are in actual use for irrigation purposes. There are many pumping plants in use for irrigation which have turned out to be both practicable and financially profitable; but the attempts to secure ground water by gravity have usually proved disappointing, and there are numerous abandoned underflow canals in many parts of the West.

COST OF PUMPING.

In estimating the cost of the water it is necessary to take into account the original cost of the wells, pumps, engines, reservoirs, ditches, and other equipment, and the cost of operation, which includes fuel, oil, repairs, labor, and other items. In considering the original cost as a factor in the cost of a unit quantity of water, it is most convenient to estimate the amount of deterioration of the plant in one year and to add this to the annual interest on the total amount invested in the plant. The sum should then be divided by the number of units of water pumped in a year. Prof. Slichter advises that the charge for depreciation and repairs should not be estimated at less than 10 per cent of the first cost of the plant.

The following tables give the results of a number of tests of small pumping plants in Arkansas Valley, Kans.,[2] and in the Rio Grande valley, N. Mex.[3]

Tests of small pumping plants, Arkansas Valley, Kans.

Kind of pump.	Horse-power of engine.	Fuel used.	Price of fuel per gallon.	Total lift.	Yield of well per minute.	Cost of fuel per acre-foot[4] of water.	Cost of fuel for each foot that an acre-foot is lifted.
				Feet.	*Gallons.*		
No. 3 centrifugal	6	Gasoline	$0.22	22.1	272	$2.93	$0.13
Menge	10	...do	.20	15.5	394	2.90	.19
Two vertical, 6 by 16 inch cylinder.	1½	...do	.22	15.06	91	3.75	.25
Chain and bucket	7	...do	.21	17.0	540	1.37	.08
Do	2½	...do	.22	15.8	215	2.78	.18
No. 4 centrifugal	10	...do	.12¼	22.13	363	2.10	.09
No. 3 centrifugal	6	...do	.12½	17.60	198	1.67	.09
No. 14 centrifugal	80	Coal	[5] 4.00	23.00	2,300	.85	.04
Two horizontal, 5 by 5 inch cylinders.	3½	Gasoline	.12½	21.7	96	1.09	.05
No. 4 centrifugal	5	...do	.12½	21.47	420	1.20	.06

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[1] Water-Supply Paper U. S. Geol. Survey No. 184, 1906, p. 22.

[2] Slichter, C. S., The underflow in Arkansas Valley in Western Kansas: Water-Supply Paper U. S. Geol. Survey No. 153, 1906, pp. 55 and 56.

[3] Slichter C. S., Observations on the ground waters of Rio Grande Valley: Water-Supply Paper U. S. Geol. Survey No. 141, 1905 pp. 34 and 35.

[4] An acre-foot contains 325,850 gallons of water, which is enough to cover 1 acre to the depth of 1 foot.

[5] Price per ton.

Principal data derived from tests of Rio Grande pumping plants.

Horse-power.	Fuel used.	Price of fuel.[a]	Total lift.	Yield per minute.	Cost of plant.	Interest and depreciation per hour.[b]	Labor and other cost per hour.	Fuel cost per acre-foot.	Total cost per acre-foot.
			Feet.	*Gallons.*					
10	Electricity	$0.05	38.93	378	$1,200	$0.108	$0.050	$3.43	$5.75
8	Gasoline	.14	30.70	269	800	.072	.120	2.26	6.13
5½	.....do	.14	27.80	258	800	.072	.140	1.58	6.02
28	Crude oil	.03	36.70	938	3,000	.270	.180	.70	3.17
22	Gasoline	.14	41.45	1,325	2,200	.198	.150	1.43	2.79
15	.....do	.14	35.87	658	1,500	.135	.150	1.73	4.10
5	.....do	.17	45.58	131	1,200	.108	.120	3.73	13.20
12	.....do	.17	40.30	658	1,200	.108	.150	1.34	3.47
21	.....do	.17	40.45	725	1,800	.162	.150	2.52	4.87
8	.....do	.17	26.85	648	900	.081	.120	1.48	3.16
12	.....do	.17	34.77	325	1,200	.108	.150	5.14	9.57
8	.....do	.17	36.05	271	800	.072	.120	5.10	8.95
10	Wood	2.00	34.16	351	1,200	.108	.180	3.47	7.91
28	Gasoline	.17	43.35	464	2,000	.180	.150	4.34	8.19
20	Wood	2.25	29.55	1,000	1,600	.144	.200	2.83	4.70
12	Gasoline	.17	23.89	837	992	.090	.090	1.04	2.21
12	.....do	.17	35.26	191	992	.090	.090	5.80	10.90
12	.....do	.17	32.36	750	992	.090	.090	1.16	2.46

[a] The price of gasoline given is for 1 gallon, the price of electricity for 1 kilowatt-hour, the price of wood for 1 cord.

[b] The depreciation and repairs are calculated at 10 per cent of the original cost and the interest at 8 per cent.

As nearly as can be estimated from rather indefinite data obtained in regard to the plant of E. A. Von de Veld, northwest of Willard, the cost for fuel is about $3.50 per acre-foot. The water is here lifted with a 160-gallon chain and bucket elevator, the average lift being about 30 feet, and the price paid for the gasoline was reported to be 31 cents per gallon. According to these data, for each foot that an acre-foot of water is lifted the cost is about 11⅔ cents and the consumption of gasoline about 0.38 gallon. With the present capacity of the well, one-fifth of an acre-foot can be drawn conveniently in one full day; and on this basis if the plant is operated 100 days it will consume $65 worth of gasoline and provide enough water to cover 20 acres to a depth of 1 foot or 10 acres to a depth of 2 feet. With gasoline bought at minimum wholesale prices and with more careful adjustments between the capacities of engine, pump, and well, the cost for fuel can be reduced materially, but the above figures are believed to be valuable in giving an idea of what has been done in practical work.

In a discussion of the cost of pumping in Arkansas Valley, Kans., the following statement is made by Prof. Slichter in regard to gas-producer plants:

> If plants of from 20 to 50 horsepower are constructed, as I believe will inevitably be the case in the near future, the cheapest power will probably be found in the use of coal in small gas-producer plants in connection with gas engines. These small gas-producer plants are largely automatic in action and can be operated by anyone. With hard coal or coke or charcoal at $8 per ton, the cost of power would be less than one-half cent per horsepower for one hour, or only one-fifth of the cost of power from gasoline at 22 cents a gallon. The writer anticipates no difficulty, therefore, in

keeping the cost of water below 60 to 75 cents an acre-foot for fuel, or below $1.25 to $1.50 per acre-foot for total expense.[1] Hundreds of such plants have been put in use in England during the past ten or more years, and they are in charge of unskilled labor. These gas-producer plants are used in England for a great variety of purposes, such as power for agricultural machinery and for small electric-light plants for country estates, etc. They are used in as small units as 5 horsepower.

In this country the producer-gas plants have been in use for several years, and at the present moment they are fast taking the place of steam power in new plants. The cost of a producer plant and gas engine is about the same as the cost of a steam engine and boiler of same size when everything is included, but the cost of power from the producer-gas plant is very much less than that obtained from small steam engines.

In producer plants ranging upward from 100 horsepower, a style of plant may be installed in which soft coal or lignite may be successfully used. This still further cuts down the cost of power. In fact, large plants of this type furnish the cheapest artificial power that has yet been devised. The saving is not only in fuel, but also in labor, as one man is capable of running a 300-horsepower plant.

In Estancia Valley gas-producer plants should be installed only after sufficiently large supplies of water have been developed to insure their success. A central power plant which will furnish an electric current for operating pumps on a number of farms may prove the most economical method of lifting water.

WINDMILLS.

Much has been written on irrigation with windmills. Their obvious advantage is that they utilize energy supplied by nature free of charge, but their original cost and the cost for oil and repairs are by no means negligible. Their greatest disadvantage lies in their dependence upon the wind, which may not blow at the time the water is most needed. They are best adapted to those parts of the valley where great depth to water or small yield permit of irrigation on only a small scale.

The following data, taken from the Yearbook of the Department of Agriculture for 1907, will give some conception of what can be done with windmills. If the lift is increased or decreased, the amount of water that can be pumped will be decreased or increased in about the same ratio.

Work done by a 12-foot windmill.

Velocity of wind in miles per hour.	Height water was lifted.	Quantity of water pumped per hour.
	Feet.	*Gallons.*
6	56	89.76
8	56	269.28
10	56	501.16
12	56	718.08
17	56	1,271.60
18	56	1,353.88

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[1] It should be remembered that this statement is made for the Arkansas Valley, where the water is near the surface.

Work done by windmills of different sizes.

Size and type of windmill.	Time.	Average wind velocity per hour.	Height water was lifted.	Quantity of water pumped.	
	Days.	*Miles.*	*Feet.*	*Gallons.*	*Acre-feet.*
16-foot, direct stroke	45¼	12.98	56	752,967	2.31
14-foot, back geared	45¼	12.98	56	666,991	2.05
13-foot, back geared	45¼	12.98	56	502,207	1.54
12-foot, back geared	45¼	12.98	56	408,854	1.25

Under "Climate" is given a table that contains data in regard to the average wind velocity of the region. It should be understood, however, that the efficiency of an average velocity is considerably different from that of a uniform velocity, because of the low efficiency both of very gentle and of very strong winds.

STORAGE AND DISTRIBUTION.

Large reservoirs are not feasible, and where the water is pumped at the cost of fuel they may not be desirable, because they involve loss both by evaporation and by seepage. Small reservoirs, on the other hand, are generally useful, especially for pumping plants of small capacity, because they diminish the labor necessary in applying the water to crops and also lessen the loss of water in the distributing ditches. Where windmills are used it is advantageous to have relatively large storage facilities.

Reservoirs made by banking up earth are least expensive, and they can usually be rendered nearly water-tight if they are puddled by driving cattle or sheep about in them. Obviously it will not do to store costly water in a leaky reservoir, and possible loss through leakage must be carefully guarded against.

