Geology and Ground-Water Resources of Hale County Texas

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1539-U

Prepared in cooperation with the Texas Board of Water Engineers and the County of Hale

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By JAMES G. CRONIN *and* LLOYD C. WELLS

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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GEOLOGY AND GROUND-WATER RESOURCES OF HALE COUNTY, TEXAS

By JAMES G. CRONIN and LLOYD C. WELLS

ABSTRACT

Hale County, in the southern High Plains of Texas, has an area of 1,033 square miles. The land surface is one of low relief, and the regional slope is about 10 feet per mile toward the southeast. Surface runoff drains into numerous playa lakes and two intermittent streams: Running Water Draw and the Double Mountain Fork of the Brazos River.

The Ogallala formation of Tertiary age is the principal water-bearing formation in the county. The Ogallala lies on red beds of Triassic age throughout most of the county and on rocks of Cretaceous age in approximately the southern fifth of the county. The Triassic and underlying Permian rocks are not fresh water bearing in the county. The Cretaceous rocks, on the other hand, are in direct hydraulic connection with the Ogallala, and a few wells tapping them yield large quantities of water from cracks and solution channels in the limestones. The Ogallala formation is overlain by thin deposits of sand, gravel, silt, and clay of Pleistocene and Recent age. These younger rocks are, for the most part, above the water table and, consequently, are not water bearing.

The water in the Ogallala formation occurs principally as unconfined water in layers and lenses of sand and gravel. The hydraulic properties of the Ogallala were determined by a long-term aquifer test at Plainview, where coefficients of transmissibility ranging from 24,000 to 38,000 gpd per foot were measured. The coefficient of storage was determined to be about 0.14.

The aquifer is recharged from precipitation in Hale County and in the southern High Plains northwest of the county. The water moves generally southeastward at about 2 inches a day.

Ground water in Hale County is used principally for irrigation. In 1955 more than 3,700 wells were used to irrigate 470,000 acres; about 560,000 acre-feet of water was pumped. About 5,000 acre-feet was pumped for other purposes, including municipal, industrial, stock, and domestic uses.

The water in the Ogallala formation in Hale County is suitable chemically for irrigation and most other uses; however, it should be softened for more satisfactory domestic use. The high silica content indicates that the water may be unsuitable for use in boilers. The fluoride content is excessive.

It is estimated that in 1955 about 39 million acre-feet of water was in storage in the Ogallala formation in Hale County; however, only about 16 million is

theoretically available to wells, and a somewhat smaller amount is practically available. About 3 million acre-feet was removed from storage during 1938–55. Water levels in wells have declined more or less steadily since 1938, and it is apparent that the ground-water resources of the county are insufficient to support large-scale perennial irrigation such as that of 1955.

INTRODUCTION

PURPOSE AND SCOPE

The investigation in Hale County was made possible through a cooperative agreement among Hale County, the Texas Board of Water Engineers, and the U.S. Geological Survey. The purpose of the investigation was to make a comprehensive study of the Ogallala formation, the principal ground-water reservoir in the county, with special attention to the thickness of the ground-water reservoir, the amount of water that has been removed from storage, the amount of water remaining in storage, the ability of the ground-water reservoir to yield water to wells, and the amount of recharge to the reservoir. As part of the investigation, the observation-well program, which has been carried on since 1937, was expanded so that the amount of water withdrawn from the ground-water reservoir can be estimated more accurately in the future.

The field investigations were begun in October 1954 and were concluded in December 1955.

Plate 1 shows the location and well numbers of all the wells for which records are available. The unpublished records may be consulted at the offices of the Geological Survey and the Board of Water Engineers at Austin, Tex. Many names of well owners were taken from a landownership map of the county available at the time of the investigation. Because of the rapid exchange of land in parts of the county, some of the owners' names may not now be correct.

LOCATION

Hale County is in the Texas Panhandle (fig. 1). It is bounded on the north by Castro and Swisher Counties, on the east by Floyd County, on the south by Lubbock County, and on the west by Lamb County. Plainview, the county seat, is in the northeastern part of the county, about 75 miles south of Amarillo, Tex.

The county is rectangular and according to the General Land Office of Texas, contains 661,382 acres—about 1,033 square miles. The population was 28,211 in 1950.

Transportation facilities include two Federal and several State highways, and an extensive network of paved and graded county highways. The Santa Fe railway system serves Plainview, Hale Center,

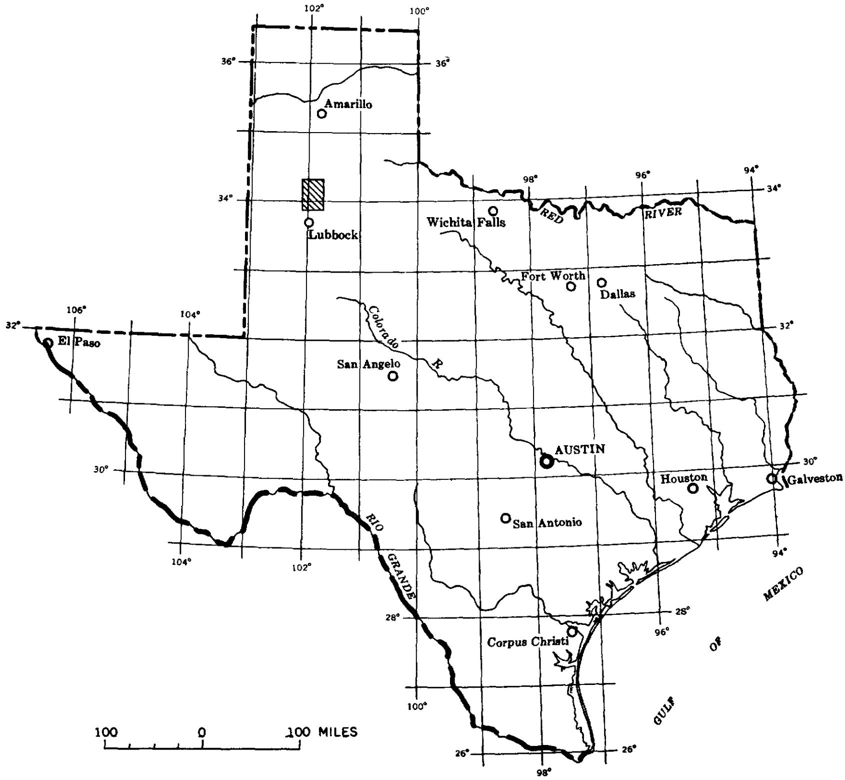

FIGURE 1.—Map of Texas showing location of Hale County.

and Abernathy, and the Burlington railway system serves Plainview, Petersburg, and Edmonson. Plainview is served also by Continental Airlines.

PHYSIOGRAPHY AND DRAINAGE

Hale County is on the High Plains of Texas, a part of the High Plains section of the physiographic province known as the Great Plains. The Canadian River in Texas separates the High Plains into two segments known locally as the northern High Plains and the southern High Plains; Hale County occupies part of the southern High Plains.

The land slopes generally from northwest to southeast at about 10 feet per mile. The total relief in Hale County is about 400 feet, the altitude ranging from about 3,200 to 3,600 feet above sea level. Many depressions in the land surface, known locally as playa lakes, form the principal topographic features on the otherwise monotonously flat land surface. Two intermittent streams, Running Water Draw and the Double Mountain Fork of the Brazos River, cross Hale County from northwest to southeast. The channel of Running Water Draw in most places is shallow and broad; the channel of the Double Mountain Fork of the Brazos River is relatively deep and narrow.

CLIMATE

The climate in Hale County is semiarid and mild. According to the Weather Bureau, the average annual precipitation at Plainview over a period of 62 years (1894–1955) was 21.28 inches. The annual precipitation ranged from a maximum of 38.10 inches in 1926 to a minimum of 10.20 inches in 1917 (fig. 2). July is the wettest month, having an average precipitation of 3.21 inches; January is the driest month, having an average of 0.50 inch.

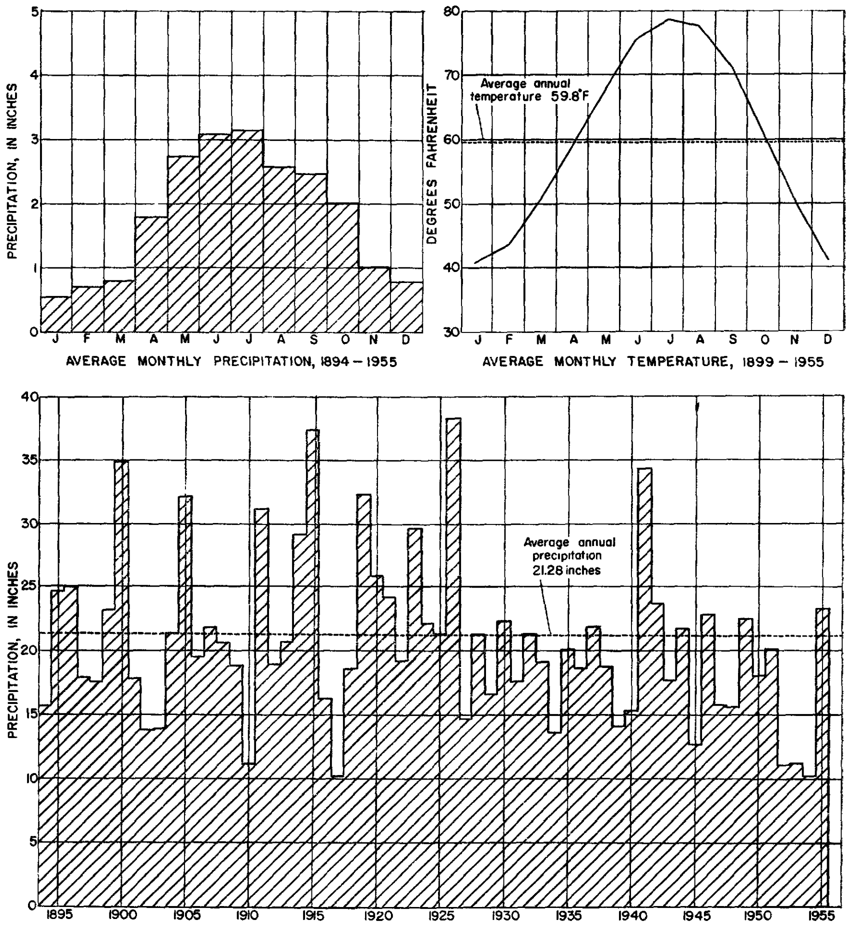

FIGURE 2.—Precipitation and temperature at Plainview. (From records of the U.S. Weather Bureau.)

The mean annual temperature at Plainview during the 57-year period 1899–1955 was 59.8° F. The highest temperature recorded during 1955 was 101°F in June, and the lowest was 3°F in February. The average monthly temperature ranges from 78.5°F in July to 40.8°F in January (fig. 2).

