UNITED STATES DEPARTMENT OF THE INTERIOR

LOCAL OVERDEVELOPMENT OF GROUND-WATER SUPPLIES

WITH SPECIAL REFERENCE TO CONDITIONS AT GRAND ISLAND, NEBRASKA

Prepared in cooperation with the
CONSERVATION AND SURVEY DIVISION OF THE UNIVERSITY OF NEBRASKA and the GRAND ISLAND WATER DEPARTMENT

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 836-E

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BY

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By Leland K. Wenzel

ABSTRACT

Attention has been focused on the lowering of ground-water levels in many parts of the United States during recent years of drought, and there has been much apprehension lest our ground-water supplies are nearing exhaustion. Probably a large part of this concern has resulted from the persistent decline of the water levels in wells in locally overdeveloped areas—that is, in small areas where the rate of ground-water withdrawal exceeds the rate of replenishment. Where local overdevelopment has occurred, investigations must be made to find practicable measures to alleviate the condition. Over large areas, however, declines have been caused chiefly or wholly by deficient rainfall, and the water levels can reasonably be expected to recover in years of normal precipitation.

A rather large depression of the water table has been created under the city of Grand Island, Nebr., in the Platte River Valley, about 130 miles west of Omaha, apparently the result of a local overdevelopment of the ground-water supply. It appears probable that if the present rate of local draft on the underground reservoir is continued a water shortage will eventually result. The pumpage for public and industrial supply from permeable deposits of Pleistocene sand and gravel that underlie the city was about 7,860 acre-feet, an average of 7,000,000 gallons a day, in 1937, whereas it is estimated that the recharge of ground water to the area amounted to only 5,900 acre-feet, an average of 5,300,000 gallons a day. As a result, considerable water was pumped from underground storage, and the water table declined in the city. The water table stands close to the land surface around the city, and in years of normal precipitation recharge is ample to maintain the water level at high stages in this area. The solution to the problem of local overdevelopment at Grand Island lies in redistributing the wells in such a manner that less water will be pumped in the city and more will be pumped from wells outside the city.

INTRODUCTION

A cooperative investigation of the ground-water resources of Nebraska has been in progress since 1930 by the Federal Geological Survey and the Conservation and Survey Division of the University of Nebraska. Attention was confined until 1934 to the south-central part of the State, and a report on this area has since been published.[1]

[1] Lugn, A. L., and Wenzel, L. K., Geology and ground-water resources of south-central Nebraska with special reference to the Platte Valley between Chapman and Gothenburg: U. S. Geol. Survey Water-Supply Paper 779, 1938.

In connection with this investigation a pumping test was made near Grand Island to determine the permeability and specific yield of the Pleistocene sand and gravel, and the results of this test were released in a separate paper.[2] In 1934 a State-wide program of water-level measurements in wells was begun [3] and in 1935 an investigation was made of the ground-water resources of Keith County.[4] The program of water-level measurements in wells was continued in 1935, 1936, and 1937, and in 1937 an investigation was made also of the geology and ground-water resources of Scotts Bluff County.[5]

The existence of a local depression of the water table beneath Grand Island, a city of about 20,000 people, in the Platte River Valley, 130 miles west of Omaha, was noted during the course of the investigation of the geology and ground-water resources of south-central Nebraska [6] but a special study of the condition was not made at that time. The water levels in the city wells at Grand Island have declined persistently for many years, probably since development was first begun in about 1885, and recently have reached stages so low that much concern has been felt regarding the ultimate exhaustion of the supply. The pumping water level in some of the wells is now from 60 to 70 feet below the land surface, in comparison to a probable original pumping level of from 30 to 40 feet, and only 20 to 30 feet of saturated sand and gravel occur below the present level. The consumption of water in Grand Island has increased from year to year and is expected to increase further in the future. The need for a study of existing conditions with a view to determining plans for future development of the city's supply became especially apparent during the recent series of drought years when serious water shortages occurred in many cities of the Middle West. In 1935 the Grand Island Water Department, C. W. Burdick, commissioner, through informal cooperation with the Geological Survey, constructed 55 observation wells in the city and immediate vicinity and began periodic

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[2] Wenzel, L. K., The Thiem method for determining permeability of water-bearing materials and its application to the determination of specific yield: U. S. Geol. Survey Water-Supply Paper 679, pp. 1–57, 1936.