The following information and advice in regard to the construction of small earth reservoirs is given in a recent bulletin by P. E. Fuller:[1]

> A means of storing water * * * should be resorted to in every instance where the flow is less than 600 gallons per minute. The reason for recommending a reservoir for flows up to this amount is that, with small streams used direct from the pumps, the loss in conveyance in ditches is excessive and the loss in the application of the water to the land is large, since a small stream will saturate a spot and a large amount of water will sink into the soil in this one place instead of spreading over a large area and moistening the surface. Further, much more labor is required to irrigate with a small stream than with a large one. * * * The reservoir should be of sufficient size to hold the water pumped between irrigations.
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> The following table gives the dimensions of circular reservoirs of different capacities; the quantities of earth in the embankments, if these have inside slopes of 3 to 1 and outside slopes of 1 to 1; the areas which can be irrigated, provided the reservoir

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[1] Fuller, P. E., The Use of Windmills in Irrigation in the Semiarid West: Farmers' Bull., U. S. Dept. Agr., No. 394, 1910, pp. 28 to 33.

full of water is used once in ten days throughout five months and the land receives water to a depth of 1 foot; and the costs of the reservoirs:

Sizes of circular reservoirs and estimated cost for various areas of land to be irrigated.

Gross capacity of reservoir.	Depth of reservoir	Diameter at bottom of embankment.	Diameter at top of embankment.	Bottom width of embankment.	Top width of embankment.	Amount of fill required.	Estimated cost of reservoir.	Area irrigated.
Acre-feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Cu. yds.*		*Acres.*
0.07	4	21.30	45.30	19	3	212.00	$21.20	1
.16	4	34.96	58.96	19	3	281.52	28.15	2
.24	4	45.62	69.62	19	3	336.25	33.62	3
.32	4	54.61	78.61	19	3	381.88	38.18	4
.40	4	62.27	86.27	19	3	422.46	42.24	5
.49	5	58.58	88.58	24	4	684.71	68.47	6
.56	5	63.64	93.64	24	4	725.80	72.58	7
.63	5	69.00	99.00	24	4	747.75	74.77	8
.72	5	74.37	104.37	24	4	813.51	81.35	9
.80	5	79.36	109.36	24	4	854.16	85.41	10

If possible a site should be chosen where the natural surface of the ground which will become the bottom of the reservoir is above the land to be irrigated, and if the highest land to be irrigated is some distance from the reservoir the bottom should be enough higher than the land to give a slope of at least 6 feet to the mile from the reservoir to the land.

All sod and vegetation should be removed from the site, as the decay of the roots will leave passage for seepage. In a circle midway between the outside and inside bank line plow a trench 2 feet wide and 1 foot deep, removing this dirt to the outside of the bank; fill in this trench with clay, or with a clay and gravel mixture. After a part of the trench has been so filled add water, and thoroughly puddle so as to form a bond between the original walls of the trench and the material added; haul in additional clay material to this section of the trench until it projects above the original ground surface at least a foot and is yet a soft mass; then proceed to build the banks, puddling and tamping the new fill so as to thoroughly bind with the core of clay material. Proceed with the embankment until the first course to a depth of 6 inches has been completed around the entire inclosure, then add a second course of the same thickness around the entire wall, allowing the teams to walk upon the top of the banks a distance of at least 20 feet each time a scraper is dumped, for in this way each course is well tamped as the work progresses. It would be far better if each course could be thoroughly wet down so as to puddle it or better to tamp the embankment; and even better results would be obtained if the clay core could be carried up with the work to the top of the bank, though this is not an easy matter and is not imperative if the material used in constructing the banks is of a clayey nature. It is well to allow the banks to settle under several rains or snows before the reservoir is filled.

The inside slope of the bank should be very gradual, so as to avoid erosion and cutting. The width of the top of the bank should be not less than 3 feet for a reservoir 4 feet deep, and 4 feet for one 5 feet deep. The slope of the outside of the embankment may be steeper, 1 to 1 if planted to grass, so as to avoid washing or cutting from rains.

Haul into the bottom a lining of clay or clay mixture several inches in excess of the depth of soil removed, and after distributing it evenly pump into the reservoir sufficient water to form a thick muck or paste and thoroughly puddle by keeping cattle or sheep in the reservoir for at least a week, and better for thirty days. Indeed, the entire success of the reservoir is dependent upon such puddling, and there can be no reason why, by placing a temporary fence around the inclosure, the cattle or sheep can not be fed and watered while so penned up for thirty days. It will of course be necessary to allow water to run into the reservoir in small quantities during the operation of puddling, so as to maintain a soft puddle. After the work of puddling is completed the banks may be trimmed to line by shovel.

The inlet and outlet pipe should be put in place while the banks are being constructed, for in this manner a water-tight joint between the pipe and banks can be secured.

The loss from evaporation in the reservoir can be reduced effectually by the planting of bush willows or some similar low-bush tree profusely around the top of the banks, thereby breaking the wind. The cutting of banks from wave motion can be eliminated entirely in an earthen reservoir by floating a boom of old railroad ties or other timbers around the inner banks facing the direction of the prevailing wind, or, if desirable, around the entire reservoir. The ties should be held together at the ends by cleats securely nailed and the entire boom should be anchored in a line 3 feet from the banks.

VALUE OF CROPS.

Intensive cultivation of crops that yield large returns per acre would, of course, leave the largest margin after the cost of the water is deducted and would thus guarantee the surest success for irrigation by pumping, but present calculations must be based on such ordinary field crops as can be depended upon in respect both to yield and market value. It is not intended here to enter into a full discussion of the various crops that might be raised, but rather to state a few facts which will give some quantitative basis for comparing crop returns with cost of water.

In regard to alfalfa, Samuel Fortier, chief of irrigation investigations in the Department of Agriculture, states:[1]

> Perhaps the most essential conditions for the production of alfalfa are abundant sunshine, a high summer temperature, sufficient moisture, and a rich, deep, well-drained soil. All of these essentials, save moisture, exist naturally in the arid region of the United States, and when water is supplied it makes the conditions ideal. * * * It is grown successfully in every State and Territory of the arid region, in localities which are not only widely separated but possess many radical differences in the way of rainfall, temperature, altitude, topography, and soil.

Mr. Fortier cites an experiment in Montana in which with 1 foot of irrigation water 4.42 tons of cured alfalfa per acre were produced, and with 2 feet, 6.35 tons, and adds:

> The results of this experiment seem to confirm the best practice of southern California, which may be summed up by stating that in localities having an annual rainfall of about 12 inches, remarkably heavy yields of alfalfa may be obtained from the use of 24 to 30 inches of irrigation water, providing it is properly applied.

C. A. Fisher[2] states that in the vicinity of Roswell, N. Mex., if 30 inches per year are properly applied, three or four crops of alfalfa may be cut, an average yield being 1 ton to the acre for each cutting. V. L. Sullivan, territorial engineer of New Mexico, estimates[3] that

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[1] Irrigation of Alfalfa: Farmers' Bulletin No. 373, U. S. Dept. Agr., 1909.

[2] Geology and underground waters of the Roswell Artesian Area, New Mexico: Water-Supply Paper No. 158, U. S. Geol. Survey, 1906, p. 28.

[3] Irrigation in New Mexico: U. S. Dept. of Agr., Bull. No. 215, 1909, p. 17.

"the yield of hay (alfalfa) in this part of the United States is 2 to 7 tons an acre when grown under irrigation; an average of 5 tons is a conservative estimate, usually producing a net return of $10 per ton." Alfalfa seed is a valuable though rather uncertain crop, but it requires little water and could perhaps be raised to advantage after one crop of hay had been harvested.

Good crops of wheat, oats, and other cereals could no doubt be raised by irrigation, but a given amount of water would probably accomplish more if applied to beans, potatoes, or forage plants such as cane, millet, and kaffir corn. Beets and other vegetables are said to thrive well when moisture is applied, and some kinds of fruit could be raised. Melons have been grown with good results.

BEST USE OF THE WATER.

The most hopeful view of the future of irrigation in Estancia Valley can not alter the conclusion that this valley must remain largely a grazing or dry farming region. Grazing yields very small returns per acre; dry farming may, if the elements happen to be propitious, yield vastly more. But the elements are capricious, and the farmer who must depend upon them entirely will of necessity have a precarious lot. The available water will, of course, be utilized in various ways, but it would seem that in the main it will be put to its best use when it is employed to supplement dry farming and stock raising.

In the first place, every farmer should irrigate a few shade trees, a small orchard, a small grass lawn, and a garden containing vegetables, shrubs, and flowers. These things will contribute much to the comfort of farm life, and, moreover, the garden will be of substantial value in supplying food for the household and in making it possible to tide over dry years. One of the very few examples of such irrigation at present found in the wide expanse of the valley is at the old Moriarty ranch. A small supply of water will prove sufficient; indeed, there are few localities in the valley where enough water can not be obtained or where it is so deep that the farmer can not afford to pump it for this purpose. For this kind of irrigation windmills will be useful, but it will be well to supplement them by small gasoline engines, so that the supply will not fail at the time it is most needed.

Where plentiful supplies of water are available within a comparatively short distance of the surface, it is believed that it can be made profitable to install a larger plant and to irrigate a number of additional acres, on which alfalfa or forage can be raised. These crops will have a high value if fed to the stock on the farm in the winter or in times of extreme drought, when otherwise the stock would suffer severely. A portion of the water may be used to raise for the market some more intensive crop, such as beans or potatoes, the proceeds of which will help to tide over years of failure in dry farming.

It may be that the ground water can be used to some extent to supplement dry farming directly. The damage to crops is due perhaps less to the absolute deficiency of rainfall than to its irregularity and uncertainty. Enough rain may fall throughout the growing season to produce a fair yield except in one period of drought. If during this period the ground could be given one good wetting the success of the crop would be assured, but the wetting does not come and the farmer is helpless to prevent the failure of his crop. Irrigation water at this critical time would have a value out of all proportion to that of its ordinary crop-producing power. It is evident that a relatively small amount of water, considered for the entire year, would cover a large acreage; and the farmer who has gone through the hard experience of seeing his entire crop ruined will readily appreciate that if, by means of the artificial application of water, even a small portion of his crop can be saved, it will be infinitely better than failure.