Long-term records of evaporation are not available for Hale County; however, the records for the station maintained by the Texas Agricultural Experimental Station near Lubbock, Tex., may be considered as nearly representative for Hale County. Records from this station for a period of 37 years (1917–53) show that the average annual evaporation from a Bureau of Plant Industry pan was 63.80 inches (Bloodgood and others, 1954, p. 22). The average monthly pan evaporation ranges from 8.83 inches in July to 1.77 inches in January (fig. 3).

NATURAL RESOURCES AND ECONOMIC DEVELOPMENT

The economy of Hale County is dependent largely on agriculture maintained by irrigation. The county is one of the most intensively cultivated in the State. In 1955 about 470,000 acres was irrigated out of a total of 536,000 in cultivation.

The principal irrigated crops are grain sorghum and cotton; about 230,000 acres of grain sorghum and 170,000 acres of cotton were irrigated in 1955. Other irrigated crops include wheat, alfalfa, sudangrass, corn, barley, oats, and pasture. Other agricultural pursuits include dairying, stock farming, and poultry production.

Oil was discovered in Hale County in 1946 and has become an important source of income. According to the Texas Railroad Commission, 2,302,198 barrels of oil was produced in 1954 from several fields in the southern part of the county.

Other industries in the county include grain storage, alfalfa dehydration, and manufacture of farm implements and machine-shop products.

PREVIOUS INVESTIGATIONS

Ground water in Hale County has not hitherto been studied in detail; however, many reports on larger areas have presented data pertaining to the county. Early reports by Johnson (1902) and Baker (1915) briefly described the geology and utilization of the High Plains. A series of reports published periodically have summarized the work of the Geological Survey and the Texas Board of Water Engineers in the High Plains; the most comprehensive of these was a report by Barnes and others (1949). Since 1938 the results of measurements of water levels in observation wells in Hale County have been published in the annual reports of the Geological Survey on water levels and artesian pressures in the United States.

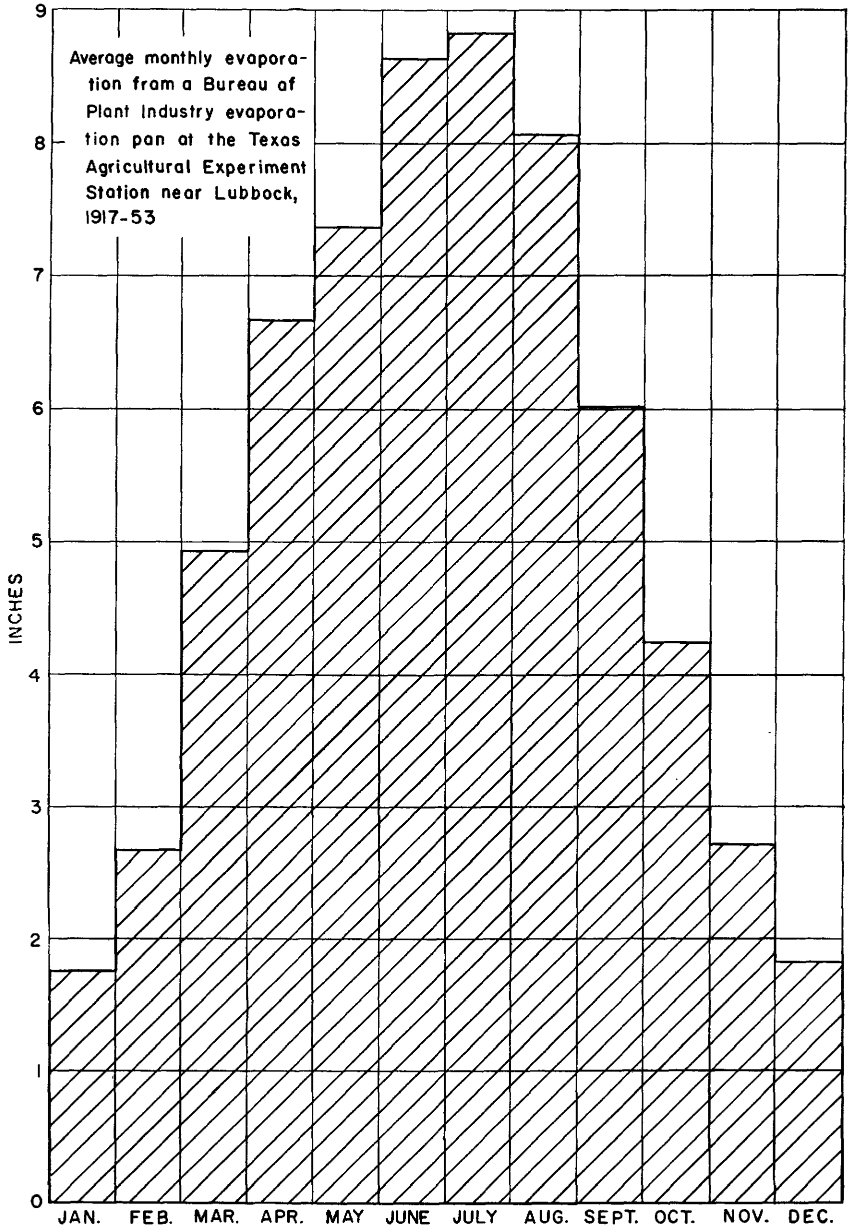

FIGURE 3.—Pan evaporation near Lubbock.

The first report specifically on Hale County was a well-inventory report by Broadhurst and others (1938). The report consists of tables of well records, well logs, and water analyses, and a map showing the location of the wells listed. A similar report (Merritt and Follett, 1946) includes records through 1946.

Annual water-level measurements made in wells on the High Plains up to and including 1953 were published by the Texas Board of Water Engineers (Follett, 1953).

The public water supplies at Abernathy, Hale Center, Petersburg, and Plainview have been described by Broadhurst and others (1951, p. 80–82).

WELL-NUMBERING SYSTEM

In the reports by Broadhurst and others (1938) and Merritt and Follett (1946), the wells were numbered consecutively in one series. With the tremendous development of irrigation in the county, this system became unwieldy and a system based on the location of the wells within the county was devised. Lines of latitude and longitude have been used to establish a modified 5-minute grid system. The grid rectangles are identified by letters of the alphabet starting with A in the northwest corner of the county and continuing in a west-to-east and north-to-south succession. Within the rectangles the wells are numbered consecutively (roughly from northwest to southeast).

Table 1 is an index of well numbers published previously and corresponding numbers in this report.

ACKNOWLEDGMENTS

The writers acknowledge their indebtedness to many farmers and ranchers for their cooperation in supplying information about their wells and permitting access to their properties. They are grateful also to the well drillers and pump companies who gave freely of data from their files and to the officials of the cities in the county for their records of municipal wells. Special thanks are extended to the mayor, the city council, and the employees of the water department of the city of Plainview for their splendid cooperation during an aquifer test for which the city drilled two observation wells.

TABLE 1.—*Index of well numbers published by the Texas Board of Water Engineers (Broadhurst and others, 1938; Merritt and Follett, 1946; and Follett, 1953) and the corresponding well numbers shown in the records of selected wells in this report*

Well No., this report	Well No., 1938 report	Well No., 1946 report	Well No., 1953 report
A- 4		63	
30		58	
31		59	
35		70	70
44	24	24	
46	23	23	
49		56	
59		55	
61	22	22	
B- 14	6	6	
17		81	81
39		131	
46		92	
67	15	15	15
C- 7	103	103	103
13		174	
24		138	138
46	105	105	105
D- 15	268	268	
16	202	202	202
33		225	225
42		285	285
50	267	267	
52	222	222	
54	228	228	
E- 1	206	206	206
8	212	212	212
44	311	311	
47	220	220	220
66		1206	
75	315	315	
F- 11	308	308	
13 [1]			
28	319	319	
30		398	
40	316	316	316
52	323	323	323
53		334	334
88	324	324	
89	391	391	
G- 20		53	
27			40a
63			31a
69	601	601	
70		641	641
97	21	21	
98	40	40	
99	31	31	
100	39	39	
H- 1	18	18	
11		93	93
32		86	86
49	36	36	36
57		153	
59		154	154
82		1610	
95		656	
103	607	607	
J- 11		159	159
20		163	163
31	118	118	
60 [2]		172	124b
75	611	611	
89	126	126	
90	124	124	
91	500	500	
K- 10		165	165
47		1223	1223
K- 49		262	
65		1226	
72	259	259	259
94	509	509	509
103		583	
109	256	256	256
110	511	511	511
111	255	255	255
L- 6	238	238	238
28		1231	1231
29	241	241	241
81	273	273	
82	272	272	
83	274	274	
89		1336	1336
116 [3]			407a
M- 1 [4]			
10	331	331	331
11	332	332	332
36	343	343	
46		367	367
60	348	348	
79		389	389
122	388	388	
123	386	386	
124	384	384	
125	385	385	
126	390	390	
127	480	480	
128	496	496	
N- 73		676	
91	623	623	
92	627	627	
P- 13	622	622	
71		698	
76		696	
98	620	620	
99	628	628	
100	629	629	629
Q- 9		661	661
37	617	617	617
68		1604	1604
95		1606	
R- 4	508	508	508
63		1501	
90 [5]			
101		546	546
115	533	533	
116	558	558	
S- 35		1447	
39		1413	
59		1417	1417
100		1428	
121	481	481	
122	518	518	
T- 19	427	427	427
51		1436	1436
67		1433	1433
77	454	454	454
97	459	459	459
98	463	463	463
99	462	462	462
100		1430	1430
110	451	451	
111	486	486	
112	438	438	
U- 9		680	
12		682	

[1] Hale County well 317a in U.S. Geol. Survey Water-Supply Paper 1159.
[2] Hale County well 124b in U.S. Geol. Survey Water-Supply Paper 947.
[3] Hale County well 407a in U.S. Geol. Survey Water-Supply Paper 1224.
[4] Hale County well 330a in U.S. Geol. Survey Water-Supply Paper 1159.
[5] Hale County well 539a in U.S. Geol. Survey Water-Supply Paper 1159.