[3] Waite, H. A., Ground-water level survey in Nebraska: Nebraska Geol. Survey Paper 7, 1935. Wenzel, L. K., A State-wide program of periodic measurements of ground-water level in Nebraska: Am. Geophys. Union Trans., 1935, pp. 495–498. Wenzel, L. K., The recovery of ground-water levels in Nebraska in 1935: Am. Geophys. Union Trans., 1936, pp. 370–371. Water levels and artesian pressure in observation wells in the United States in 1935: U. S. Geol. Survey Water-Supply Paper 777, pp. 86–94, 1936. Water levels and artesian pressure in observation wells in the United States in 1936: U. S. Geol. Survey Water-Supply Paper 817, pp. 89–167, 1937. Water levels and artesian pressure in observation wells in the United States in 1937: U. S. Geol. Survey Water-Supply Paper 840, pp. 187–233, 1938.

[4] Wenzel, L. K., and Waite, H. A., Ground-water resources of Keith County, Nebr.: U. S. Geol. Survey Water-Supply Paper 848 (in press).

[5] Wenzel, L. K., Cady, R. C., and Waite, H. A., Geology and ground-water resources of Scotts Bluff County, Nebr.: U. S. Geol. Survey Water-Supply Paper — (in preparation).

[6] Lugn, A. L., and Wenzel, L. K., op. cit., p. 87.

measurements of the water levels in them. Arrangements were made for the collection of pumpage data by the Water Department and for the study and interpretation of the water-level records and related information by the Geological Survey as a part of the cooperative ground-water investigation of the State. This report presents the results of the study.

The progressive lowering of the water table in Grand Island appears to be the result of local overdevelopment—that is, the withdrawal of water for a period of years from a comparatively small area at a rate greater than the rate at which water is added. Such a condition does not imply a regional depletion of the ground-water reservoir but only that the supply in a part of it is being slowly exhausted.

The problem of local overdevelopment at Grand Island is similar to that confronting many other municipal, industrial, and private users of ground water. Wells frequently are constructed in convenient locations with very little regard to the effects of the withdrawals on the ground-water reservoirs. Where the quantity of water withdrawn is in excess of the recharge a part of the water is taken from storage in the underground reservoir and a progressive lowering of the water level results. Although the rate of decline may be very slow, eventually the water level reaches such a low stage that the yields of wells are seriously reduced and a water shortage threatens. The solution to many such problems lies in relocating wells in such a manner that recharge to the area immediately surrounding each well is equal to the pumpage.

In some places the water-bearing materials are so nearly impermeable and the movement through them is so slow that local overdevelopment may result from pumping only small quantities of water, such as are needed for domestic and stock use on farms. In such localities the quantity of water reaching the wells by percolation over extended periods is even less than the small quantity that is pumped. As a result the water levels in the wells decline persistently until the wells become dry or contain so little water that further pumping is impracticable. The depressions of the water level created in this manner are comparatively steep and deep and usually extend over only very small areas. Therefore, wells drilled only short distances away may encounter adequate supplies, but they, too, may fail in the same manner. If pumping ceases for a time, the depressions will be refilled by underground percolation or by seepage from the surface, and the wells may again be used. Fundamentally, no difference exists between the local overdevelopment brought about by pumping large quantities of water, such as for public supply, and local overdevelopment caused by pumping small quantities, such as for domestic supply. In the first instance the permeability of the formation is usually high and the depression is comparatively large whereas in the second instance the permeability must necessarily be low and the depression small.

Attention has been focused on the lowering of ground-water levels throughout much of the United States during the recent years of drought, and there has been much apprehension lest our ground-water supplies are nearing exhaustion. Probably a large part of this concern has resulted from the persistent decline of the water levels in pumped wells in locally overdeveloped areas. Where local overdevelopment has occurred investigations must be made to find practical measures to alleviate the condition. Over wide areas, however, the decline in ground-water levels has been caused chiefly or wholly by deficient rainfall, and the water levels can reasonably be expected to recover with recurring years of normal precipitation.

The following pages contain quantitative estimates of the discharge, recharge, and movement of ground water in the vicinity of Grand Island. Any adequate quantitative study of the ground-water supply in an area must be based on data accumulated over a considerable period of time, and the longer the record the more accurate are the resulting conclusions. This study is based chiefly on records obtained over a period of only about 2 years, and a longer period of record would be highly desirable. Although the quantitative estimates may be somewhat in error, it is believed that the general magnitude of the estimates and the conclusions reached through them are reasonably accurate.