If the reader will turn to the records of precipitation given under "Climate" (p. 31) he can pick out for himself the months when artificial watering was necessary. Brief as the records are, they show that the crop-ruining months are sufficiently numerous to do heavy damage. They also show that while deficiency of rainfall is most common in the spring, when the crops ought to be started, it may strike any part of the growing season.

There will, of course, be difficulties in developing a feasible method of combining irrigation and dry farming, but there appears to be no inherent reason why such a combination method can not be evolved.

The limits to the area in which the larger use of water is practicable and the limits to the amount of irrigation that is possible in any given locality within this area must be determined gradually by experience. The situation tends strongly toward an economical use of the water, and economy will tend in two ways to enlarge the scope of irrigation. It will reduce to a minimum both the expense of pumping and the waste of the limited underground supply. The first concerns the immediate welfare of the individual; the second concerns the permanent welfare of the entire community. To a certain extent individual self-interest will here abet the public welfare, for the pumps will not be operated except when necessary.

THE ALKALI PROBLEM.

The answer to the question whether water of a certain quality can be successfully used for irrigation depends largely on a number of related conditions, among which may be mentioned the kind of crops to be raised, the amount of alkali already in the soil, the natural drainage of the land or the ease with which artificial drainage could be established, and the cost and abundance of the water itself. If all of these conditions are favorable, water containing large amounts of sodium sulphate and sodium chloride can be used with success, but if all or most of them are unfavorable the case is entirely different.

During the summer of 1902, T. H. Means, of the Bureau of Soils, visited certain oases in Sahara Desert, in eastern Algeria, in which water carrying large quantities of soluble matter is used for irrigation with good results. Some of the vegetables successfully grown are those considered sensitive to alkali, and yet they were being irrigated with water containing, in some instances, as much as 8,000 parts per million of soluble salts, sometimes as much as one-half of these salts being sodium chloride. The methods used are described as follows:[1]

> The Arab gardens are divided into small plats, about 20 feet square, between which run drainage ditches dug to a depth of about 3 feet. The soils being very light and sandy, this ditching at short intervals insures the most rapid and thorough drainage. Irrigation is by the check method, and application is made at least once a week, though often two wettings a week are deemed necessary. A large quantity of water is used at each irrigation. Thus a continuous movement of the water downward is maintained, there is little opportunity for the soil water to become more concentrated than the water as applied, and the intervals between irrigations being so short but little accumulation of salt from evaporation at the surface takes place. What concentration or accumulation does occur is quickly corrected by the succeeding irrigation.

It is essential to note that the successful use of this water depends entirely upon good drainage conditions and the application of large amounts of water. In the same paper, Means says:

> The limit for concentration for irrigation water in the United States, even where only the most resistant crops are to be grown, has been placed by some authorities at 300 parts sodium chloride (common salt) or sodium carbonate (black alkali) and at from 1,700 to 3,000 parts of the less harmful salts, per million of water.[2] Those who place the low limit of safety for alkaline irrigation waters have taught that where water was badly alkaline irrigation should be sparing. They have not insisted on thorough drainage, and they have warned irrigators against too frequent irrigation. With such practices the limit of concentration which they set is probably high enough, and even then all except the most sandy soils or those with exceptionally good natural drainage would ultimately be damaged.

In regard to the same subject, C. W. Dorsey says:[3]

> When the soil contains a relatively large amount of salt and but little water containing much salt is frequently applied, the ordinary evaporation will increase the salt content of the soil to such an extent that crops can no longer survive, whereas if adequate drainage is provided and a large amount of water is used the excess of salt resulting from the evaporation of previous applications of water may be removed and the soil moisture be maintained at nearly the same concentration as the water supply.

The data given under "Soil" and "Quality of water" furnish a basis for a rather definite conclusion in regard to the feasibility of irrigating in the alkali area of Estancia Valley. The samples of soil

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[1] Means, T. H., The use of alkaline and saline waters for irrigation: Bureau of Soils, Circular No. 10, U. S. Dept. Agr.

[2] In the original paper the quantities are expressed in parts per 100,000 of water.

[3] Reclamation of alkali soils: Bull. Bureau of Soils, No. 34, U. S. Dept. Agr., 1906, p. 11.

that were analyzed have a high alkali content, and the water in the same region is rich in dissolved chlorides and sulphates. Within the area of saline shallow water (that is, the area in which the shallow ground water has a chlorine content of more than 1,000 parts per million) nine samples of deeper water were tested, and the average chlorine content of these samples was found to be 595 parts per million. On the assumption that all the chlorine is in equilibrium with sodium, the average content of common salt would be 982 parts per million, or more than 2,500 pounds per acre-foot. By the time 10 feet of water would have been applied to a field, 25,000 pounds of common salt would have been placed on each acre irrigated, a quantity equivalent to 0.625 of 1 per cent of the soil if concentrated in the first foot, or 0.156 of 1 per cent if distributed through the upper 4 feet.

If good drainage conditions could be established and water applied unsparingly, then, by the use of the deeper water, the alkali now in the soil and that introduced by the water could be disposed of by leaching it downward and draining it away. Unfortunately, the natural drainage is poor and the expense of establishing artificial drainage would be great. Unfortunately, too, the liberal use of water would be prevented by the limitations of the supply and the cost of pumping. In view of these facts it seems that the general conclusion can not be avoided that in the most alkaline portion of the central flat irrigation by pumping from wells is not feasible, and it becomes necessary to advise against expenditures for pumping plants within this area. A caution should also be given for a wider region having poor drainage, water of intermediate chlorine content, or soil that shows alkali symptoms, lest in the course of time the sparing application of water pumped from wells will result in an injurious accumulation of alkali.

SUMMARY.

The conclusions in regard to irrigation with ground water can be briefly summarized as follows:

In spite of the high cost of fuel, if the water is lifted in the most economical manner and is wisely used, pumping for irrigation can under favorable conditions be made profitable. The underground supply is not large enough to irrigate more than a small part of the total arable area, but it is sufficient to add greatly to the agricultural product of the valley. Even where the depth to water is great the irrigation of a garden, lawn, and orchard will generally be feasible. In the central area, however, the presence of alkali may seriously impair the quality of the water or may prohibit its use. Taken as a whole, the water of Estancia Valley is a valuable resource that should be developed, but its development should be conducted carefully and with full cognizance of the inherent limitations.

TABLES.

The following table shows the depths to water by townships:

Table of depths to water in Estancia Valley.

No.	Quarter of section.	Section.	Township north.	Range east.	Situation of well.	Depth to water.
						Feet.
1		9	2	11		*a* 130
2		15	2	11		*a* 45
3		22	2	12		*a* 215
4	SW.	27	2	12	In Cedarvale	*a* 174
5	NW.	31	2	12		*a* 206
6	NE.	11	3	9	Approximately located	*a* 80
7	SW.	15	3	10	Progresso station	35
8	NW.	23	3	10		25
9	NE.	1	4	6		*a* 45
10	NW.	5	4	7	In the arroyo	16
11	NW.	8	4	7		*a* 50
12	SW.	8	4	7		*a* 55
13	NE.	11	4	7		110
14	SW.	34	4	7	Relatively low ground	165
15	SW.	14	4	8		90
16		16	4	8	Approximately located	68
17	NE.	23	4	8		93
18	NE.	24	4	8		63
19	SE.	24	4	8		66
20	NE.	26	4	8		105
21	SW.	3	4	9		21
22	SE.	6	4	9		40
23	NE.	7	4	9		42
24	NW.	8	4	9		35
25	NE.	8	4	9	Northwest corner	35
26	NE.	9	4	9	.....do	25
27	NW.	11	4	9		8
28	NW.	31	4	9		*a* 85
29	SW.	3	4	10	North margin	30
30	NE.	9	4	10	Southeast corner	43
31		3	5	6	In the arroyo	*a* 80
32	NE.	25	5	6		98
33	SE.	25	5	6		46
34		5	5	7		*a* 158
35	NE.	13	5	7		51
36	SE.	17	5	7		*a* 93
37	NW.	21	5	7		*a* 80
38	NW.	24	5	7		47
39		25	5	7	West margin	13
40	SW.	28	5	7	In the arroyo	*a* 26
41	SW.	28	5	7		28
42	SW.	28	5	7		38
43		30	5	7	East margin	42
44	SW.	31	5	7		40
45	NW.	33	5	7		*a* 28
46	SW.	33	5	7	In the arroyo	*a* 80
47	NE.	1	5	8		22
48	NE.	2	5	8		4
49	SW.	5	5	8		47
50	SW.	6	5	8	Northwest corner	82
51	SE.	8	5	8		50
52	SW.	8	5	8	Northwest corner	47
53		9	5	8	North margin	*a* 36
54	SE.	9	5	8	On the hill	50
55	NE.	10	5	8		5
56	NW.	11	5	8		*a* 3
57	SW.	13	5	8	Southeast corner	32
58	SW.	13	5	8		21
59	SW.	14	5	8		14
60	SE.	15	5	8		15
61	SW.	15	5	8		18
62	NW.	18	5	8	Southwest corner	35
63	SE.	21	5	8		23
64	NE.	24	5	8		30
65	SE.	25	5	8		30
66	SE.	31	5	8		76
67	SW.	33	5	8		*a* 110
68	NE.	35	5	8		31
69	NW.	5	5	9		20
70	NE.	18	5	9		24
71	NW.	19	5	9		26

a Depth not measured, but given on the authority of owner, driller, or other responsible person.

Table of depths to water in Estancia Valley—Continued.