TABLE 1.—*Index of well numbers published by the Texas Board of Water Engineers*—Continued

Well No., this report	Well No., 1938 report	Well No., 1946 report	Well No., 1953 report	Well No., this report	Well No., 1938 report	Well No., 1946 report	Well No., 1953 report
U- 40	707	707	----------	EE-104	818	818	----------
74	----------	----------	704a	FF- 48	----------	945	----------
86	625	625	----------	55	942	942	942
V- 14	----------	688	----------	146	----------	1917	----------
115	----------	634	----------	159	964	964	964
116	639	639	----------	160	929	929	----------
117	710	710	----------	161	949	949	----------
W- 4	----------	1609	1609	GG- 91	----------	738	738
51	----------	764	----------	99	740	740	----------
112	573	573	----------	100	739	739	----------
X- 36	569	569	569	HH- 1	724	724	724
37	----------	562	562	9	----------	726	----------
38	----------	1527	----------	120	725	725	----------
47	553	553	553	JJ- 40	848	848	848
98	801	801	----------	64	850	850	----------
99	802	802	----------	65	849	849	----------
100	803	803	----------	66	----------	1816	----------
Y- 9	----------	----------	1529	123	732	732	----------
49	----------	902	----------	124	----------	1817	----------
81	923	923	923	125	----------	1818	----------
99	805	805	----------	126	862	862	----------
100	921	921	----------	127	731	731	----------
Z- 17	467	467	467	KK- 45	857	857	----------
73	906	906	906	54	----------	1811	1811
121	471	471	----------	115	854	854	----------
122	469	469	----------	LL- 35	----------	1829	----------
AA- 82	721	721	----------	52	----------	1928	----------
83	722	722	----------	54	973	973	----------
BB- 14	717	717	----------	77	----------	1932	----------
19	----------	714	714	103	977	977	----------
29	----------	762	----------	106	975	975	----------
91	723	723	----------	MM- 50	----------	1924	----------
104	----------	786	----------	52	----------	1923	----------
113	749	749	----------	61	----------	1921	1921
114	716	716	----------	77	974	974	----------
CC- 1	----------	713	----------	81	----------	----------	1957
21	----------	829	829	96	----------	1945	----------
120	828	828	828	120	978	978	978
121	827	827	----------	137	979	979	----------
122	728	728	----------	159	969	969	----------
EE- 20	816	816	816	160	----------	1908	----------
74	840	840	840	163	----------	1942	----------

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING PROPERTIES

GENERAL GEOLOGY

Hale County is underlain in most places by unconsolidated rocks of Pliocene and younger age, a part of which constitutes the Ogallala formation, the principal fresh-water-bearing formation in the county. These deposits lie on an erosion surface of rocks of Cretaceous and Triassic age and dip gently toward the southeast, in the general direction of topographic slope.

Cretaceous rocks of marine origin, some of which yield large quantities of water, underlie the Ogallala formation in about one-fifth of the county and have been removed by erosion in the remainder of the county. Where the Cretaceous rocks are absent, the Ogallala overlies red beds of Triassic age. The Triassic rocks overlie red beds of Permian age.

Pertinent data concerning the water-bearing formations in Hale County are summarized in table 2. The geologic sections (pl. 2) show the geologic structure of the formations underlying the county and the relations between the various formations.

PERMIAN SYSTEM

Rocks of Permian age in Hale County consist of beds of red sandstone, clay, shale, gypsum, dolomite, and limestone more than 5,000 feet thick. The rocks have not been penetrated by water wells, and their water-yielding properties have not been determined. Electric logs of oil tests, however, indicate that the Permian rocks contain saline water.

TRIASSIC SYSTEM

DOCKUM GROUP

Rocks presumed to be of the Dockum group of Triassic age underlie Hale County at depths ranging from 150 to nearly 400 feet below the land surface. The Dockum group ranges in thickness from about 300 to 1,000 feet and consists characteristically of variegated shale, most of which is dark-red to maroon micaceous sandstone and conglomerate. The group comprises the red beds immediately underlying the Cretaceous rocks and the Ogallala formation in the county. The Triassic rocks resemble the underlying Permian rocks closely, and it is difficult to distinguish the two. In general, however, the Triassic shale is more massive and deeper red than the Permian shale, and it is micaceous whereas the Permian shale is not.

The Dockum group has not been tested for water in Hale County; however, data from tests in nearby areas suggest that the water is too highly mineralized, insufficient in quantity, or both, to be used for irrigation, industrial, or municipal supplies. The chemical analysis of a water sample from the Dockum group from a well 2 miles northwest of Lubbock showed 20,600 ppm (parts per million) of dissolved solids and 10,800 ppm of chloride. The water was obtained at a depth of 953 to 999 feet from a sandstone in the Dockum group. Another well testing the same sandstone at a depth of 825 feet in Floyd County, 1½ miles north and 5 miles east of Petersburg, produced water containing 13,700 ppm of dissolved solids and 7,320 ppm of chloride. The initial yield of this well was 250 gpm (gallons per minute), but after 72 hours of pumping the yield decreased to 150 gpm. An exploratory well testing the Dockum group in Bailey County failed to yield adequate quantities of water for irrigation after pumping 10 minutes, according to reports. In Cochran County a water sample obtained from a drill-stem test of the Dockum group contained 2,070 ppm of dissolved solids and 590 ppm of chloride. This well, however, produced only 15 gpm with a large drawdown.

TABLE 2.—*Geologic formations and their water-bearing properties, Hale County, Tex.*

System	Series	Subdivision		Thickness (feet)	Physical character	Water-bearing properites	Remarks
Quaternary	Recent and Pleistocene			0–75	Silt, clay, sand, gravel, and caliche	Not a source of water.	Sand dunes, streams, channels and playa deposits.
Tertiary	Pliocene	Ogallala formation		70–400+	Fine to coarse sand, gravel, clay, silt, and caliche. Sediments generally are reddish.	Principal aquifer in the county.	
Cretaceous	Comanche	Washita and Fredericksburg group	Duck Creek limestone (Washita) and Kiamichi formation (Fredericksburg) undifferentiated	0–110±	Yellowish limestone, yellow, blue, and white clay, and sandstone.	Cracks, crevices, and caverns in limestone yield large quantities of water locally.	Underlies approximately one-fifth of the county.
Triassic		Dockum group		300–1,000	Variegated shale, micaceous sandstone, and conglomerate.	Contain highly mineralized water.	Locally called red beds; underlies all the county.
Permian				5,000±	Red shale, sandstone, clay, limestone, dolomite, and gypsum.	Contain highly mineralized water.	Locally called red beds. Penetrated only in test for oil and gas.

CRETACEOUS SYSTEM

COMANCHE SERIES

FREDERICKSBURG AND WASHITA GROUPS

KIAMICHI FORMATION AND DUCK CREEK LIMESTONE, UNDIFFERENTIATED

Rocks of Cretaceous age in Hale County consist of the Kiamichi formation of the Fredericksburg group and the Duck Creek limestone of the Washita group. The Cretaceous rocks are not exposed in the county, and it is difficult to distinguish the formations in the subsurface; consequently, they are not differentiated in this report. The two formations have been differentiated in outcrop in Lamb County (Leggat, 1957, p. 14).

The Cretaceous rocks lie unconformably on rocks of the Dockum group and are, in turn, overlain unconformably by the Ogallala formation. The strata dip gently southeastward. Cretaceous rocks formerly underlay all the county, but they were removed by pre-Ogallala erosion from all but approximately the southern fifth of the county. The areal extent and altitude of the top of the Cretaceous rocks are shown on plate 3. The Cretaceous strata, where present, range in depth below the land surface from less than 50 to nearly 200 feet. The buried Cretaceous rocks form mesas, buttes, and plateaus similar in form to those exposed in the Edwards Plateau country to the south.

Cretaceous rocks in Hale County consist mainly of limestone and shale and minor amounts of sandstone. The uppermost unit of the Cretaceous rocks consists of a layer of hard yellow limestone that averages 20 to 30 feet in thickness. The limestone is underlain mainly by beds of yellow and blue shale and in places by beds of gray or white shale. The rocks contain a few thin layers of sandstone in some places. Cretaceous rocks in the county range in thickness from 0 to about 110 feet. The Cretaceous section probably was much thicker before the pre-Ogallala erosion.

Cretaceous rocks yield water in amounts as much as 900 gpm to wells from cracks or caverns in the limestone. A well that penetrates a single large crack may have a smaller yield than a well that penetrates smaller but more numerous cracks. Limestone having numerous cracks resembles a loose sand hydrologically. Wells that do not penetrate cracks or cavities yield only small quantities of water.

Aquifers in the Cretaceous limestone presumably are recharged through the overlying Ogallala formation, as is strongly suggested by the similarity of the chemical analyses of water from two wells (Z-82 and JJ-125) tapping the Cretaceous rocks and nearby wells (Z-121 and LL-55) tapping the Ogallala formation.

TERTIARY SYSTEM

PLIOCENE SERIES

OGALLALA FORMATION

The Ogallala formation underlies the entire county. The formation was deposited upon the eroded surface of Triassic and Cretaceous rocks by streams whose headwaters were in the Rocky Mountain area to the west. The erosion surface upon which the Ogallala was deposited is shown in plate 3. In general, the pre-Ogallala surface was more mature and had greater relief than that of the present. The Triassic rocks were eroded to form low hills and wide, gentle-sided valleys containing deep, narrow stream channels. The Cretaceous rocks were more resistant to erosion and remain as small buried mesas or buttes. Streams in pre-Ogallala time flowed generally southeastward, as do the streams of the present, although the remnant Cretaceous buttes may have diverted some streamflow northeastward for short distances. The streams were laden heavily with gravel, sand, and silt and shifted their courses widely over the area that is now the High Plains. At each change in the course of the streams, deposits of sand, gravel, and silt were left in the old channels and on flood plains that were later buried beneath similar material during subsequent shifting of the streams. According to Johnson (1902, p. 638), the Ogallala was laid down in substantially its present position as to elevation and dip. The Ogallala dips southeastward about 10 feet per mile.

Since the deposition of the Ogallala, streams have begun to degrade the formation. The Canadian River has cut through the Ogallala in most of its course through Texas, so that the formation is divided into two units having little hydraulic connection. Erosion on the eastern, southern, and western edges of the High Plains has formed escarpments where the Ogallala formation, Cretaceous rocks, and red beds crop out. The southern High Plains, although relatively flat, stands in high relief and is hydraulically independent of contiguous areas.

The Ogallala formation consists of interfingering bodies of fine to coarse sand, gravel, silt, clay, and caliche. The lithology varies greatly within short distances, both laterally and vertically. The material is predominantly red. For the most part, the beds of sand and gravel are unconsolidated, but in places they are fairly well cemented. The formation ranges in thickness from about 70 to more than 400 feet.

Caliche is a major constituent of the Ogallala, especially in the upper part of the formation. In many places the caliche forms hard, dense layers, which tend to impede the movement of water. In other places the caliche is soft and porous or is fractured and offers comparatively little resistance to the flow of water.

The Ogallala formation is the principal aquifer throughout the High Plains, and it yields large quantities of water to wells for irrigation, public supply, and industrial uses in Hale County. Yields of wells range from a few gallons per minute from domestic and stock wells to as much as 1,800 gpm from irrigation wells. The water generally is of good chemical quality except that it is hard; the fluoride content is excessive in most places, however.

QUATERNARY SYSTEM

PLEISTOCENE AND RECENT SERIES

Rocks of Pleistocene and Recent age mantle the Ogallala formation throughout most of Hale County. The rocks of Pleistocene age consist of beds of clay, silt, fine to coarse sand, and gravel which range in thickness from 0 to about 75 feet. Clay and silt predominate in the playa-lake deposits and the coarser materials predominate in the valleys of the Double Mountain Fork of the Brazos River and Running Water Draw.

Valley fill of the Double Mountain Fork of the Brazos River and Running Water Draw consists of deposits of Recent age. Sand dunes in the western part of the county and windblown material that mantles most of the land surface are of Recent age. Recent deposits probably are not more than 40 feet thick at a maximum.