HISTORY OF THE GRAND ISLAND PUBLIC WATER SUPPLY [7]

The Grand Island public supply dates back to 1879 when the first bonds were issued for the laying of water mains from wells owned by the Union Pacific Railroad Company. From 1885 to 1888 bonds were issued for the construction of a municipal supply and about 40 wells, ranging from 2 to 6 inches in diameter, were driven to the water-bearing sand and gravel. The wells were connected to a common suction header and water was pumped from them by steam power into an overhead standpipe. This system was operated until about 1910 at which time 6 wells with 10-inch steel casings were drilled on the east side of Locust Street from the right-of-way north to Seventh Street. The wells were equipped with individual submerged pumps and were electrically operated. Water was pumped to a ground-level reservoir through one discharge pipe and thence into the mains through a pressure pump. The overhead standpipe and driven wells were abandoned at the completion of this system.

[7] Supplied chiefly by C. W. Burdick, Water Commissioner, Grand Island, Nebr.

In 1917 a concrete-cased well was constructed by the Kelly Well Co. on Locust Street between Sixth and Seventh Streets. Since

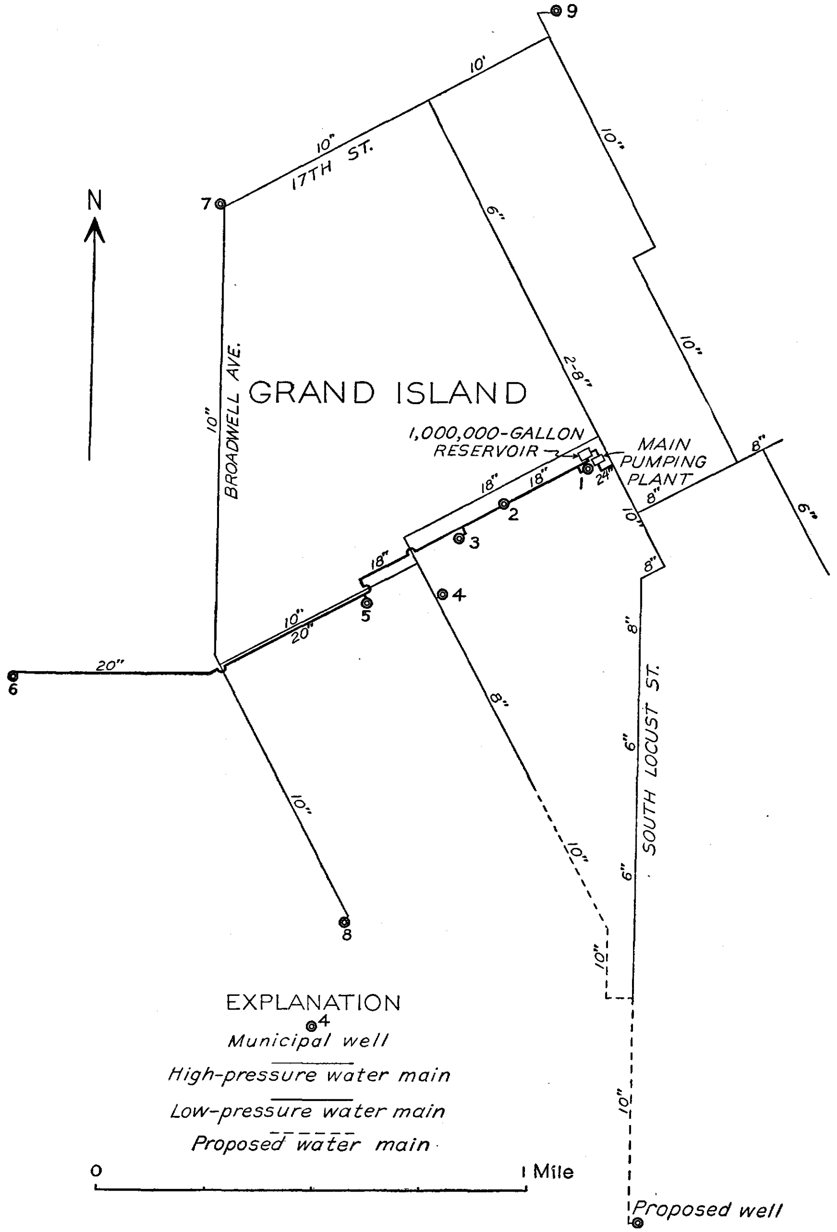

FIGURE 42.—Map showing location and size of principal feeder water mains and location of wells pumped for municipal supply in Grand Island.

that time nine other wells of this type have been installed, and another well is now under construction. The steel-cased wells, which gave considerable trouble because many of the perforations were closed by corrosion, were abandoned after the installation of the first two or three concrete-cased wells. The location of the wells that are now in use is shown on plate 16, and the records of the wells are given in the accompanying table. The principal feeder mains into which the wells discharge and the location of the reservoir and pumping plant are shown in figure 42. Wells 1, 2, 3, 5, and 6 are equipped with low-head pumps that discharge through feeder mains into a 1,000,000-gallon reservoir, and wells 4, 7, 8, and 9 are equipped with high-head pumps that discharge directly into the system. A high-head pump will be installed on the well now under construction, and water will be pumped directly into the system. Water from the reservoir is pumped through the pumping plant into the system at a pressure of 70 to 85 pounds per square inch by two electrically powered horizontal centrifugal pumps with capacities of 2,500 gallons a minute each. A Corliss engine-driven pump is maintained in readiness in case of a failure of the electric current.