No.	Quarter of section.	Section.	Township north.	Range east.	Situation of well.	Depth to water.
						Feet.
72	SE.	10	5	10		20
73	NE.	13	5	10		[a] 66
74	SE.	13	5	10		[a] 95
75	SW.	4	5	11		56
76	SE.	6	5	11		39
77		8	5	11	West margin	40
78		8	5	11	North margin	40
79	SE.	1	6	7		140
80		5	6	7		[a] 110
81	NE.	14	6	7		170
82	SE.	14	6	7		[a] 165
83		17	6	7	East margin, in the arroyo	90
84	SE.	23	6	7	In the arroyo	75
85	SW.	34	6	7	do	[a] 100
86	SW.	35	6	7	do	[a] 90
87	SW.	36	6	7	On the upland	102
88	NW.	1	6	8		[a] 26
89	NE.	2	6	8		[a] 18
90	SW.	2	6	8		[a] 8
91	SW.	2	6	8		16
92	NW.	3	6	8		70
93	SW.	3	6	8		16
94	NE.	9	6	8		65
95	SE.	9	6	8		55
96	NW.	10	6	8		45
97	SW.	10	6	8		40
98	SW.	11	6	8		13
99	NE.	12	6	8		18
100	SW.	12	6	8		12
101	NW.	18	6	8		110
102	SE.	19	6	8		[a] 110
103	SW.	19	6	8	Level upland	115
104	NE.	20	6	8		[a] 85
105	SE.	20	6	8		70
106	NW.	21	6	8		[a] 85
107	SW.	21	6	8		[a] 50
108	SW.	22	6	8		28
109	SE.	23	6	8		14
110	NE.	28	6	8		33
111	NE.	26	6	8		6
112	NE.	31	6	8	In the arroyo	35
113	SW.	33	6	8		7
114	SE.	34	6	8	Southwest corner	6
115	NE.	35	6	8		10
116	NW.	35	6	8		[a] 6
117	SW.	1	6	9		[a] 10
118	SE.	3	6	9		[a] 8
119	SW.	5	6	9	Northwest corner	13
120	SW.	5	6	9		14
121		6	6	9	West margin	18
122		7	6	9	North margin	12
123	SW.	10	6	9	Northwest corner	[a] 7
124	NW.	11	6	9		12
125	SE.	11	6	9		[a] 5
126	NE.	12	6	9		20
127	SE.	15	6	9		[a] 6
128	SW.	15	6	9		[a] 5
129	SW.	17	6	9		15
130	SW.	18	6	9	Northwest corner	12
131	NW.	19	6	9		[a] 8
132	SW.	20	6	9		17
133	NW.	29	6	9		18
134	SW.	29	6	9		18
135		26	6	10	Approximately located	36
136		4	6	10	do	47
137	SE.	31	6	11		[a] 50
138		15	7	7	East margin, in the arroyo	138
139	SE.	36	7	7		135
140	NW.	1	7	8		30
141	SE.	2	7	8		15
142	NW.	3	7	8		48
143	NW.	4	7	8		[a] 75
144	NW.	6	7	8		[a] 94
145	SW.	7	7	8	In the arroyo	[a] 45
146		10	7	8	East margin	14
147	SW.	12	7	8		33
148	SW.	13	7	8		35
149	SW.	14	7	8		16

[a] Depth not measured, but given on the authority of owner, driller, or other responsible person.

Table of depths to water in Estancia Valley—Continued.

No.	Quarter of section.	Section.	Township north.	Range east.	Situation of well.	Depth to water.
						Feet.
150	NE.	15	7	8		57
151	SW.	19	7	8	Upland	94
152	SE.	21	7	8		44
153	NW.	26	7	8		14
154	SW.	36	7	8		12
155	NW.	4	7	9		*a* 25
156	SW.	4	7	9		*a* 16
157	SW.	9	7	9		*a* 18
158	SE.	9	7	9		*a* 14
159	SW.	15	7	9		*a* 16
160	SW.	16	7	9		*a* 10
161	SE.	19	7	9		10
162	SE.	20	7	9	South margin	10
163	SE.	21	7	9	....do	*a* 12
164	NW.	22	7	9		*a* 16
165	SW.	27	7	9		*a* 8
166	NW.	28	7	9		10
167	SE.	30	7	9		10
168	NW.	34	7	9		*a* 12
169	SW.	35	7	9		*a* 12
170	NE.	8	7	10		*a* 56
171	SW.	8	7	10		*a* 50
172	....	9	7	10	South margin	*a* 70
173	SW.	15	7	10		66
174	NE.	16	7	10		70
175	....	22	7	10	North margin	*a* 70
176	....	31	7	11		*a* 45
177	SE.	36	8	7		*a* 85
178	NW.	1	8	8	In the arroyo	16
179	SE.	11	8	8		38
180	NW.	12	8	8		38
181	NE.	14	8	8		28
182	SE.	22	8	8		68
183	NE.	23	8	8	Southeast corner	*a* 18
184	NE.	23	8	8	Near base of cliff	*a* 9
185	SW.	24	8	8		19
186	SE.	27	8	8		54
187	NE.	33	8	8		70
188	NW.	8	8	9	Northeast corner	25
189	NE.	17	8	9	Southeast corner	24
190	NW.	28	8	9		22
191	NW.	28	8	9	Southwest corner	20
192	SW.	32	8	9		*a* 25
193	SW.	33	8	9		20
194	NE.	7	8	10		184
195	NE.	10	9	8		57
196	NW.	14	9	8	Level upland	59
197	NE.	17	9	8	In the arroyo	34
198	NE.	22	9	8	....do	*a* 21
199	NE.	23	9	8		45
200	NE.	24	9	8		36
201	SE.	27	9	8		55
202	NE.	28	9	8		*a* 83
203	NE.	29	9	8		*a* 138
204	NE.	31	9	8		*a* 58
205	NW.	31	9	8		*a* 98
206	NW.	32	9	8		*a* 78
207	NE.	32	9	8		*a* 114
208	NW.	33	9	8		*a* 100
209	NE.	33	9	8		*a* 130
210	NE.	35	9	8		27
211	SE.	36	9	8	In the arroyo	30
212	NW.	1	9	9	Southeast corner	63
213	SE.	4	9	9	Southwest corner	26
214	NE.	9	9	9		34
215	SE.	9	9	9		24
216	....	11	9	9	Center of section	*a* 25
217	NW.	11	9	9		*a* 22
218	NW.	12	9	9		*a* 43
219	SW.	15	9	9		27
220	SW.	17	9	9		24
221	NW.	19	9	9		26
222	NE.	20	9	9		15
223	SW.	29	9	9		16
224	SE.	30	9	9		18
225	SW.	5	9	10		129
226	NE.	1	10	8		88
227	NW.	2	10	8		135

a Depth not measured, but given on the authority of owner, driller, or other responsible person.

Table of depths to water in Estancia Valley—Continued.

No.	Quarter of section.	Section.	Township north.	Range east.	Situation of well.	Depth to water. *Feet.*
228	SW.	2	10	8		*a* 148
229	SW.	4	10	8	In the arroyo	159
230	S.	8	10	8		*a* 174
231	SE.	9	10	8		*a* 110
232	NW.	11	10	8		*a* 135
233	NW.	14	10	8		*a* 115
234	SE.	14	10	8		*a* 80
235	NE.	15	10	8		*a* 85
236	SE.	15	10	8	Upland	*a* 97
237	NE.	17	10	8		*a* 165
238	NW.	21	10	8		*a* 141
239	NW.	21	10	8	Southwest corner	127
240	NW.	22	10	8	In the arroyo	*a* 100
241	SW.	22	10	8	Upland	*a* 112
242	NE.	23	10	8		*a* 80
243	NW.	24	10	8		*a* 80
244	SE.	27	10	8	In the arroyo	55
245	NE.	34	10	8	Upland	74
246	SW.	34	10	8		*a* 165
247	NE.	35	10	8		*a* 44
248	SW.	1	10	9		*a* 105
249	NW.	3	10	9		99
250	SE.	4	10	9		*a* 66
251	SE.	4	10	9	Northeast corner	*a* 82
252	NE.	5	10	9		78
253	NW.	5	10	9		75
254	SW.	5	10	9	Northwest corner; in arroyo	*a* 60
255	....	6	10	9	North margin	72
256	SE.	6	10	9		62
257	SE.	9	10	9	Northeast corner	75
258	SW.	17	10	9	Southeast corner	*a* 42
259	....	18	10	9	East margin	51
260	NE.	19	10	9		42
261	SW.	26	10	9	Northwest corner	35
262	SW.	27	10	9		27
263	NW.	29	10	9		45
264	NW.	34	10	9	In the arroyo	*a* 20
265	SW.	34	10	9		*a* 15
266	SW.	35	10	9	Northwest corner	*a* 15
267	SE.	35	10	9	Northeast corner	25
268	NE.	5	10	10		*a* 165
269	SW.	1	11	8	In the arroyo	*a* 200
270	....	22	11	8	South margin	*a* 135
271	SW.	24	11	8		*a* 110
272	SE.	28	11	8	Upland	*a* 184
273	SE.	8	11	9		144
274	NE.	18	11	9	Southeast corner, depth of well 139 feet	....
275	....	19	11	9	South margin	*a* 90
276	SE.	20	11	9	In the arroyo	*a* 110
277	NW.	28	11	9		147
278	SE.	28	11	9	In Stanley	152
279	....	31	11	9	North margin; slightly above the arroyo	82
280	NE.	28	11	9		*a* 107
281	SE.	30	11	10		*a* 213
282	....	32	11	10	Near center of section	*a* 175

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a Depth not measured, but given on the authority of owner, driller, or other responsible person.

Field assays of water in Estancia Valley.

[Quantities in parts per million.]