Pleistocene and Recent deposits are above the water table in the county and are not water bearing. The sandy areas, however, particularly those having dunes, facilitate recharge to the underlying Ogallala formation.

GROUND WATER

OCCURRENCE

The fresh-water aquifer underlying Hale County is part of the extensive aquifer underlying the southern High Plains. The only source of recharge to the aquifer is precipitation, the plains being hydraulically isolated from the surrounding area by erosion. A small part of precipitation on the area percolates downward to the water table (upper surface of the saturated zone) and then moves laterally to be discharged from seeps along the edge of the plains or from wells and springs. The principal water-bearing formation in Hale County and in the High Plains is the Ogallala formation. Limestone of Cretaceous age, which contains appreciable quantities of water in the southern part of Hale County, underlies and is hydraulically connected with the Ogallala formation and is considered part of the same aquifer.

The aquifer has no lateral boundaries within the county. The relatively impermeable red beds of Triassic age form the lower boundary of the aquifer and mark the lower extent of fresh water. The ground water generally is unconfined. Locally, however, where the water is confined beneath lenticular bodies of clay of limited areal extent, it may be under slight artesian pressure.

Water in the saturated zone fills the pore spaces or voids in the rocks. The voids in the Ogallala range in size from very small pores in the clay and silt to large solution channels in the caliche. Most of the water available to wells from the Ogallala is in the sand and gravel.

The size of the voids in the Cretaceous formations may vary more than in the Ogallala, ranging from minute pores to cavernous passageways. Most of the water available to wells occurs in cracks, crevices, and solution channels in the limestone.

HYDRAULIC PROPERTIES OF THE AQUIFER

The capacity of an aquifer to yield water to wells depends largely upon its hydraulic properties. The coefficients of permeability, transmissibility, and storage are terms used to describe these properties.

The coefficient of permeability is the rate of flow of water, in gallons a day, through a cross section of 1 square foot under a unit hydraulic gradient. The standard coefficient is defined for water at a temperature of 60° F. The field coefficient of permeability requires no temperature adjustment and the units are stated in terms of the prevailing water temperature.

The coefficient of transmissibility is the number of gallons of water that will move in 1 day through a vertical strip of the aquifer 1 foot wide and having the height of the aquifer when the hydraulic gradient is unity (Theis, 1938, p. 894). It is the field coefficient of permeability times the thickness of the aquifer, in feet.

The coefficient of storage of an aquifer is the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. For an unconfined aquifer the coefficient of storage is virtually the same as the specific yield, which is defined as the unit volume of water that will drain by gravity from a unit volume of saturated material.

Coefficients of permeability, transmissibility, and storage may be determined or estimated by field and laboratory methods. Previous ground-water investigations in the High Plains of Texas and New Mexico have employed both methods.

Theis (1937, p. 566) reported that the coefficient of permeability ranged from 15 to 125 and averaged 60 gpd per square foot for 23 samples of the Ogallala formation in Lea County, N. Mex.

Alexander, Broadhurst, and White (1943, p. 15–16) estimated the specific yield by comparing the pumpage with the volume of Ogallala deposits dewatered during a 3-year period, 1938–41. The estimates assume that no recharge occurred during this period. They estimated the specific yield to be 14.1 percent for the "Plainview district" and 14.5 percent for the "Hereford district." Barnes and others (1949, p. 39–41) determined the specific yield of eight samples of sand and gravel from the Ogallala formation. They concluded that the average specific yield of the Ogallala probably is greater than 15 but less than 20 percent.

Pumping tests made in the High Plains before 1954 were too short for an accurate determination of the coefficients of transmissibility or storage. In 1954 and 1955, recharge tests of long duration near Amarillo, Tex. (Moulder and Frazor, 1957, p. 15), showed that the coefficient of transmissibility of the aquifer ranged from 6,000 to 7,000 gpd per ft and that the coefficient of storage ranged from 0.09 to 0.16.

A long-duration test made in cooperation with the city of Plainview during the period November 1955 to March 1956 provided additional data on aquifer properties in Hale County. During the test, well L–84, a public-supply well, was pumped and water levels were observed in it and in two observation wells (L–112 and L–113) drilled especially by the city for the test. The pumping period, drawdown and recovery of water levels, and location of the wells are shown on figure 4. The two observation wells were checked twice—once before pumping and once near the end of pumping—by pouring water down the wells to verify the hydraulic connection between the wells and the aquifer. The pumping rate was kept within 1 percent of the average rate at all times during the test.

The water-level data were adjusted and plotted against time (figs. 5, 6 and 12). The adjustments and computations were made according to methods developed by Theis (1935), Jacob (1944), and Cooper and Jacob (1946).

Only data from late in the drawdown and recovery tests were used in calculating aquifer coefficients. The water-level data from the early part of the drawdown and recovery tests were not used for calculating aquifer coefficients, principally because one of the assumed conditions of the nonequilibrium (unsteady-state) method was not approximated closely during these periods. The method assumes that water is released from or taken into storage immediately as the

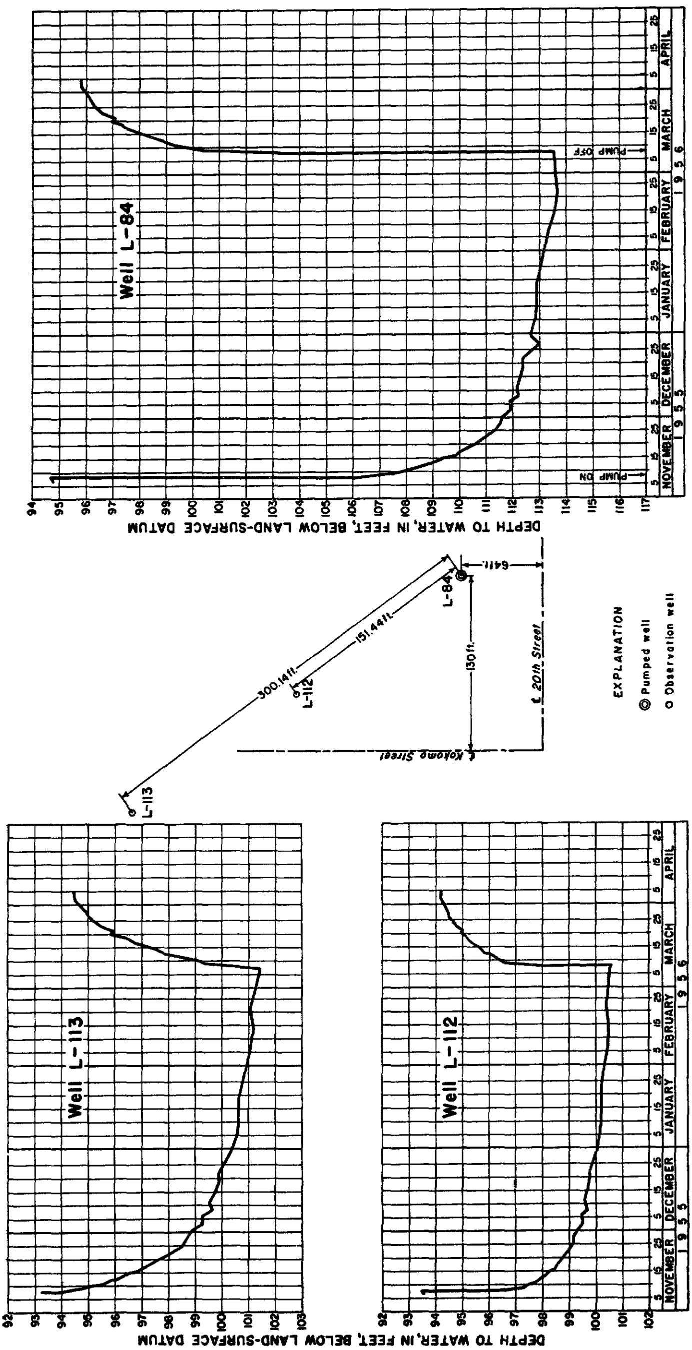

FIGURE 4.—Pumping period, drawdown and recovery of water levels, and location of test wells, Plainview.

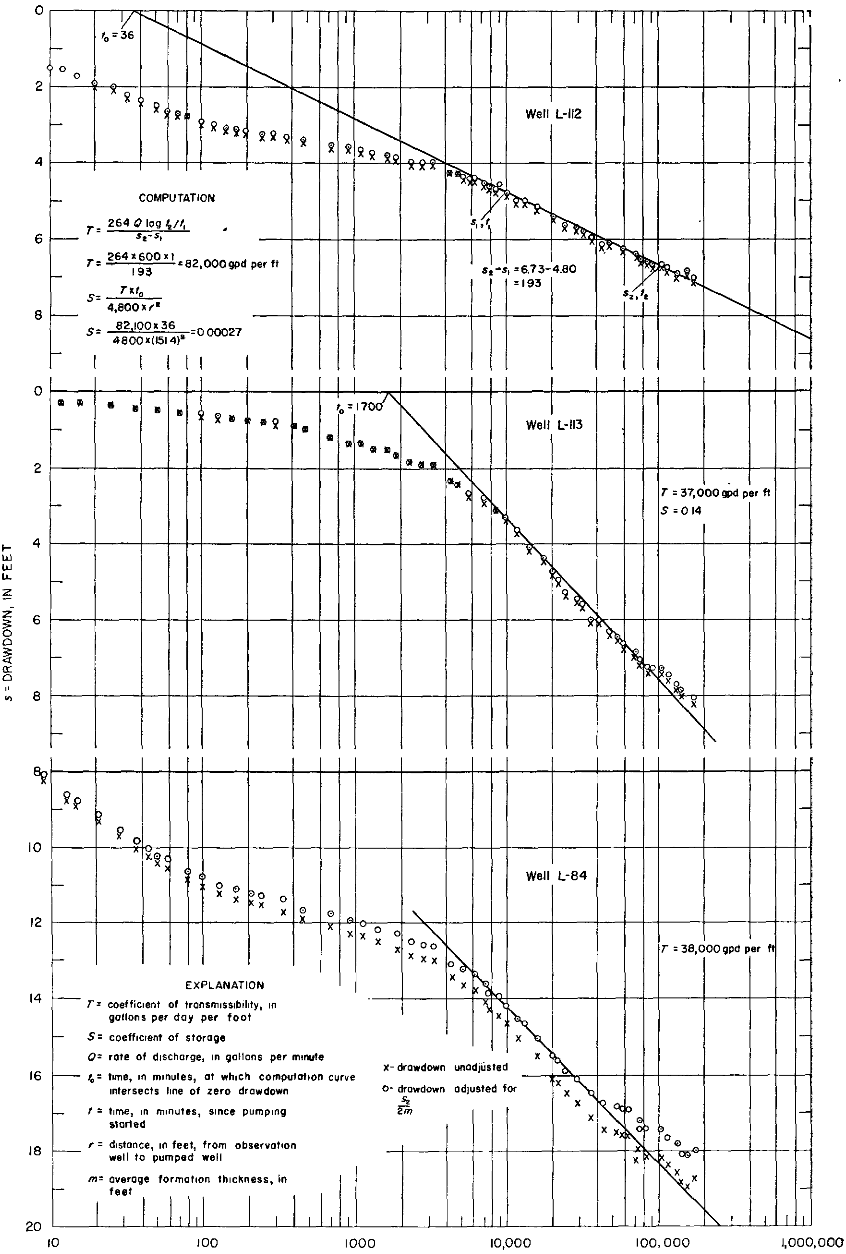

Figure 5.—Nonequilibrium method of analysis of drawdown data for wells L–112, L–113, and L–84.