Records of wells pumped for municipal supply in Grand Island in 1936

Well No.	Name	Location	Depth (feet)	Inside diameter (inches)	Approximate depth to water level while pumping (feet)
1	Ice plant	North Front and Pine Sts.		25	66
2	Cedar	Fourth and Cedar Sts.	86	25	68
3	Cleburn	North Front and Cleburn Sts.	88	25	62
4	Clark	South Front and Clark Sts.		25	
5	Lincoln	North Front and Lincoln Sts.	89	25	61
6	Hart	North Front St. and Hart Ave.	82	25	47
7	Broadwell	17th St. and Broadwell Ave.	101	25	
8	Jackson	Jackson and Anna Sts.	91	25	41
9	Blaine	Illinois Ave. and Ohio St.	104	25	32

The city of Grand Island in addition to maintaining a public water supply generates electricity for public use and operates a municipally-owned ice plant. The Water Department maintains a laboratory and bacteriologist for making analyses of the water.

GEOLOGIC CONDITIONS

GENERAL FEATURES

Fluviatile Pleistocene deposits underlie Grand Island and its vicinity to depths of 80 to 200 feet or more. From these permeable unconsolidated materials are pumped all the water supplies of the area, including water for municipal, industrial, irrigation, and domestic uses. Grand Island marks the approximate eastern limit of Tertiary beds; thin remnants of the Ogallala formation occur in the area beneath the Pleistocene sand and gravel. Where the Ogallala is absent the Niobrara formation, of Cretaceous age, is usually encountered below the sand and gravel. No wells in the area are known to draw water from either the Ogallala or Niobrara or from deeper-seated formations. Some of the Cretaceous and older formations yield supplies of water to wells in eastern Nebraska but the quality is frequently poor and the quantity is small in comparison to that obtained from the Pleistocene sand and gravel at Grand Island. The Pleistocene deposits are by far the most productive in the area and they are the only deposits that will yield large supplies of water.

DISTRIBUTION AND THICKNESS OF PLEISTOCENE DEPOSITS

The fluviatile Pleistocene deposits of south-central Nebraska comprise two formations of sand and gravel and two of sandy clay and silt.[8] They are believed to be the correlatives of the glacial formations of eastern Nebraska, Iowa, and other areas, from the Nebraskan stage to the Yarmouth stage, inclusive. The sand and gravel formations (Holdrege formation and Grand Island formation) occur almost continuously over several thousand square miles in south-central Nebraska including the Platte Valley, but the sandy clay formation (Upland formation) that overlies the upper sand and gravel deposit (Grand Island formation) and the clay formation (Fullerton formation) that separates the Grand Island and Holdrege formations are discontinuous and therefore absent at many places. A full description of the origin, character, and distribution of the Pleistocene formations in south-central Nebraska, including those at Grand Island, is given in Water-Supply Paper 779. More detailed descriptions of these formations are published in a separate paper by Lugn.[9]

The sand and gravel of the Holdrege and Grand Island formations are thought to have been deposited by rivers from the west and northwest and by waters from melting ice sheets to the east. They are therefore fluvioglacial deposits that were built up as an alluvial plain in south-central Nebraska. The Fullerton and Upland formations are thought to have been formed during quiescent interglacial stages when the competency of the streams carrying sediments from the west and northwest was low and sedimentation was limited to fine material.

The Upland formation is not known to be present in the Valley of the Platte River at Grand Island, and the sand and gravel of the Grand Island formation occur a few feet below the land surface.

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[8] Lugn, A. L., and Wenzel, L. K., Geology and ground-water resources of south-central Nebraska: U. S. Geol. Survey Water-Supply Paper 779, pp. 29–53, 1938.

[9] Lugn, A. L., The Pleistocene geology of Nebraska: Nebraska Geol. Survey Bull. 10, 2d ser., 1935.