No.	Owner.	Location.	Description of well.	Depth of well.	Depth to water.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).[a]	Chlorine (Cl).
				Feet.	*Feet.*				
1	Cedarvale well	SW. ¼ sec. 27, T. 2 N., R. 12 E.	Drilled, partly cased	298	174	0	424	>625	55
2	Mountainair village well	Mountainair.	Drilled	303		0	212	157	9
3	Elijah Bradley	NE. ¼ sec. 11, T. 3 N., R. 9 E.	do	100	80	0	170	>625	25
4	Progresso well	SW. ¼ sec. 15, T. 3 N., R. 10 E.	Dug		35	0	158	574	33
5	J. S. Penny	NE. ¼ sec. 1, T. 4 N., R. 6 E.	do	50	45	0	206	<30	13
6	S. R. Seymour	SW. ¼ sec. 8, T. 4 N., R. 7 E.	Drilled	110	55	0	170	<30	17
7		NE. ¼ sec. 11, T. 4 N., R. 7 E.	do	150	110	0	218	<30	13
8	J. B. Vincent	NE. ¼ sec. 23, T. 4 N., R. 8 E.		95	93	0	194	160	24
9	E. P. Parker	NE. ¼ sec. 24, T. 4 N., R. 8 E.	Dug		63	0	146	146	20
10		SE. ¼ sec. 24, T. 4 N., R. 8 E.	do		66	0	158	181	18
11	W. R. Walden	NE. ¼ sec. 26, T. 4 N., R. 8 E.	do	120	105	0	158	181	18
12	Ranch	NE. ¼ sec. 32,[b] T. 4 N., R. 8 E.				0	121	>625	25
13	Eugene Forbes	SE. ¼ sec. 6, T. 4 N., R. 9 E.	Dug	40	40	0	194	197	31
14	Atchison, Topeka & Santa Fe Ry. wells at Willard.	NW. ¼ sec. 8, T. 4 N., R. 9 E.				0	218	238	46
15		NW. ¼ sec. 11, T. 4 N., R. 9 E.	Dug		8	0	291	>625	417
16	A. P. Hanna	NW. ¼ sec. 31, T. 4 N., R. 9 E.	do	98	85	0	109	>625	17
17	Ranch	SW. ¼ sec. 3, T. 4 N., R. 10 E.	do		30	0	412	>625	1,165
18	do	Sec. 33,[b] T. 4 N., R. 10 E.				0	133	383	40
19	J. B. Teague	SE. ¼ sec. 17, T. 5 N., R. 7 E.		115	93	0	230	<30	9
20	Ranch	SW. ¼ sec. 33, T. 5 N., R. 7 E.	Dug		15	0	327	35	17
21	L. Knight	NE. ¼ sec. 1, T. 5 N., R. 8 E.	Large dug hole	27	20	0	243	80	15
22	Thomas Elgin	SW. ¼ sec. 6, T. 5 N., R. 8 E.	Dug		82	0	182	<30	7
23		NE. ¼ sec. 35, T. 5 N., R. 8 E.	do		31	0	267	42	15
24		NE. ¼ sec. 18, T. 5 N., R. 9 E.	6-inch, with casing	36	24	0	545	478	65
25	E. L. Moulton	SE. ¼ sec. 13, T. 5 N., R. 10 E.	Drilled and cased	120	95	0	121	>625	141
26	Fletcher Brown	SW. ¼ sec. 4, T. 5 N., R. 11 E.	do	84	65	0	340	406	261
27	Stream	Sec. 26,[b] T. 6 N., R. 6 E.					158	<30	10
28	Spring in foothills	Sec. 34,[b] T. 6 N., R. 6 E.				0	388	<30	7
29	Porter ranch	SW. ¼ sec. 34, T. 6 N., R. 7 E.		125	100	0	218	<30	7
30	L. C. Weaver	NW. ¼ sec. 1, T. 6 N., R. 8 E.	Not cased	40	26	0	679	328	140
31	R. B. Cochran	SW. ¼ sec. 11, T. 6 N., R. 8 E.	Dug		13	0	267	<30	35
32	Estancia Spring	SE. ¼ sec. 11, T. 6 N., R. 8 E.				0	291	<30	17
33	Box factory, Estancia	NW. ¼ sec. 12, T. 6 N., R. 8 E.	Cased to 59 feet		20	0	873	>625	251
34	W. J. Adair	NW. ¼ sec. 12, T. 6 N., R. 8 E.	Dug		18	0	631	574	693
35	Valley Hotel, Estancia	SW. ¼ sec. 12, T. 6 N., R. 8 E.				0	320	383	54

[a] >=more than; <=less than.

[b] Approximate location.

Field assays of water in Estancia Valley—Continued.

No.	Owner.	Location.	Description of well.	Depth of well.	Depth of water.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).[a]	Chlorine (Cl).[a]
				Feet.	*Feet.*				
36	N. E. Bilsing	SE. ¼ sec. 13, T. 6 N., R. 8 E		12	9	0	243	344	84
37	H. C. Williams	NE. ¼ sec. 26, T. 6 N., R. 8 E	Dug		6	0	243	50	20
38	do	NE. ¼ sec. 26, T. 6 N., R. 8 E	Drilled and cased	318	4	0	533	66	139
b39	H. N. Summers	SW. ¼ sec. 1, T. 6 N., R. 9 E	3-inch casing to 45 feet	65	10	0	243	431	438
b40	do	SW. ¼ sec. 1, T. 6 N., R. 9 E	do	65	10	0	243	553	393
41	N. Williams	SE. ¼ sec. 3, T. 6 N., R. 9 E	Cased	26	9	0	364	>625	914
42	T. J. Moore	SW. ¼ sec. 5, T. 6 N., R. 9 E	Dug		13	0	340	383	80
43	Mrs. N. L. Williams	NE. ¼ sec. 10, T. 6 N., R. 9 E	Cased	32	7	0	303	>625	15,075
44	Unsuccessful test well	SW. ¼ sec. 10, T. 6 N., R. 9 E	Cased to 205 feet	215	7	0	533	553	784
45	A. Abbott	SE. ¼ sec. 11, T. 6 N., R. 9 E	Cased to 100 feet	159	5	0	243	328	309
46	Charles May	NE. ¼ sec. 12, T. 6 N., R. 9 E	Dug	20	20	0	259	>625	16,442
47	A. Abbott	SE. ¼ sec. 15, T. 6 N., R. 9 E	Cased to 120 feet	156	6	0	424	553	603
48	do	SW. ¼ sec. 15, T. 6 N., R. 9 E	do	156	5	0	582	553	932
49	J. J. Smith	NW. ¼ sec. 19, T. 6 N., R. 9 E	Drilled, 6-inch casing	60	8	0	315	91	40
50	W H. Hancock	NE. ¼ sec. 20, T. 6 N., R. 9 E	Drilled and cased	90		0	679	>625	603
51	C. B. Cornell	SW. ¼ sec. 28, T. 6 N., R. 9 E	Not cased	18	14	0	728	>625	269
52	A. L. Bilsing	N. ½ sec. 33, T. 6 N., R. 9 E	Drilled and cased	100	14	0	752	>625	587
53	Wm. Dunbar	Sec. 4,[c] T. 6 N., R. 10 E		50	47	0	194	553	283
54		Sec. 26,[c] T. 6 N., R. 10 E	Dug		36	0	218	>625	2,412
55	E. F. Heal	SE. ¼ sec. 31, T. 6 N., R. 11 E	do	60	50	0	194	492	361
56	J. B. Gwaltney	SE. ¼ sec. 36, T. 7 N., R. 7 E	Drilled	139	135	0	170	<30	13
57	Antelope Spring	SW. ¼ sec. 14, T. 7 N., R. 8 E				0	364	<30	20
58	M. Freilinger	SW. ¼ sec. 24, T. 7 N., R. 8 E	Dug		35	0	340	42	55
59	J. B. Striplin	SE. ¼ sec. 20, T. 7 N., R. 9 E	do		10	0	267	265	219
60	B. W. Honnold	SE. ¼ sec. 21, T. 7 N., R. 9 E	Drilled and cased	140	12	0	243	383	234
61	J. W. Kooken	NW. ¼ sec. 28, T. 7 N., R. 9 E	Not cased		10	0	680	>625	5,276
62	T. J. Curtis	SE. ¼ sec. 30, T. 7 N., R. 9 E	Dug		10	0	352	287	85
63	Duncan McGillivray	NE. ¼ sec. 8, T. 7 N., R. 10 E	Drilled	93	56	0	133	150	40
64	E. F. Moore	SW. ¼ sec. 15, T. 7 N., R. 10 E			66	0	170	256	65
65	Allan McGillivray	Sec. 31, T. 7 N., R. 11 E	Drilled	120	45	0	97	>625	60
66	S. E. Keehnel	SE. ¼ sec. 36, T. 8 N., R. 7 E		140	85	0	279	30	25
67		NW. ¼ sec. 1, T. 7 N., R. 8 E	6-inch, not cased		30	0	315	43	25
68	John T. Lee	NW. ¼ sec. 28, T. 8 N., R. 9 E	Not cased	25	22	0	218	460	319
69	J. O. Justus	SW. ¼ sec. 33, T. 8 N., R. 9 E	do	25	20	0	291	>625	2,010
70	Ranch	SE. ¼ sec. 8,[c] T. 9 N., R. 8 E			34	0	194	<30	10
71	Michael T. Moriarty	NE. ¼ sec. 22, T. 9 N., R. 8 E	Dug	32	21	0	218	82	301
72	W. C. Maurer	NW. ¼ sec. 1, T. 9 N., R. 9 E	Drilled	70	63	0	158	460	274
73	Robert Hickman	SE. ¼ sec. 4, T. 9 N., R. 9 E	Not cased	30	26	0	170	460	251
74	Edith B. Rush	SW. ¼ sec. 29, T. 9 N., R. 9 E	Dug		16	0	206	574	222

75	B. Hill	NW. ¼ sec. 28, T. 9 N., R. 10 E.	Drilled	189		0	194	197	20
76	A. Stewart	NW. ¼ sec. 21, T. 10 N., R. 8 E.	do		127	0	206	<30	10
77	R. H. Harper	NE. ¼ sec. 34, T. 10 N., R. 8 E.	do	100	74	0	194	34	15
78	S. F. Kelly	NW. ¼ sec. 3, T. 10 N., R. 9 E.	do		99	0	194	61	13
79	John H. Cantwell	NW. ¼ sec. 5, T. 10 N., R. 9 E.	do	103	75	0	170	95	13
80	E. H. Clayworth	SW. ¼ sec. 27, T. 10 N., R. 9 E.	Dug		27	0	146	383	119
81	G. W. Hearte	NE. ¼ sec. 5, T. 10 N., R. 10 E.		180	165	0	243	56	14
82	Deserted ranch	SW. ¼ sec. 1, T. 11 N., R. 8 E.	Dug	250	200	0	182	78	8
83	Stanley village well	Stanley		160	152	0	230	52	13
84	W. C. Asher	do	Drilled	207	100	0	243	94	18

[a] >=more than; <=less than. [b] Samples 39 and 40 were taken from the same well, but at different times and after different rates of pumping. [c] Approximate location.

Tests made by the Atchison, Topeka & Santa Fe Railway Co. of water from its wells in Estancia Valley, N. Mex.