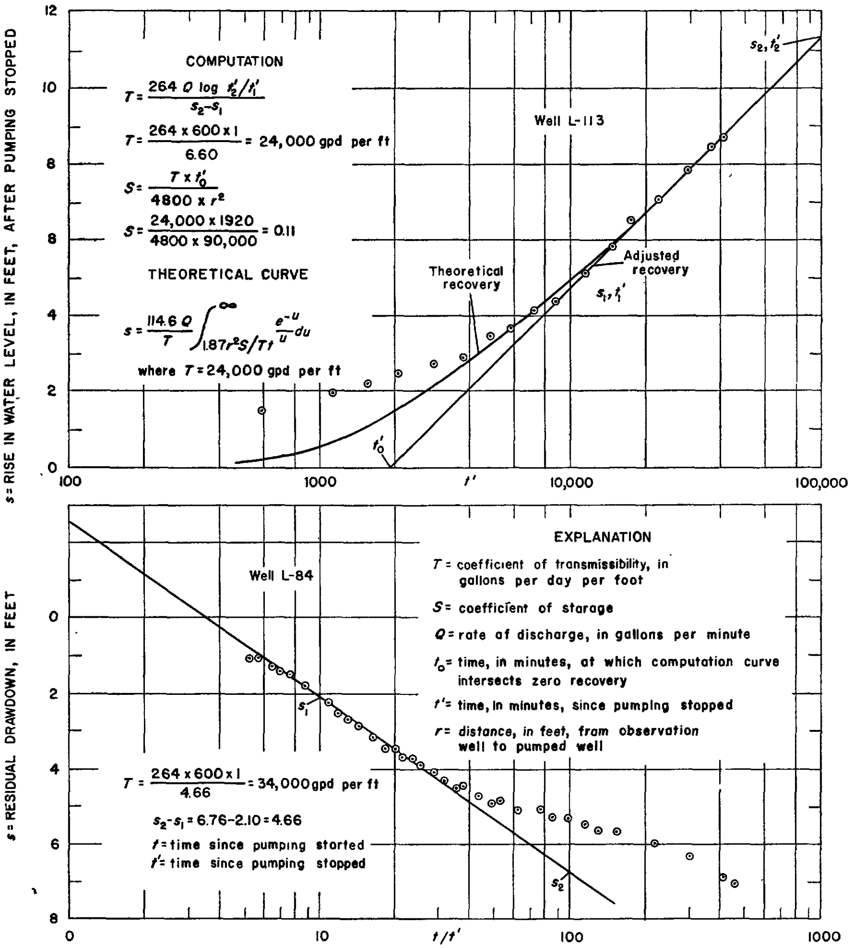

Figure 6.—Nonequilibrium method of analysis of adjusted recovery data for wells L–113 and L–84.

piezometric surface rises or declines, as indicated by water levels in wells. Actually, when pumping starts, an appreciable amount of water becomes suspended temporarily above the rapidly lowering water table near the pumped well. As the rate of decline decreases, the suspended water drains to the water table and the cone of depression develops more nearly in accordance with the conditions assumed by the nonequilibrium method.

The water-level data from well L–112 probably are unsuitable for calculating aquifer coefficients. The drawdown data from well L–112 obviously conflict with data from wells L–84 and L–113. Figure 4 shows that the total drawdown in well L–113 was greater than in well L–112, despite the fact that well L–113 is farther away from the pumping well. The cause is not readily apparent as both wells were constructed similarly and neither well showed signs of being even partly plugged. Although both wells were of the same depth, neither penetrated the full thickness of the aquifer as did the pumping well. A possible explanation is that well L-113 and well L-84 tap a highly permeable zone that is not present in well L-112.

The fact that the rate of drawdown in well L-113 during the late part of the pumping period corresponds closely with the rate of drawdown in the pumped well (L-84) suggests that the data from both these wells can be used to compute aquifer coefficients.

Precise values for aquifer coefficients at the test site appear to be unobtainable owing to certain discrepancies. Transmissibilities based on the drawdown data from wells L-84 and L-113 agree closely; however, the transmissibility calculated from the recovery data is slightly less for well L-84 and considerably less for well L-113 (figs. 5 and 6). Part of the difference between drawdown and recovery data could be explained if the water levels at the test site before the test were recovering from previous pumping from this well and nearby irrigation wells. Although an insufficient number of water-level records is available to show a trend before pumping, nearby irrigation wells were shut down for the winter and water levels probably were rising. If such a trend appreciably affected water levels at the test site, the true transmissibility would be less than that calculated from the drawdown data.

Probably the true coefficient of transmissibility at the test site is between 24,000 and 38,000 gpd per foot; it may be somewhat less than 38,000 but probably is not less than 34,000 gpd per foot. The true coefficient of storage is between 0.11 and 0.14 but probably is nearer 0.14.

The coefficient of storage from the test is representative of only the part of the aquifer dewatered by the pumping; however, it agrees closely with estimates by previous investigators. The apparent field permeability of the formation is between about 100 and 170 gpd per square foot, on the basis of the total saturated thickness.

No data are available for the High Plains regarding the hydraulic properties of the Cretaceous rocks.

MOVEMENT

The configuration of the water table in Hale County in 1955 is shown by contour lines on plate 5. Ground water tends to move in the direction of the greatest slope of the water table, which is perpendicular to the contour lines. In general, the water moves southeastward through the county, and the average slope of the water table is about 9 feet per mile. The movement of the water is very slow. If the average permeability of the aquifer in the county is equal to that determined from the aquifer test at Plainview, if the porosity of the aquifer is 0.3, and if the average slope of the water table is 9 feet per mile, the water is moving through the county at roughly 2 inches per day.

Uniform hydrologic conditions generally are reflected by a smoothly sloping water table. Irregularities in the contour pattern are the result of differences in recharge-discharge relation, in the permeability and thickness of the water-bearing material, and in the slope of the confining beds underlying the aquifer.

RECHARGE

NATURAL RECHARGE

The aquifer in Hale County is recharged by precipitation in Hale County and in part of the southern High Plains to the northwest. Most of the precipitation on the plains is retained temporarily in depressions or in the soil close to the land surface, from which it evaporates or is transpired by plants. A small part of the water percolates downward below the root zone and eventually reaches the water table.

Recharge to the aquifer by underflow from the northwest is fairly uniform, but recharge from the surface is irregular, owing to irregular rainfall and differences in topography and soils. Recharge from the surface is the most important to residents of Hale County because accretions from this source cause a rise in the water table, whereas the accretions from underflow into the county are approximately negated by underflow out of the county.

Several factors tend to retard the rate of recharge from the surface in the county. Two of the most important are the clay-loam soil and the layer of caliche that closely underlies the land surface throughout much of the county. Some of the caliche is relatively impermeable and retards the downward movement of water, holding it in reach of the roots of plants which consume it by transpiration. The clay-loam soils common in Hale County have a low permeability and are capable of storing large quantities of water as soil moisture between periods of precipitation. As the soil close to the land surface becomes dry from evapotranspiration, differences in vapor pressure and capillarity cause water from the deeper moist zones to move upward. Recharge is retarded also by relatively impermeable silt and clay deposits that form the bottom of most of the lakes and ponds and by compacted soil in uncultivated areas.

Recharge is greatest when rains are of sufficient intensity and duration to increase the soil moisture to a point where the capillary forces in the soil become small in comparison to gravitational forces. During and after rains of this type, considerable quantities of water may recharge the aquifer in areas where the caliche is absent or where it contains cracks and solution channels. The caliche is absent in most places along the principal drainageways, which generally are underlain by relatively coarse material. Thus, the drainageways are the most favorable areas for recharge. A sharp rise in water level in wells near the drainageways after heavy precipitation substantiates this conclusion. The abrupt rise in water level, as shown in the hydrograph of well K–110 (fig. 7), which is near Running Water Draw, can be correlated with intense storms.

Records of daily precipitation at Plainview in 1955 and daily water-level measurements in wells J–92 and L–116 (fig. 8) show the effect of heavy precipitation on the water table. The water levels in both wells rose appreciably after the heavy rains in May. A rise in water level after an extended wet period probably is caused only in part by the percolating water recharging the aquifer; part of the rise is caused by a decrease in withdrawal of water for irrigation during the wet period. Because these two factors cannot be separated quantitatively with existing data, the amount of rise from recharge cannot be estimated accurately.

Water levels rose after the abnormally great rainfall in 1941 (34.35 inches recorded at Plainview). Water levels in all the observations wells rose noticeably and some rose nearly 10 feet (well T–99, fig. 7). A large part of the rise during this period can be attributed to recharge.

The effect on water levels of precipitation in 1947, 1951, and 1955 is shown by the hydrographs of wells T–99, T–77, J–92, and L–116 (figs. 7, 8). The effect is shown either as a rise in water level or as a reduced rate of decline. A part of the change in water level during these periods was caused by recharge, although some of it may have resulted from reduced withdrawal.

A comparison of water-level changes with precipitation data suggests that water levels rise appreciably only when rainfall totals 10 inches or more within a period of 2 or 3 months. Accretions to the aquifer during periods of less intense rain may occur despite the lack of evidence shown by the water-level records. Further study is needed to determine more accurately the relation between precipitation and recharge.