Silt and clay, probably the Fullerton formation, are encountered by many wells between two sand and gravel deposits (Grand Island and Holdrege formations). Shale of the Niobrara formation generally forms the bedrock. In this report, no distinction is drawn between the sand and gravel of the Grand Island and Holdrege formations because their character and water-bearing properties are for most purposes the same. The separating Fullerton formation is grouped with the overlying and underlying sand and gravel because its occurrence and thickness is very irregular and the combined section of water-bearing material is considered as Pleistocene sand and gravel.

Throughout most of south-central Nebraska the fluviatile Pleistocene formations are overlain with thick deposits of loess. In the Platte Valley, however, most of the loess has been eroded away so that it is generally less than 10 feet thick. At the Platte River it is entirely absent and Pleistocene sand and graved are exposed in the river bed. The loess is not water-bearing at Grand Island.

The thickness of the Pleistocene deposits varies considerably, reflecting irregularities of the bedrock surface on which they were deposited. The logs of 6 test holes (1, 2, 3, 4, 5, and 8) drilled in the Platte Valley near Grand Island in conjunction with the investigation in south-central Nebraska are given on pages 69–71 of Water-Supply Paper 779. The thickness of deposits encountered in these holes ranged from about 80 to 180 feet. The following table gives logs of seven of the wells pumped for public supply at Grand Island and of seven test holes in the vicinity, furnished by the Kelly Well Co. The Pleistocene deposits indicated by these logs range in thickness from about 80 to 250 feet. Most of the logs show some clay between an upper and a lower sand and gravel.

Logs of wells and test holes in Grand Island and vicinity

City well 2 (Cedar)

[Fourth and Cedar Sts.]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Soil	6	6	Gravel, coarse sand	17	65
Gravel, sand	13	19	Sand, fine	2	67
Sand	7	26	Gravel, sand	19	86
Sand, very fine	15	41	Clay.		
Gravel, sand	7	48			

City well 3 (Cleburn)

[North Front and Cleburn Sts.]

Soil	2	2	Clay, sandy	2	75
Sand	3	5	Sand, fine	11	86
Gravel, sand	21	26	Clay, sandy	3	89
Sand, fine, and clay	11	37	Clay, blue.		
Gravel, sand	36	73			

City well 5 (Lincoln)

[North Front and Lincoln Sts.]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Soil	2	2	Clay	1.5	67.5
Sand	11	13	Sand, fine	3.5	71
Sand, fine	12	25	Sand, coarse	5	76
Sand, very fine	8	33	Sand, very fine	2	78
Sand, fine	16	49	Sand, coarse	12	90
Sand, medium	15	64	Clay.		
Sand, very fine	2	66			

City well 6 (Hart)

[North Front St. and Hart Ave.]

Sand, fine	20	20	Gravel, sand	5	74
Sand, very fine	12	32	Clay, blue	2	76
Gravel, sand	28	60	Sand, fine, and clay	7	83
Sand, fine, with clay balls	7	67	Clay.		
Clay	2	69			

City well 7 (Broadwell)

[Broadwell Ave. and 17th St.]

Soil	2	2	Clay, yellow	11	71
Sand	16	18	Sand, fine	9	80
Sand, fine	11	29	Sand, coarse	6	86
Sand, very fine, and clay	5	34	Sand, fine	6	92
Sand	21	55	Sand, coarse	9	101
Sand, clay	5	60			

City well 8 (Jackson)

[Jackson and Anna Sts.]

Sand	16	16	Gravel and fine sand	2	42
Clay and fine sand	4	20	Gravel and coarse sand	21	63
Sand, fine	7	27	Clay	2	65
Gravel, sand	13	40	Gravel, sand	26	91

City well 9 (Blaine)

[Illinois Ave. and Ohio St.]

Soil	4	4	Clay, yellow	8	66
Sand, fine	16	20	Sand, coarse	6	72
Sand, very fine	8	28	Gravel, fine	4	76
Clay, sandy	4	32	Sand, fine	9	85
Sand, fine	8	40	Gravel and coarse sand	7	92
Sand, coarse	5	45	Sand, medium	8	100
Gravel and coarse sand	6	51	Gravel and coarse sand	3	103
Sand, fine	7	58	Clay	1	104

Test hole 1

[NE¼ sec. 16, T. 11 N., R. 9 W., 4th and Locust Sts.]