[Reported by the railway company in grains per United States gallon but recalculated, for convenience in comparison, to parts per million.]

No.	Location.	Depth of well.	Depth to water.	Depth from which water was taken.	Incrustants, including silica and iron, and carbonates, sulphates, and chlorides of calcium and magnesium.	Foaming material (including organic matter and carbonates, sulphates, and chlorides of sodium and potassium).	Total solids.
		Feet.	*Feet.*	*Feet.*			
1	Mountainair	330	210	283	1,038	171	1,209
2	do	330	210	295	516	85	601
3	do	330	210		246		410
4	do	330	210	300	210	50	260
5	Willard	440	35	41	340	111	451
6	do	440	35	41	337	299	636
7	do	440	35	52	404	123	527
8	do	440	35	52	395	128	523
9	do	440	35	130	325	92	417
10	do	440	35	146	320	108	428
11	do	440	35	223	369	116	485
12	do	440	35	233	364	135	499
13	do	440	35		304		412
14	do	440	35		340	92	432
15	do	440	35		556	121	677
16	do	440	35		400	207	607
17	Lucia	350	40	120	2,724	429	3,153
18	do	350	40	315	2,348	198	2,546
19	do	350	40	350	2,139	216	2,355

NOTE ON GEOGRAPHIC NAMES.

Estancia Valley has occasionally been called "Sandoval Basin" or "Sandoval Bolson" after the large Antonio Sandoval land grant which it once contained, but the name "Estancia Valley" is now in general use.

For generations the Mexican inhabitants have had definite names for the principal mountains, buttes, arroyos, salt basins, and other topographic features, but the American settlers who have recently come into the valley show a tendency to ignore these Spanish names. Frequently the English translation of the Spanish name is used, but in some cases entirely new names are applied or no name at all is known. In this paper the Spanish names are consistently retained because they have the sanction of long usage and are more distinctive and euphonious than the English names of recent origin. Below are given some translations and alternative names:

Arroyo Fecundo	Fertile Draw.	Laguna Chica	Little Lake.
Arroyo del Cibolo	Buffalo Draw.	Punta de Agua	Point of water.
Arroyo del Sinsonte	Mocking Bird Draw.	Manzano (range)	Apple-tree (range).
Arroyo Mesteño	Ranchers' Draw.	El Cuervo (butte)	Crow (butte).
Cañada Colorado	Red Canyon.	Cerrito del Lobo	Wolf Hill.
Laguna del Perro	Dog Lake.	Pedernal (mountain)	Flint (mountain).
Laguna Salina	Salt Lake.		

Arroyo Mesteño is well known as Manzano Draw, and Arroyo de Ortiz as Moriarty Draw.

GROUND-WATER CONDITIONS IN PARTS OF CENTRAL NEW MEXICO.

A RECONNAISSANCE IN ENCINO BASIN, NEW MEXICO.

LOCATION AND AREA.

Encino Basin lies in the central part of New Mexico, immediately east of Estancia Basin (fig. 1). Like the latter, it forms a closed depression whose drainage channels lead to a low central flat, but it is much smaller than Estancia Basin, its area being not much more than one-tenth as great. It is bordered on the north by the drainage basin of Cañada Pintada, which leads to Pecos River, on the east by a gently undulating upland that is drained eastward, and on the south by a closed depression known as Pinos Wells Basin and by a very small closed basin that intervenes between Encino and Pinos Wells basins.

PHYSIOGRAPHY AND GEOLOGY.

UPLAND AREAS.

The borders of Encino Basin are in general much lower than those of Estancia Basin, and at no place do they assume the character of mountain ranges. Most of its area consists of gently undulating, grass-covered upland that lies west and northwest of the low flat and is traversed by arroyos that drain the storm waters toward this flat, the divides which separate the upland from Estancia Basin and Cañada Pintada being inconspicuous. The divides on the south and east are relatively near the flat and are still lower and less conspicuous. On the northeast the basin is bordered by a low mesa that supports some trees.

The western upland is underlain largely by granite with associated schist and quartzite, but a series of stratified formations, probably continuous with some of the Carboniferous formations found in Estancia Basin, also appears. In the railway excavation west of Negra, there is an exposure of gray, chocolate, and greenish shales and an overlying pink conglomerate, derived chiefly from granite. The conglomerate rests upon the shale with pronounced unconformity. It outcrops at other points and has been encountered in some of the wells near Negra. Limestone is exposed a short distance east of this station, and sandstone and other rocks appear in the divide on the east side of the basin. West and south of the flat south of Encino there is a conspicuous cliff, several miles in total length, in which red beds containing thick layers of gypsum come to the surface. In general the stratified beds are horizontal or have only gentle dips, but at some points displacements and abrupt changes in dip are found. Beds underlain by gypsum are likely to be more or less disturbed by caving that results from the removal of the gypsum through its solution in percolating waters.

ANCIENT LAKE BED.

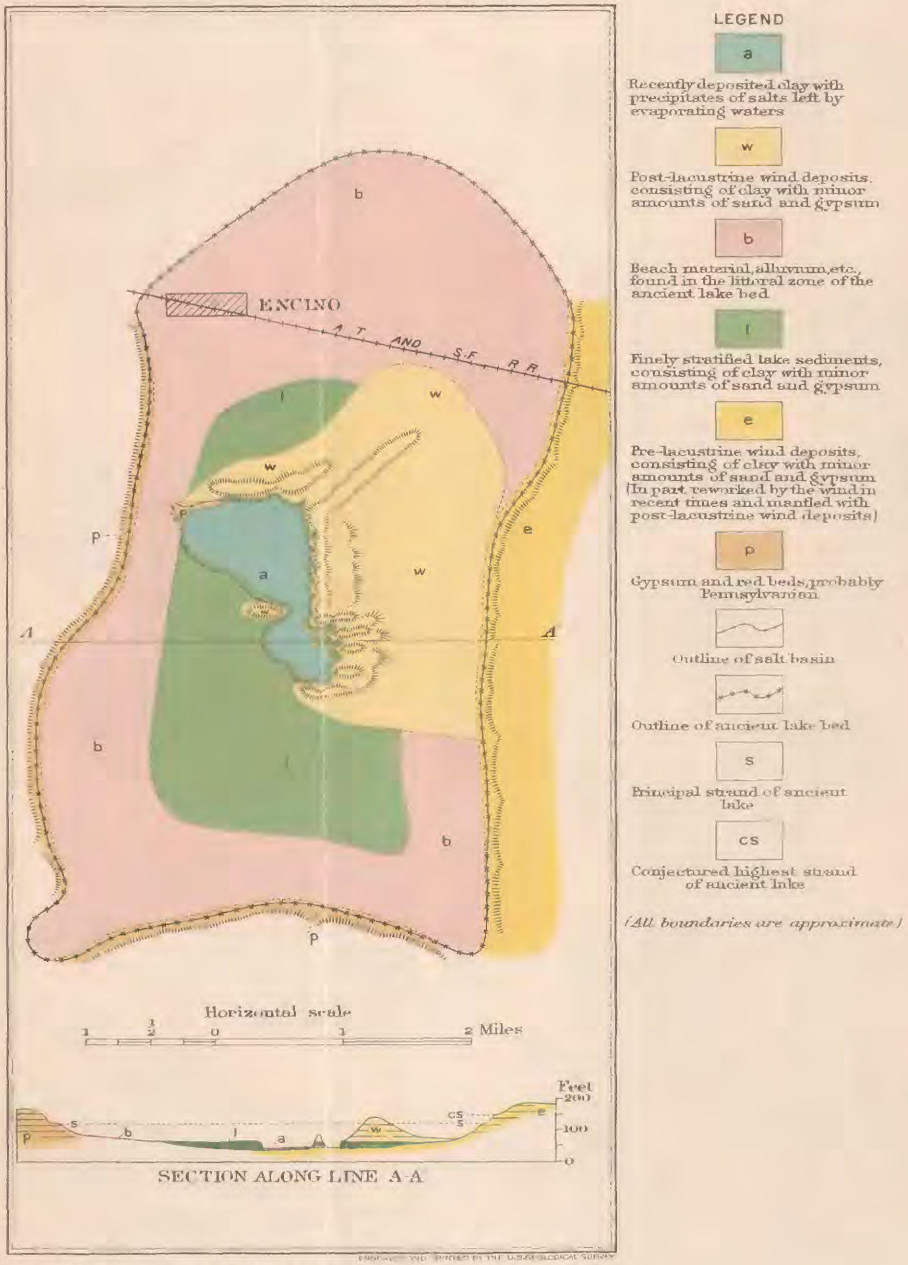
Although this basin is so much smaller than Estancia Basin and has no mountain ranges to supply water, there is indisputable evidence that its lowest part was at one time occupied by a lake (Pls. XII and XIII). As in Estancia Basin, this evidence is furnished by the delicately laminated sedimentary beds, such as are deposited only at the bottom of a body of standing water, by a flat plain characteristic of the bed of a desiccated lake, and by terraces, beaches, and other markings, whose occurrence at certain levels indicate ancient strands or shore lines.

LAKE SEDIMENTS.

In the village of Encino exposures afforded by cellars and dug wells show irregular beds of sand, gravel, and clay, but no beds that resemble the laminated lake sediments in Estancia Valley. The same is true of wells and cellars east and southeast of the village, in the vicinity of the railroad; but less than a mile south and a short distance east of Encino, on slightly lower ground, a dug well was found in which about 4 feet of typically laminated lake beds occur. They rest on nonlaminated yellow sand and gravel and are overlain by about 2½ feet of dark soil with some pebbles at the surface.

About a mile farther south there is a salt basin similar to those in Estancia Valley (Pl. XIV, *A*). At the north margin of this basin lake sediments are only imperfectly developed, while beds of gypsum and other old formations make up the floor and the lowest parts of the sides of the basin. The floor is strewn with pebbles, which have evidently been washed thus far by water but which could not be removed by the wind when it excavated the basin.