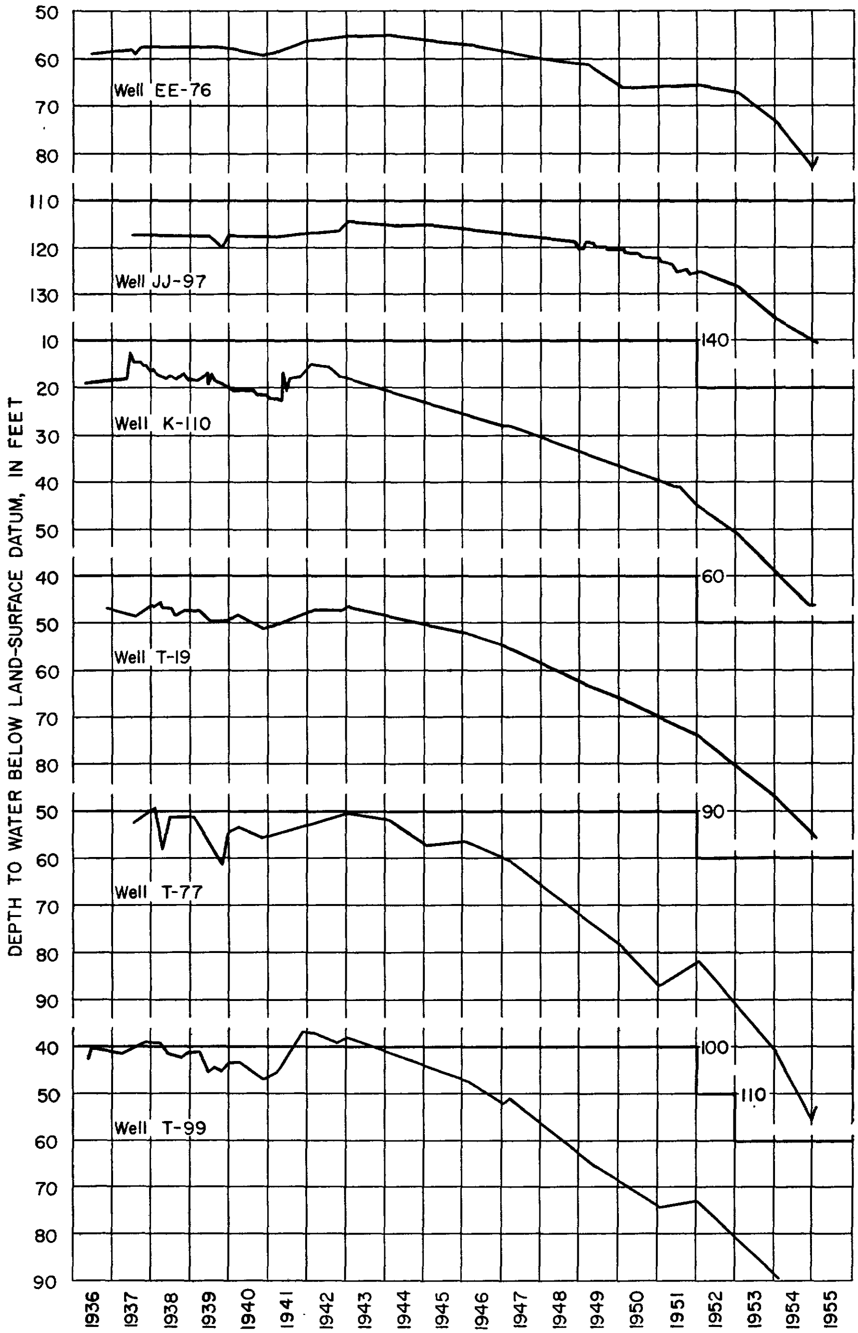

FIGURE 7.—Hydrographs of representative wells in Hale County.

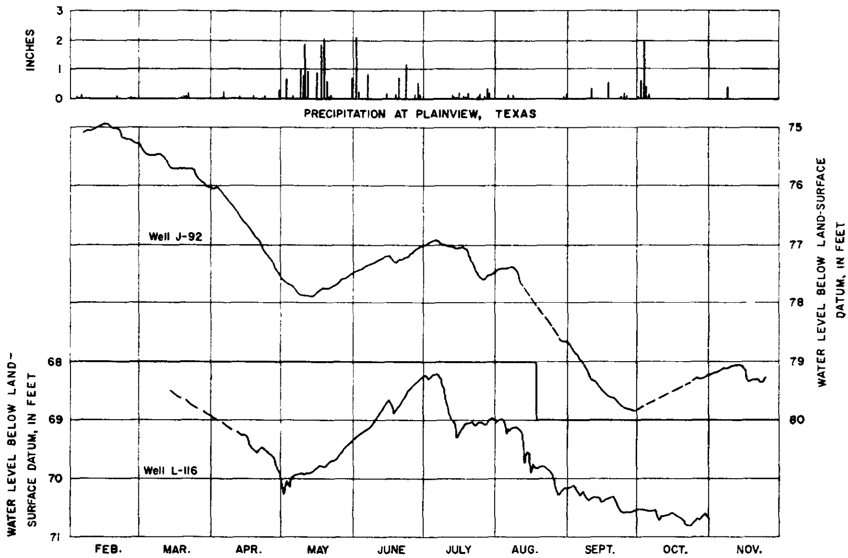

FIGURE 8.—Hydrographs of wells J–92 and L–116 and daily precipitation at Plainview, February–November 1955.

ARTIFICIAL RECHARGE

Artificial recharge has been given considerable attention, although in 1955 it was not practiced extensively in Hale County except unintentionally. Return flow from irrigation may be considered as a form of artificial recharge. Field observations suggest that recharge from this source probably is of little consequence, owing to low rates of application of irrigation water and high rates of evapotranspiration. However, waste water in ditches and ponds is evidence that in some areas the fields are being irrigated in excess of crop requirements. Some of this excess water undoubtedly returns to the aquifer in areas where the soil and subsoil are relatively permeable.

Artificial recharge may be divided into three classes: (a) recharge by surface spreading; (b) recharge through pits, ditches, and ponds; and (c) recharge through wells. Recharge from irrigation losses is a form of surface spreading. Each of the three methods of recharging has been practiced successfully in various parts of the United States, but each method has certain unfavorable aspects. The principal difficulty, clogging, is common to all three methods. The pore spaces on the surface of the ground, sides of the pits, or walls of the well tend to become clogged by sediment or organic materials, or by chemical and physical reactions.

Several recharge experiments have been made on the High Plains with varying degrees of success. The city of Lubbock has spreading grounds for sewage effluent east of the city. Although the primary purpose is disposal to avoid contaminating surface-water supplies, the project has demonstrated that surface spreading may be a feasible method of recharging the aquifers in the High Plains. Most of the other recorded recharge projects or experiments have involved the use of recharge wells.

The well method of recharge appears to be the most popular to the conservation-minded people of the High Plains because it greatly reduces the loss of water by evaporation. Several recharge wells in Hale County have been used periodically since 1950. Basically the installations are similar; each recharge well is constructed like most of the irrigation wells except that the casing is connectd by a pipe to a pond or lake which is the source of recharge water. Each well is equipped with a turbine pump, which is used to recover the recharge water and to pump out sediment or other material that may tend to clog the well screen and surrounding aquifer. Experience on the plains to date indicates that pumping the recharge wells periodically during recharge operations will keep the wells from becoming seriously clogged; so far, the required ratio of backpumping to recharge time has had to be determined by experiment at each installation.

Recharge studies made near Amarillo (Moulder and Frazor, 1956) showed that sediment-free water similar in quality to the native water can be recharged without clogging.

Broadhurst (1957, p. 3) experimented with filters made from cottonseed hulls. The filters were designed to remove much of the suspended solids from lake or pond water before injection. The experiment was unsuccessful.

Little information has been recorded on the quantity of water available for recharge, the performance of recharge wells, and the feasibility of an extensive recharging program in the High Plains. Studies now in progress with these and other objectives are being made jointly by the Harvest Queen Mills, the Texas Board of Water Engineers, and the Geological Survey.

NATURAL DISCHARGE

Most if not all of the natural discharge from the county occurs by underflow to the southeast. The water table is several feet below the lowest topographic depressions, so there are no springs or seeps in the county. It is unlikely that many plants in the county have roots extending to the water table.

Baker (1915, p. 83) reported the presence of springs and subirrigated land along Running Water Draw and the Double Mountain Fork of the Brazos River in 1914. He stated:

> The water table is so near the surface in the valleys of some of the "draws," as for instance in the Blanco near Running Water postoffice, Hale County, and along

the Double Mountain Fork in southwestern Hale County, that the valley is subirrigated for alfalfa. Similarly, the valley of the "draws" may locally be cut below the general ground-water level and give rise to springs, such as are found in both of the stream valleys in the places just mentioned.

Withdrawals for irrigation and other uses subsequent to 1914 apparently were sufficient to lower the water table enough to stop the spring flow by 1938, because no springs were reported in a ground-water study by Broadhurst and others (1938) at that time. The shallowest depth to water reported during that study was 14.3 feet below the land surface in a well near Running Water Draw. In 1939 a brief survey was made of possible ground-water discharge along Running Water Draw, upstream from Plainview. The survey revealed a few places where the water table was at or near the bed of the channel, indicating a small amount of ground-water discharge by evapotranspiration from the draw. Further decline of water levels since that time has no doubt halted or at least lessened this discharge.

WITHDRAWALS OF WATER FROM WELLS

IRRIGATION SUPPLIES

The first irrigation well on the southern High Plains was drilled in 1910 a few miles west of Plainsview. It was pumped at 1,700 gpm. The Texas Land and Development Co., encouraged by the success of this well, bought several thousand acres of land and began installing wells, but the death of the head of the company in 1915 delayed the program, so that as late as 1933 (see fig. 9) fewer than 100 wells were in operation in the county.

Starting with 1934, the development of ground water for irrigation accelerated until the start of World War II, when the production of war materials cut deeply into the supply of steel and manpower for civilian needs. Toward the end of the war and until 1948, development increased at an unprecedented rate. By the end of 1947, more than 1,500 irrigation wells were in use in the county. Development continued at a reduced rate until 1951, when again the rate increased. From the end of 1950 to the end of 1955 more than 1,700 irrigation wells were put into operation, an average of about 340 per year.

The increase in withdrawal of ground water for irrigation has paralleled approximately the increase in the number of irrigation wells and the irrigated acreage. A study made in the Lubbock area during 1947–49 by Bonnen and others (1952, p. 12) showed that, despite a wide range in precipitation, the range in unit use of water for irrigation was relatively small. The use of water on heavy soils, in acre-inches per acre, reportedly ranged from 8.1 in 1949, when the