Sand, fine to medium	50	50	**Sand, fine to medium, gray**	**69**	**219**
Gravel and coarse sand	38	88	Clay, gray	11	230
Clay, blue	47	135	Clay, gray, sandy	17	247
Clay, blue, sandy	15	150			

Test hole 2

[SE¼ sec. 17, T. 11 N., R. 9 W., Blake St. and city limits]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Sand, fine	35	35	Clay, hard	10	105
Gravel and coarse sand	30	65	Clay, sandy	15	120
Gravel and fine sand	10	75	Sand, fine	30	150
Gravel and coarse sand	10	85	Gravel and coarse sand	30	180
Clay, soft	10	95	Sand, fine, gray	79	259

Test hole 3

[SE. corner of sec. 36, T. 11 N., R. 10 W.]

Gravel and coarse red sand	55	55	Clay, yellow	27	147
Gravel, coarse	10	65	Clay, yellow, hard white layers	18	165
Gravel and coarse sand	20	85	Clay, white, hard	20	185
Clay, yellow, soft	35	120			

Test hole 4

[SE. corner of sec. 23, T. 11 N., R. 10 W.]

Sand, fine, red	50	50	Clay, yellow, soft	20	165
Gravel and coarse sand	30	80	Clay, yellow, hard	25	190
Gravel, gray, and coarse sand	35	115	Clay, yellow, stiff	15	205
Clay, yellow, stiff	30	145			

Test hole 5

[NW. corner of sec. 27, T. 11 N., R. 9 W.]

Clay, sandy	25	25	Clay, sandy, blue	10	155
Gravel and coarse red sand	48	73	Sand, fine	70	225
Gravel and fine sand	22	95	Clay and fine sand	10	235
Gravel and coarse sand	50	145	Clay, white, soft	13	248

Test hole 6

[NE¼ sec. 35, T. 11 N., R. 9 W.]

Gravel and coarse sand	31	31	Clay, sandy, light colored	10	146
Clay, hard	7	38	Clay, sandy, blue	20	166
Gravel and coarse red sand	82	120	Clay, blue	35	201
Sand, fine	16	136	Clay, yellow, hard	17	218

Test hole 7

[SW. corner of sec. 36, T. 11 N., R. 9 W.]

Gravel and sand	16	16	Clay, blue	22	175
Clay, yellow	5	21	Sand, fine, and white clay	21	196
Gravel and coarse sand	113	134	Clay, white, hard	8	204
Clay, sandy, blue	19	153			

HYDROLOGIC PROPERTIES OF THE PLEISTOCENE SAND AND GRAVEL

The two most important hydrologic properties of water-bearing materials are permeability and specific yield. Permeability is a measure of the ability of a formation to transmit water; specific yield is a measure of the quantity of water that the formation will yield when it is drained. Permeability is usually expressed as a coefficient of permeability, defined in field terms as the number of gallons a day, at

60° F., that is conducted laterally through each mile of water-bearing bed under investigation (measured at right angles to the direction of flow) for each foot of thickness of the bed and for each foot per mile of hydraulic gradient.[10] Specific yield of a water-bearing material is defined as the ratio of (1) the volume of water which, after being saturated, it will yield by gravity to (2) its own volume.[11] The quantity of water that will percolate through a given cross-section of water-bearing material under a known hydraulic gradient is directly proportional to the coefficient of permeability of the material. The quantity of water that will be yielded for each foot of decline of the water table, or is represented by each foot of rise of the water table, is directly proportional to the specific yield.

The permeability and specific yield of the Pleistocene deposits in the Platte Valley about 4 miles east of Grand Island were determined by a pumping test in 1931 during the investigation of south-central Nebraska.[12] The average coefficient of permeability was found to be about 1,000 and the specific yield about 24. Nineteen samples of material were taken from 6 to 105 feet below the surface during the drilling of a well at the location of the pumping test. Their coefficients of permeability, which were determined in the hydrologic laboratory of the Geological Survey at Washington, ranged from 2 for clay to 4,350 for sand and gravel. The average permeability of the samples, weighted according to the thickness each sample represented in the section, was about 1,200. The porosity and moisture equivalent of a sample of sand and gravel collected from within the range of fluctuation of the water table were determined in the hydrologic laboratory to be 27.1 and 2.6, respectively. Using Piper's relation between moisture equivalent and specific retention,[13] which gives a specific retention of about 5 for materials with a moisture equivalent of 2.6, the specific yield is computed to be 22.1.

The Pleistocene deposits are heterogeneous in character and hence additional determinations of permeability and specific yield should be made at other locations before the above values can be applied with assurance to all of the Pleistocene deposits at and near Grand Island. However, it is believed that the average values determined by the pumping test may be regarded as approximate values for the deposits as a whole.

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[10] Stearns, N. D., Laboratory tests on physical properties of water-bearing materials: U. S. Geol. Survey Water-Supply Paper 596, p. 148, 1928.