In the southeastern part of the basin the conditions are entirely different. Here more than 20 feet of typical lake sediments outcrop (Pl XIV, *B*). They contain some sand and gypsum but consist chiefly of laminæ of clay. The perfect stratification and fineness of the material is remarkable when the small size of the ancient lake is considered. Near the bottom there are calcareous beds, the heaviest of which has a thickness of more than half an inch. At a few places a nonlaminated formation appears below the lake sediments, thus



ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

RECONNAISSANCE GEOLOGIC MAP OF THE ANCIENT LAKE BED IN THE ENCINO BASIN, NEW MEXICO

A. TERRACE ON EAST SIDE OF ANCIENT LAKE BED NEAR ENCINO.
See page 77.

B. TERRACE ON SOUTH SIDE OF ANCIENT LAKE BED NEAR ENCINO.
See page 77.

C. GAP IN ANCIENT BEACH BAR NEAR ALLEN McGILLIVRAY RANCH.
See page 20.

A. ENCINO SALT BASIN.

See page 78.

B. STRATIFIED LAKE SEDIMENTS IN ENCINO SALT BASIN.

See page 76.

showing that the entire lake series is exposed. No pebbles are found on the floor of this part of the salt basin.

The exact extent of the lake sediments is not known, but they appear to be present in the materials thrown up from wells sunk at different points on the flat south of the basin. They probably extend beneath the low flat part of the ancient lake bed and are absent where the surface rises perceptibly. Their presence at the surface is probably indicated by the abundance of the large brush, *Atriplex canescens* (?).

SHORE FEATURES.

As nearly as was ascertained, the area of the ancient lake was about 18 square miles, or only one-twenty-fifth of the area of Lake Estancia. Since the size of shore features depends largely upon the size of the waves, and the latter depends largely upon the size of the lake and consequent sweep of the wind, it might be expected that the shore line of Lake Encino would be very feebly marked. It is therefore rather surprising to find that some of the features rival in size those in Estancia Valley but that they are generally less distinct and less well preserved.

The principal shore features in this basin consist of cliffs and attendant cut and built terraces. These are found on the steep west, south, and east sides, where conditions were favorable for this kind of wave work.

On the west and south sides the cliffs and terraces are for the most part cut into the soft red beds, which yield readily to wave work, and into somewhat harder layers of gypsum (Pl. XIII, *B*). Since the caving produced by the gypsum causes small gentle synclines and anticlines, the lake terrace is repeatedly interrupted and is therefore rather disappointing in its general appearance; but the fact that it retains its horizontality and intersects the dipping strata greatly strengthens the evidence that it is a true ancient strand.

On the east side the shore line was for the most part imposed upon wind-deposited clay (Pl. XIII, *A*). The character of this material is such that it must have yielded very freely to wave work, and hence it is not surprising that the lake terraces should here be large. The character of the material also affords the explanation for their poor preservation. While on the Estancia lake bed running water has accomplished but little destructive work, post-lacustrine wind erosion has been notably effective, and the shore features are well preserved because they are generally gravelly and hence not susceptible to wind erosion. Examination shows that the partial destruction of the lake terrace on the east side of Lake Encino is mainly the work of the wind and to only a small extent of the streams. When one observes the great amount of wind work that has been accomplished since the drying up of the lake in the excavation of the salt basin and takes note of the present erosive activity of the wind, the poor state of preservation of the terraces is no longer puzzling.

While the lake in Encino Basin was very much less extensive than that in Estancia Basin, it did not compare so unfavorably in depth. The shore line referred to in the foregoing description is the only distinct and certain one. As nearly as could be estimated it stands about 60 feet above the lowest part of the lake flat. No shore features were observed at lower levels, but there is some evidence (which need not be discussed here) that the water stood temporarily at a higher level. If this is true, the lake history of this basin would appear to be correlated with that in Estancia Basin, inasmuch as a temporary high-water stage is postulated for both lakes.

SALT BASIN AND POST-LACUSTRINE WIND DEPOSITS.

The lake flat contains a single large salt basin, which is of the same type as the salt basins on the flat of Lake Estancia (Pl. XIV, *A*). Like them, it was obviously excavated by the wind to the ground-water level and has a flat bottom and precipitous walls. As in Estancia Valley, the effect of prevailing westerly winds is obvious, the west margin being entirely destitute of wind deposits while the east margin is bordered by ridges and hills, the highest of which reach an altitude of fully 100 feet above the floor of the basin. As in Estancia Valley, the wind deposits form a sharp contrast with the lake sediments, upon which, in some places, they rest with pronounced unconformity. Again, as in Estancia Valley, the clay deposits hug the basin closely, producing a topographic feature that bears a superficial resemblance to a volcano with a large crater. If the material excavated were more granular, like sand, it would be carried farther and would not remain in such close proximity to the salt basin. The sand and gypsum sand present are found chiefly at the tops of the ridges or in the thin blanket of eolian material that is spread over the lake bed to the leeward of the clay hills. The wind is constantly attacking the structures which it has itself thrown up. It gouges out precipitous trenches on the windward side of the clay hills and deposits the material thus acquired in elongated mounds to the leeward (Pl. XII).

In the northern part of the valley the clay hills have a subdued aspect and are covered with grass, indicating that wind work has not been active in recent times, but in the southern section the hills are higher, more fantastically carved, and largely destitute of vegetation on the windward side, showing in every way that the wind is still actively at work. In some places the wind has eroded thin layers of limestone and other indurated deposits.

At the time the basin was visited most of its floor was miry, but only a small part was covered with water. The position of the submerged part is significant. The work of the wind is to a small extent undone by the occasional rains which wash some of the excavated material back upon the floor of the basin, producing miniature alluvial slopes. Since the wash is greatest from the highest clay hills, the lowest depression, where the water stands longest after a rain, is located on the west side of the basin as remote as possible from these hills, just as on a larger scale in Sevier Desert, Utah, the lowest depression, occupied by Sevier Lake, is remote from the lofty mountains that yield the most alluvium.

PRELACUSTRINE WIND DEPOSITS.

The deposit found beneath the lake sediments in the southeastern part of the salt basin consists of a light slate-colored, granular, gypsiferous material in which no stratification was noticeable. At no place was an outcrop more than a few feet thick observed, and the exposures were so poor that its character could not be positively ascertained. Yet its appearance indicates that it is probably a prelacustrine wind deposit in which the yellowish tint was changed to bluish by the deoxidation of the iron present. In the wells that have been sunk on the flat south of the salt basin, the same bluish, granular, gypsiferous material is invariably brought to the surface after the lake sediments have been passed through.

On the east side the depression occupied by the ancient lake bed is bordered by pale yellowish gray clay whose character, as a typical wind deposit, is well shown in the railway cut, where a thickness of more than 20 feet is freshly exposed. The topography is also typical of wind work. On the windward side the deposit has been thrown up to form an almost precipitous escarpment, but on the leeward side it slopes gradually, as shown in the section, Plate XII, and eventually disappears altogether. Its general prelacustrine age is fixed by the lake terrace built upon it.

As has been explained, the depression occupied by the ancient lake is bordered on the west, south, and east by abrupt, cliff-like walls. This depression with its precipitous walls was not formed by the lake itself. It was in existence before the advent of the lake and afforded a basin in which the surplus waters collected and were held within definite and constricted limits, without which perhaps no permanent lake would have been produced. The effect of the lake was merely to fill the lowest parts of the depression sufficiently to produce a central flat and to cut a notch at a certain level into the precipitous walls. The general relations suggest that the depression itself may be, at least in part, the product of prelacustrine wind work.

THE MAP.

The map of the ancient lake bed in the Encino Basin (Pl. XII) is introduced to illustrate the features described. It was sketched without an adequate base and the boundaries are merely approximate.

SOIL.

An investigation of the soil would probably develop the fact that Encino Basin is divisible into four soil provinces—the uplands, where the soil is no doubt generally fertile; the littoral zone of the ancient lake bed (*b* in Pl. (II), where the soil is probably also good but is likely to contain more soluble salts; the lake flat (*l* in Pl. XII), where there is likely to be an objectionable amount of alkali and where the predominant vegetation consists of brush; and the areas covered by wind deposits (*w*, and perhaps also *e*, in Pl. XII), where the soil is probably rich in gypsum but less heavily impregnated with alkali than the soil of the lake flat, and where grass instead of brush is the predominant vegetation.

The following analysis indicates a soil that is not seriously impregnated with alkali, nearly all of its soluble matter being gypsum.

Analysis of soil at Encino, N. Mex.

	Per cent of total soil.
Total soluble solids:	
First foot	0. 11
Second foot	1. 15
Third foot	1. 15
Composite of upper 3 feet:	
Total soluble solids (calculated)	. 80
Calcium (Ca)	. 21
Magnesium (Mg)	. 004
Sulphate (SO_4)	. 48
Carbonate (CO_3)	None.
Bicarbonate (HCO_3)	. 024
Chlorine (Cl)	. 002

The samples were taken near the residence of David Liles, north of the depot. The analyses were made in September, 1910, by F. M. Eaton, Oakland, Cal. The percentages are based on the air-dried soil.

GROUND WATER.

OCCURRENCE AND HEAD.

Wells are found in the ancient lake bed and at numerous points on the uplands. At Encino the water table stands 20 to 25 feet below the surface, and it is said to be at about this depth through the low flat area that extends southward from the village. It no doubt coincides approximately with the floor of the salt basin. On the uplands the depth to water is, of course, greater, and most of the wells are located in arroyos.

At Negra, which is located in an arroyo west of Encino, the Atchison, Topeka & Santa Fe Railway Co. has sunk several wells and is at present drilling two others. The principal railroad well now in use is 500 feet deep. It has an 8-inch casing extending to a depth of 350 feet and 6-inch casing from 350 feet to the bottom. The well is said to extend through various rock formations. Strainers are inserted at six horizons and difficulty is experienced in keeping out the fine sand. The other well at present in use is 171 feet deep. The normal water level in the wells is said to be about 70 feet below the surface and the pump in the 500-foot well 280 feet below the surface. As a rule both wells are pumped continuously and furnish about 3,400 gallons per hour, about 14 gallons per minute being drawn from the 171-foot well and 42 gallons per minute from the 500-foot well. At the time the station was visited this was the maximum yield of the wells, but it was believed that by cleaning out the sand that had accumulated the supply could be materially increased.