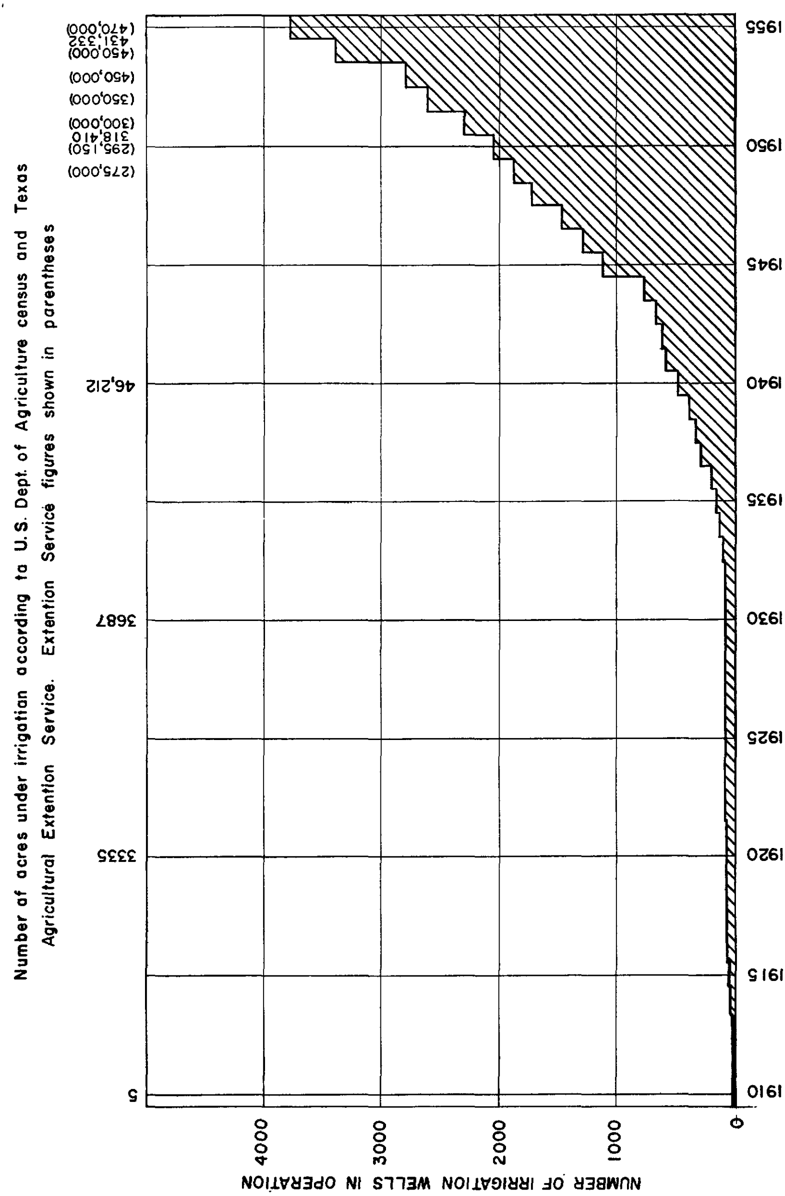

FIGURE 9.—Irrigation development, Hale County, Tex., 1910–55.

rainfall at Lubbock was more than 29 inches, to 13 in 1948, when the rainfall was 9.5 inches. Although the quantity of water withdrawn annually per acre of irrigated land is somewhat dependent upon climatic conditions, irrigated acreage generally is indicative of withdrawals.

Withdrawals of ground water for irrigation in 1955 were estimated from data collected on acreage irrigated, pumping rates, power consumption, and time of pump operation. Engines on 30 wells in Hale County were equipped with time-totalizing meters. Several times during the year the meters were read and the rate of flow was measured. Only 13 meters were operative for an entire year. The average use of water from the 13 metered wells serving about 2,100 acres from March 1955 to March 1956 was 0.94 acre-feet per acre. The electric-power consumption of pumps on 47 wells was used to estimate the use of water on about 6,900 acres. The average use was about 1.3 acre-feet per acre. The weighted average use of the 60 wells is about 1.2 acre-feet per acre. If the average use of water for irrigation in the county is assumed to be the same as the average for the 60 wells, about 560,000 acre-feet of water was used in 1955 to irrigate about 470,000 acres. The rate of withdrawal for irrigation was nearly triple that in 1949, when it was estimated that 200,000 acre-feet was pumped to irrigate 275,000 acres.

OTHER SUPPLIES

Withdrawal of ground water for all uses in Hale County other than irrigation was about 5,000 acre-feet in 1955, or less than 1 percent of the total pumpage. The city of Plainview was the largest user, pumping about 3,100 acre-feet, or 2.8 mgd (million gallons per day). Withdrawals for other municipal supplies were as follows: Abernathy, 0.33 mgd; Hale Center, 0.36 mgd; and Petersburg, 0.11 mgd. The Tuco plant of the Southwestern Public Service Co. was the largest industrial user of water in the county, using about 0.4 mgd principally for cooling. Other industrial uses, mostly for the processing of agricultural products, were small. Some of the industries are supplied water by municipalities; those having their own wells probably use a total of less than 50,000 gpd. Wells supplying livestock and domestic needs in rural areas use about 100,000 gpd.

DISTRIBUTION OF PUMPING

In 1955, irrigation wells were rather uniformly distributed throughout the county (pl. 1). The density of wells generally ranged from about 3 to 5 and averaged about 3.8 per square mile, as compared to 2.1 in 1960, 1.1 in 1945, and 0.5 in 1940. Inventories in 1937 and in 1945–46 showed that irrigation wells were most heavily concentrated in the northeastern quarter of the county, becoming more evenly distributed to the south and west by 1945.

The density of wells in an area is an indication of the distribution of pumping, but the yield of the wells also affects the distribution. The annual withdrawal per well is more uniform throughout the county than would be expected from the great range in pumping rates, because wells having small yields usually are pumped for longer periods than wells having large yields. Wells having the largest yields generally are in the areas where the saturated thickness of the Ogallala formation is greatest and where the water table is closest to the surface. However, in the southern part of the county where the saturated Ogallala is thin, some of the wells yield large quantities of water from Cretaceous rocks. Thus, annual withdrawals are smallest from areas where the Ogallala deposits are thin and where the Cretaceous rocks are absent or poorly productive.

PUMPING EQUIPMENT AND WELL CONSTRUCTION

Improvements in pumping equipment and well construction through the years have materially aided the development of irrigation. Some of the early irrigation wells were dug to a depth of about 30 feet by hand and cased with wood or bricks. Because the yield from these wells declined as the water table was lowered, they were abandoned or drilled deeper. Until recent years most of the wells did not penetrate the water-bearing material completely; now most of them are drilled to the red beds.

Rotary drilling has gained in popularity in recent years, and cable-tool rigs nearly disappeared from the irrigation scene in the county. As a result, well drilling is becoming more standardized. Most wells drilled since 1940 are equipped with a 16-inch casing perforated below the water table with slots about 18 inches long and ¼ to ¾ inch wide.

Larger yields from wells of smaller diameter were made possible by the introduction of the deep-well turbine pump during the 1920's. Before that time irrigators depended upon low-capacity plunger-type pumps, where the water table was deep, or low-lift centrifugal pumps where the water table was shallow. About 1934 the change from the slow oil-burning engine to the more efficient gasoline engine with direct drive brought a sharp reduction in the cost of pumping and encouraged irrigation development. This type of engine has retained its popularity, but the trend has been toward the use of cheaper fuels. Butane commonly is used, but the use of natural gas is increasing. Electric motors also have become popular in recent years owing to their low cost of maintenance.

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WATER IN STORAGE

VOLUME IN 1955

It is practicable to recover for irrigation only a part of the water stored in the aquifers in Hale County. As the water table declines, part of the water in the unsaturated deposits is retained in the pore spaces by capillarity, and it may be impractical to recover all the gravity water in the lower part of the aquifer owing to increased lift and decreased well yield. In general, the quantity of water available for development in Hale County is dependent upon the thickness of saturated material in the aquifer.

The zone of saturation in the Ogallala formation in Hale County in 1955 was thickest in a small area northeast of Petersburg, where more than 300 feet of the formation was saturated (pl. 6). Other thick sections are along the Swisher County line north of Edmonson, small areas north of Hale Center and east of Plainview, and extensive areas along the Floyd County line, especially in the vicinity of Petersburg. The zone of saturation in the Ogallala is less than 50 feet thick in large areas in the vicinity of Happy Union and Abernathy; however, these areas are underlain by Cretaceous rocks that contain fresh water. The thickness of the Cretaceous rocks is shown in plate 3.

The volume of water stored in the Ogallala formation in the county is the product of the volume of saturated material and the porosity. The volume of saturated material was determined for the winter of 1955 from plate 6. Assuming an average porosity of about 34 percent (Barnes and others, 1949, p. 39–40), about 39 million acre-feet of water was stored in the Ogallala formation in Hale County in 1955. Only a part of this water (that represented by the coefficient of storage) is available to wells; a part is held by capillarity as the water table is lowered. The storage coefficient determined from the pumping test at Plainview was 0.14. If it is assumed that this storage coefficient is representative, 16 million acre-feet of the water in storage in Hale County in 1955 was theoretically available to wells. This quantity of water represents the ultimate amount of water recoverable from the Ogallala, assuming that no recharge occurs and that net underflow into and out of the county is zero. As the saturated thickness and the quantity of water in storage decrease, however, the yield from wells also will decrease; thus not all the 16 million acre-feet of "available" water is practically recoverable. It is not possible to estimate how much of the 16 million acre-feet could be recovered, largely because it is impossible to predict the economic trends that determine the cost of well construction and pumping.

The quantity of water available from storage in the Cretaceous rocks is not known, because no data are available on specific yield or porosity. The limestome does not lend itself readily to the evaluation of these factors because of the difficulty of determining the amount of void space. Examination of cuttings and exposures of Cretaceous limestone suggests, however, that both porosity and specific yield are considerably less than in the Ogallala.

DEPLETION OF STORAGE

Ground water is being withdrawn from the aquifer in Hale County at a much greater rate than it is being replenished, as shown by the persistent decline of water levels throughout the county during the several years before 1956. The approximate rate of decline of the water table in the eastern half of the county is shown by the composite graph showing change in water level in 19 wells (fig. 10). An insufficient number of records is available to show the average rate of decline of the water table in the western half of the county; however, the available record suggests that the decline in the western half was somewhat less until about 1950, but thereafter it was as great or nearly as great as in the eastern half.

Before about 1950 the uneven distribution of withdrawals resulted in some areas being depleted faster than others. Water levels in a large number of wells were measured in 1938 and were remeasured in 1955. The decline of the water table, as interpreted from these measurements, is shown on plate 7. In general, the area where ground water has been withdrawn for the longest time are the areas where the water table has declined the most. For example, wells T–77 and T–99 (fig. 7), which are in an area where irrigation wells have been closely spaced since 1938, show a much greater decline than wells EE–76 and JJ–97, which are in areas that contained relatively few wells until about 1950. Because the distribution of pumping has become more uniform, the rate of depletion throughout the county may be expected to become more uniform.

The map showing the decline of the water table (plate 7) has been used to compute the depletion of storage for the period 1938–55. About 21.5 million acre-feet of material was dewatered, representing an average decline of the water table throughout the county of about 34 feet. On the assumption that the average coefficient of storage of the dewatered material is 0.14, it is calculated that about 3 million acre-feet of water was removed during the period 1938–55. The data are not sufficiently accurate to determine the difference between deplection and pumping for this period, but they indicate that the depletion accounts for a very large percentage of the withdrawal, perhaps 90 percent or more.