[11] Meinzer, O. E., Outline of ground-water hydrology, with definitions: U. S. Geol. Survey Water-Supply Paper 494, p. 28, 1923.

[12] Wenzel, L. K., The Thiem method for determining permeability of water-bearing materials and its application to the determination of specific yield: U. S. Geol. Survey Water-Supply Paper 679, pp. 1–57, 1936.

[13] Piper, A. M., Notes on the relation between moisture equivalent and the specific retention of water-bearing materials: Am. Geophys. Union Trans., pp. 481–487, 1933.

PUMPAGE

The total pumpage of the Grand Island Water Department from the Pleistocene sand and gravel in 1937 was 5,590 acre-feet, an average of about 5,000,000 gallons a day. The maximum daily pumpage was 9,400,000 gallons on August 16, and the minimum pumpage in any 24 hours was 2,730,000 gallons on December 12.

The pumpage for public supply in Grand Island has varied somewhat from year to year, but it has increased rather steadily since 1918, when records were first collected. Figures for annual pumpage from 1918 to 1937 are given in the following table. The peak pumpage was reached in the drought year of 1934, when an average of about 5,700,000 gallons a day was pumped. From 1918 through 1928 no record was kept of the water pumped for condenser use at the city electric plant, and therefore the figures for those years are less than the actual quantity pumped. During the summer from 2,000,000 to 4,000,000 gallons a day are used at the electric plant, and water is wasted by discharging it into storm sewers. In the winter, however, less water is used at the electric plant, and most of it is discharged into the storage reservoir, where it is repumped for public consumption.

Average daily pumpage, in gallons, for public supply at Grand Island

1918	[1] 1,640,000	1925	[1] 2,150,000	1932	4,110,000
1919	[1] 1,530,000	1926	[1] 2,290,000	1933	4,900,000
1920	[1] 1,440,000	1927	[1] 2,120,000	1934	5,720,000
1921	[1] 1,590,000	1928	[1] 2,510,000	1935	5,340,000
1922	[1] 1,760,000	1929	3,650,000	1936	5,410,000
1923	[1] 1,830,000	1930	3,520,000	1937	5,000,000
1924	[1] 2,040,000	1931	4,160,000		

[1] Does not include water pumped for condenser use at municipal electric plant.

The pumpage from city wells increased from an average of about 2,440,000 gallons a day in 1920, assuming that 1,000,000 gallons a day were used in that year at the electric plant, to an average of about 5,000,000 gallons a day in 1937. The population of Grand Island was 13,947 in 1920 and 18,041 in 1930, and was estimated to be 20,000 in 1936, thus indicating that the pumpage has increased somewhat more rapidly than the population. However, it is probable that an increase in transient and industrial use has accounted for most of the increased use per capita. In 1936, when the daily pumpage averaged about 270 gallons per person, the city water department estimated the per capita consumption to be 116 gallons a day. The following table gives the consumption in 1936 of 7 of the largest users of the public supply.

Water consumed in 1936 by large users of the Grand Island public supply, in gallons

Union Pacific Railroad	32,800,000
Stock barns	9,100,000
St. Francis Hospital	8,300,000
Yancey Hotel	8,000,000
City cemetery	6,500,000
Sugar factory	6,000,000
Stratton Hotel	3,200,000

The public supply at Grand Island was pumped in 1936 from nine wells and in 1937 from eight wells, all located within the city. Five of the wells are concentrated in the heart of Grand Island along a line about parallel to the Union Pacific Railroad and the other four are in the north, west, and south outlying parts of the city (pl. 16). No record has been obtained of the pumpage from individual wells, but the number of hours that each well is pumped has been kept. The number of hours per month each city well was pumped from December 1935 to March 1938 is shown graphically in figure 43.

All the city wells are 25 inches in diameter and are equipped with about the same pumping installations. Thus it is likely that the yield of individual wells does not differ greatly, although the wells that are concentrated in downtown Grand Island probably yield less water than the outlying wells because the water table there is drawn down considerably by the pumping; hence the lift is greater, and the thickness of the saturated sand and gravel is less. The number of hours that each well is pumped, therefore, gives a general comparative figure for the pumpage from that well. In 1936, an average of 5,410,000 gallons of water was pumped daily from nine wells that were operated a total of 35,850 hours. The average rate of pumping from each well was, therefore, 920 gallons a minute. In 1937, an average of 5,000,000 gallons of water was pumped daily from eight wells that were operated a total of 34,040 hours and the rate of pumping from each well averaged 893 gallons a minute.