The well of D. J. Bigbee is located in the NW. ¼ sec. 23, T. 7 N., R. 13 E., about 15 miles northwest of Encino. It is in the arroyo of Cañada Pintada, a short distance north of the divide. This well was drilled 230 feet deep, and the water, which was encountered at 226 feet, rose to a level about 185 feet below the surface. It is reported that 5,000 gallons have been pumped from it in 10 hours without noticeable effect. A similar well is located about 1 mile farther south, and several other wells with windmills were observed in the arroyo that leads toward the village of Encino.

The vicinity of Encino is underlain by sand and gravel that will probably yield its water freely. Less certainty exists as to the water-bearing capacity of the underlying deposits farther south, on the lake flat. No gravel or quartz sand was observed in the materials brought out of the wells on the flat south of the salt basin, and in some localities the gypsum and red-beds series is near the surface.

QUALITY.

The water from the upland wells is generally reported to be of good quality. The railroad supply at Negra is said to be preferred to the water at Willard for use in boilers. At Encino the water is so highly mineralized that it is avoided for drinking and household use. On the flat farther south it is reported still worse. Numerous dug wells were found on the flat south of the salt basin, but none seemed to be in use. It is likely that the conditions in this basin are analogous to those found in Estancia Basin.

Below is given an assay of the water from the well of H. B. Markham, in the village of Encino. This is a dug well about 25 feet deep. It penetrates irregularly deposited bodies of clay and gravel and ends in a bed of sand. The water level is 22 feet below the surface. The assay indicates that the water is similar to the gypsiferous water in the Estancia Valley.

Assay of well water at Encino, N. Mex.

[Parts per million.]

Carbonate radicle (CO_3)	0
Bicarbonate radicle (HCO_3)	109
Sulphate radicle (SO_4)[a]	2, 300
Chlorine (Cl)	126

IRRIGATION.

The rainfall is not sufficient to assure crops by dry-farming methods, and there are no permanent streams. A remote possibility exists that flowing wells could be obtained, but the indications are less promising than in Estancia Valley, where drilling has developed unfavorable results. There is, however, reason to believe that some land can be successfully irrigated by pumping from wells. In parts of the shallow-water belt detrimental quantities of alkali are likely to be present. Hence, before a pumping plant is installed analysis should be made of the soil that is to be irrigated and of the water that is to be used. The principal water supply is to be expected from the sand and gravel in the valley fill, and, since the average thickness of this fill appears not to be great, the amount of available ground water is probably not large. Pumping plants of moderate size should first be installed, and after these have been successfully operated further developments can be made. The most promising field for irrigation is not on the low flat, where alkali conditions are likely to be encountered, nor on the elevated uplands, where the depth to water is great and the supply is generally small, but on intermediate ground, where the soil is not strongly impregnated with alkali and where water of fairly good quality occurs at moderate depths in the porous materials of the valley fill. However, the fact that irrigation of small plats is feasible even where the water is far below the surface is shown on D. J. Bigbee's ranch, where an abundant yield of vegetables for home use was raised by irrigating with water lifted by a windmill from a depth of nearly 200 feet.

RECONNAISSANCE IN PINOS WELLS BASIN, N. MEX.

PHYSIOGRAPHY AND GEOLOGY.

Pinos Wells Basin lies east of Estancia Basin and south of Encino Basin (fig. 1), and is comparable in size to the latter. Like the others, it has no drainage outlet, the waters of its occasional storms flowing from the relatively high tracts near its margin toward the

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[a] Turbidimeter method, by dilution.

lower ground in the interior. In the low central part there are two large salt basins which bear some resemblance to those on the Estancia and Encino flats. They have been produced in the same way by westerly winds, which have eroded to the ground-water level and deposited their loads on the eastern or leeward sides. The peculiar susceptibility of the clay in these three basins to yield to wind erosion is perhaps to be found in its gypsiferous character.

With these general resemblances, however, the parallelism between this basin and the other two ends. No ancient shore features were found, although search was made for them at all levels. Tracts of relatively smooth lowlands adjoin the salt basin on the west, but they lack the distinctive flatness that characterizes the ancient lake beds. No cliff-like walls such as are formed by the laminated lake sediments surround the salt basin. Sediments of this character are lacking, though at a few points south of the west basin stratified beds bearing some resemblance to the laminated lake sediments were observed. The deposits underlying the lowlands in the vicinity of the salt basins are of various kinds, among which are found gravel and pebbly clay. A pavement of pebbles like that found at the north end of the Encino salt basin is spread over the floors of the salt basins in many localities. Such a pavement is not found where lake sediments alone have been eroded. In some places these residual pebbles have accumulated to such an extent as to prevent further wind erosion, thus forming miniature monadnocks on the eolian peneplain.

The wind deposits are different from those in the other two basins. They consist more largely of gypsum, and in some places constitute an almost pure gypsum sand. The gypsum sand is more granular than clay and drifts more readily with the wind; hence a somewhat different wind topography has resulted. The deposits do not hug the salt basins so closely and do not produce so much of the crater effect. They have been carried farther from the salt basins and cover a larger area, forming mounds and hills that more nearly resemble ordinary sand dunes, although they differ from these in being more irregular and fantastic. Gypsum sand also differs from clay in its character as a soil. It supports a scattered growth of small pines, which are not found on the clay hills, and appears to produce a better growth of grass in some places.

GROUND WATER.

Wells are numerous in the dune area and on the low tracts that surround the salt basins. Near the basins are dug wells filled to the brim with water. Some of these wells are pumped by windmills and afford supplies for sheep and other live stock, but the water is so highly mineralized that it is not used for drinking or for culinary purposes. West of the west basin and at a somewhat higher level there are springs which yield better water. All the inhabitants of the region are said to haul their household supplies from these springs.

Below is given an assay of the water from the well of Julian Chavez. It is a shallow dug well at the margin of one of the salt basins and is filled with water virtually to the top.

Assay of water in well of Julian Chavez, near Pinos Wells, N. Mex.

[Parts per million.]

Carbonate (CO_3)	0
Bicarbonate (HCO_3)	750
Sulphate (SO_4) [a]	2,750
Chlorine (Cl)	1,350

SMALL INTERMEDIATE BASIN.

The small basin that lies between Pinos Wells and Encino basins has already been mentioned. It embraces a drainage area of only a few square miles. Its central depression is comparatively flat but still far above the ground-water level, as is proved by a deep well that has been sunk on it. Wind work has been effective here as in the larger basins, and has built a distinct clay ridge more than a mile long on the east side of the central depression. This depression, like nearly all the other wind-formed basins of this region, has a north-south elongation.

NOTES ON WELLS AT VAUGHN, N. MEX.

East of Encino Basin the surface forms in general an upland that slopes toward the Pecos Valley (fig. 1), and in parts of this upland there is difficulty in procuring enough water for domestic purposes and for the stock. In the village of Vaughn, at the intersection of the El Paso & Southwestern Railroad with the Belen cut-off of the Atchison, Topeka & Santa Fe Railway, some deep drilling has been done with poor success, and at the time the village was visited, in the summer of 1909, the inhabitants depended largely upon water hauled from Willard by the railway company. Since that time the pipe line of the El Paso & Southwestern Railroad Co. has been extended to Vaughn.

The following data have been furnished by the Atchison, Topeka, & Santa Fe Railway Co.:

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[a] Turbidimeter method, by dilution.

Section of the "Epris" well, on the El Paso & Southwestern Railroad.

[Altitude of surface about 5,935 feet above sea level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Clay and gravel	70	70
Red clay	50	120
Soft lime	10	130
Red clay	20	150
White lime	30	180
Red clay	46	226
Hard limestone	4	230
Red clay	30	260
White lime	30	290
Soft sand rock	36	326
Brown sand rock	14	340
White sand rock	30	370
Soft yellow sand rock	32	402
White lime	13	415
Soft white and yellow sand rock	345	760
Soft yellow sand rock (water)	71	831
Fine white sand rock	19	850
Sandy shale	47	897
Hard ledge of rock	....	897
Red clay	158	1,055
Clay with sand streaks	120	1,175
Red clay	75	1,250
White sand	6	1,256
Red clay	34	1,290
White sand	8	1,298
Light-colored clay	12	1,310
White sand (water)	20	1,330
Bottom of hole, June 6, 1906	....	1.355

Miscellaneous notes on the "Epris" well.

Depth (feet).

820 Light vein of water.

829 Vein of water which rose to 800 feet. Yield about 7 gallons per minute. The following analysis shows an extremely hard water:

	Parts per million.
Incrustants	2,678
Foaming constituents	.....
Total solids	2,807

880 The water from the depth of 1,330 feet rose to this level.

900 Light vein of water.

980 Vein of water which rose to the 900-foot level.

1,000 Depth of well November 23, 1905.

1,015 Salt water, 18 gallons in 24 hours.

1,110 Salt water, 36 gallons in 12 hours.

1,175 Salt water, 90 gallons in 12 hours.

1,200 Very little water.

1,330 From this depth is reported an analysis which indicates a strong brine.

Section of the "Tony" well, on the El Paso & Southwestern Railroad.

[Altitude of surface about 5,800 feet above sea level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Soil mixed with gypsum and bowlders	190	190
Limestone	23	213
Red gypsum and lime	18	231
Limestone	20	251
Quartzite sandstone	60	311
Yellow stone, badly fissured	450	761
Red volcanic clay	40	801
(Small vein of water.)		

The following information in regard to the "abandoned well at Vaughn on the El Paso & Southwestern Railroad" was supplied by F. M. Clough, general foreman, writing under date of December 16, 1909:

> The well is 854 feet deep; size of hole, 8 inches. The water level is 600 feet from the surface. At the time this well was abandoned, about eighteen months ago, the water supply was about 600 gallons per hour. I do not have any copy of the analyses of this water. However, for your information, I will state that we gave the water a heavy treatment with caustic soda, sal soda, and soda ash, and even after this treatment the water was very bad for engine use, so we could hardly keep it in the boilers. It is a very poor quality of water, and one that could not very well be used for domestic purposes.

Surface indications of water are lacking, and the sink holes northwest of the village are unfavorable conditions. If further prospecting is undertaken, it might be best to drill in the flat west of and some distance from the quarry located northwest of the El Paso & Southwestern Railroad station.

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