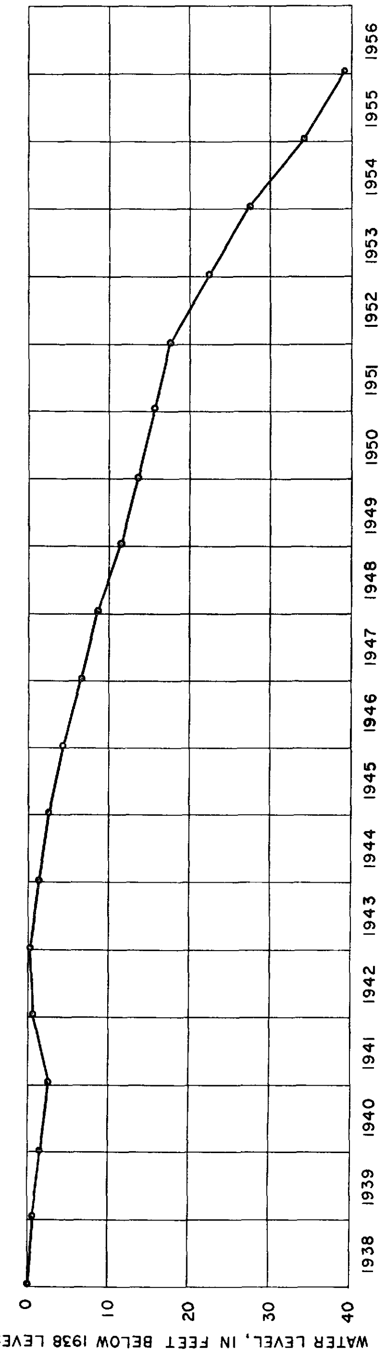

FIGURE 10.—Average water level in 19 wells in Hale County, 1938–1956.

QUALITY OF WATER

Ground water from the Ogallala formation and Cretaceous rocks in Hale County has a fairly low mineral content, averaging less than 400 ppm of dissolved solids.

In comparison with water from many unconsolidated formations in Texas, the chemical quality of water is uniform throughout the county. Calcium generally is the principal cation; the water commonly contains 40 to 60 ppm. The magnesium content generally is slightly less than that of calcium, and the sodium a little less than the magnesium. The principal anion is bicarbonate, averaging more than 300 ppm. The concentrations of sulfate and chloride ions are commonly less than 50 ppm each. The water is characteristically hard and in most places has an objectionable concentration of fluoride. Except for the excessive fluoride content, the water is suitable for irrigation and public supply. The hardness and high concentration of silica make it somewhat objectionable for domestic and many industrial uses, however.

No analyses were made of water from rocks older than Cretaceous, but reports from drillers and other reliable sources indicate that water from older rocks is highly mineralized and thus would be unsuitable for most uses. Chemical analyses of samples collected over a 20-year period show that the water is suitable for irrigation—the principal use of water in the county.

SUITABILITY FOR IRRIGATION

Water from the Ogallala formation and rocks of Cretaceous age has proved to be suitable for irrigation in Hale County. It has been used for several decades with satisfactory results; no reports have come to the writers' attention that the quality of water in the county has adversely affected crop growth. According to the U.S. Salinity Laboratory Staff (1954), the principal factors affecting the use of water for irrigation are related to the concentration of dissolved solids, sodium, and boron. The analyses show that water from aquifers bearing fresh water in Hale County does not contain these constituents in excess of the limits of tolerance of most crops.

SUITABILITY FOR OTHER USES

The excessive content of fluoride makes the water undesirable for public supply and domestic use. The continued use of water containing more than 1.5 ppm fluoride may cause the teeth of children to become mottled (Dean, Dixon, and Cohen, 1935, p. 424–442). However, water containing about 1.0 ppm inhibits tooth decay. Although only 15 samples were analyzed for fluoride content, the fact that 13 contained quantities in excess of the permissible limit of 1.5 ppm and that mottled teeth are prevalent in the county suggest that excessive fluoride concentration is a countywide characteristic of the water. Other constituents generally considered objectionable in drinking water were not present in excessive quantities. Water suitable for human consumption is, of course, suitable for stock.

Hardness and silica content are important properties of the water for domestic and industrial use. Both properties are related to the formation of scale in boilers, hot water pipes, coils, and other heating equipment. The scale reduces the flow of water through pipes and because of its insulating property interferes with heat transfer. Soap and detergent consumption in washing and laundering operations increases as the hardness increases. Soap used with hard water forms an insoluble adherent scum, whereas detergents do not. Water having a hardness of more than 200 ppm is considered very hard and should be softened for most purposes. The hardness of 87 samples from wells in Hale County averaged about 300 ppm; the lowest was 199 ppm.

According to Moore (1940, p. 263), water containing silica in excess of 40 ppm should not be used in boilers operating at pressures of as much as 150 pounds per square inch, and water containing silica in excess of 20 ppm should not be used at pressures of as much as 250 pounds per square inch. Concentrations of silica in 10 of 12 determinations exceeded 40 ppm, and all exceeded 30 ppm. The data suggest that the silica content of water in Hale County is too high for the water to be used satisfactorily in boilers.

OUTLOOK FOR THE FUTURE

The water resources of Hale County are insufficient to support irrigation perennially on the scale of 1955 unless a new source of water becomes available. The transportation of water from other areas, although remotely possible, is infeasible under present economic conditions. To increase precipitation materially by cloud seeding or other artificial means is also only a remote possibility. If demineralization of saline water becomes economically feasible, water from geologic formations older than Cretaceous may be exploited, but it is doubtful that these formations would yield water as abundantly as the Ogallala. Undoubtedly other plans for supplementing the water supply will be considered during the next few decades.

A more feasible plan for ameliorating the water-depletion problem is to improve water-conservation practices; but this would serve only to extend the life of large-scale agricultural production, not to make it perennial.

Considering the economic value of irrigation, conserving the water supply to permit even a few additional years of large-scale production appears worthy of a concerted effort. The farmers in the county have already adopted many practices designed to conserve water. These include the distribution of water to the fields through underground pipes, improved land practices, and in a few places the artificial recharge of the aquifer with water from small lakes and ponds. The quantity of water available from the lakes and ponds is small by comparison to the 1955 withdrawals, but an accurate estimate of the quantity is awaiting the result of recharge studies begun in 1956. Other conservation measures that may be of increasing value in the future include (a) reduction in amount of, or reuse of, waste water from irrigated fields, (b) widespread adoption of irrigation and land practices designed to reduce evaporation and transpiration by nonbeneficial plants, and (c) production of crops requiring less water.

Three readily apparent facts will be of especial significance to the future of irrigation in Hale County if the trends observed in 1955 continue: (a) the maximum rate of withdrawal of ground water and decline of water levels will not greatly exceed the rate of 1955; (b) after the maximum irrigation development has been reached, the annual withdrawal will gradually decrease as the area of substantial lowering of water levels becomes larger; and (c) the length of time that any particular area in the county will produce water in sufficient quantities for irrigation is largely dependent upon the thickness of water-bearing material underlying that area.

In 1955 about 470,000 acres of land was irrigated, of an estimated total of 550,000 irrigable acres in the county. Thus, the potential increase in development was less than 20 percent. If the rate of increase during the 5 years before 1955 continues, irrigation development will reach its maximum in less than 10 years. If the rates of withdrawal and depletion increase proportionately, the average annual withdrawal will probably never exceed 700,000 acre-feet, and the average annual decline of the water table will probably never exceed 7 feet.

Wells in certain small areas in the county would not yield water in sufficient quantities for economical irrigation in 1955 because the Ogallala deposits had been nearly dewatered (pl. 6). As the water table declines, the nonproductive area will grow larger and the productive area will become smaller.

The water table may continue to decline at nearly a constant rate even after the rate of withdrawal begins to decrease, if it is assumed that the rate of withdrawal per unit area remains the same in the productive area. This supposition is based on the fact that the area containing saturated Ogallala deposits becomes smaller as the storage in the remaining area is depleted. If, as previously stated, the maximum rate of decline expectable is 7 feet per year, and if the minimum rate of decline expectable is 5 feet per year (the average rate for the 3-year period 1953–56), the productive life of any area in the county can be predicted roughly. For example, the area shown on plate 6 as having saturated Ogallala deposits less than 150 feet thick in 1955 was about 250 squares miles (160,000 acres). Figure 11 indicates that the deposits in this area will become dewatered between 1976 and 1985. The nonproductive area, however, will be somewhat larger because part of the remaining area will not have a great enough thickness of saturated rocks to support irrigation wells.

In some areas where water-bearing Cretaceous rocks underlie the Ogallala, dewatering may be delayed as much as 10 years beyond the time indicated by plate 6 and figure 11. However, the potential water supply from the Cretaceous rocks is of little importance to the county as a whole, because the areal extent and the thickness of the water-bearing material are small.

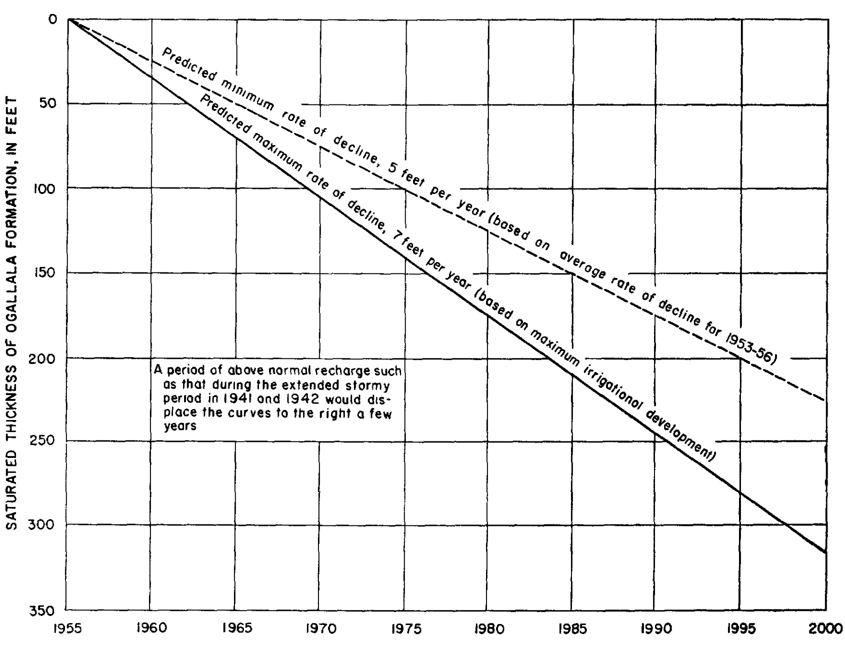

FIGURE 11.—Predicted maximum and minimum rates of decline of the water table, Hale County, 1955–2000

More wells will be needed to produce the same quantity of water per unit area as the zone of saturation becomes thinner. The pumping rate per unit drawdown is largely a function of the thickness of saturation, so that, when the yield of a well can no longer be increased by lowering the pump, the yield will decrease with a further lowering of the water table. Thus the ultimate number of wells per unit area will be determined by economic conditions.

Water supplies for cities and industries will be affected similarly by storage depletion. Plate 6 and figure 11 can be used to predict the approximate life of wells for industries and cities as well as for irrigated farms. Plate 6 shows that Petersburg is most favorably situated; Plainview and Hale Center also are in areas having a considerable thickness of saturated rocks; but Abernathy likely will have difficulty finding an adequate supply within the city limits before 1965. However, the cities in Hale County, among other cities on the High Plains, have long-range plans to replace or supplement their ground-water supplies with surface water from a proposed reservoir on the Canadian River.

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