The five wells in downtown Grand Island, Nos. 1, 2, 3, 4, and 5, were operated a total of 22,900 hours in 1936 and 23,085 hours in 1937. This indicates that about 64 percent of the pumpage in 1936 and about 68 percent of that in 1937 was withdrawn from the wells in this small area. Well 6, directly up-gradient from the five centrally located wells, was operated 8,388 hours in 1936 (an average of about 23 hours a day) and 7,669 hours in 1937. Thus, about 87 percent of the pumpage in 1936 and about 90 percent of that in 1937 was from wells on about an east-west line through the middle of Grand Island and the rest was from the three wells in the north and south outlying districts of the city.

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The diagrams showing monthly hours of pumping (fig. 43) indicate that wells 7, 8, and 9 are used only in the summer when the demand is high and that the number of hours each is pumped during this time is about proportional to the demand. Wells 3, 5, and 6 are pumped throughout most of the year and they supply most of the winter consumption. Well 1 is operated almost every month but the number of hours pumped varies according to the demand,

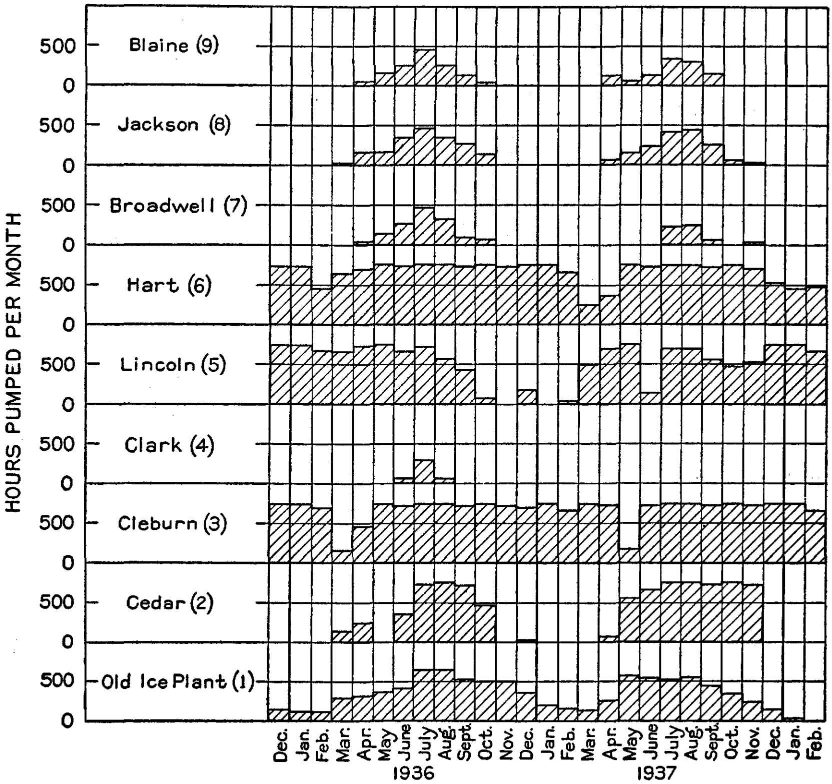

FIGURE 43.—Graphs showing operation of city wells in hours per month.

whereas well 2 is operated chiefly in the summer and is pumped very little during the winter. Well 4 was in use only a few hours in June, July, and August, 1936.

Although the wells are distributed over the city the system of operating them is such that most of the pumpage is from a comparatively small area in the central part of Grand Island. Doubtless this distribution of pumpage has caused the water table to decline more in the downtown section than it would have declined had more of the water been pumped from the wells in the outlying parts of the city.

There is considerable pumpage for industrial purposes and for irrigation from the Pleistocene sand and gravel in Grand Island and vicinity. Although no accurate figure for this pumpage is available it can be estimated from an inventory of industrial wells made by the Grand Island Water Department in 1937 and from an inventory of irrigation wells made in 1931 by the Geological Survey in connection with the investigation in south-central Nebraska. Records of wells pumped for industrial supply in and near Grand Island and records of irrigation wells in the vicinity are given in the following tables. The location of all wells is shown on plate 16.

If all of the industrial wells were pumped at rates corresponding to their reported capacities and for the times indicated in the table their total pumpage would amount to an average of about 4,100,000 gallons a day, or almost as much as the pumpage for public supply. However, it is not likely that the wells are operated at their capacities, but rather at lower rates, probably not in excess of 75 percent of capacity. With such an assumption the average daily pumpage from industrial wells would amount to about 3,100,000 gallons.

Records of wells pumped for industrial supply in and near Grand Island

Well No.	Owner	Year completed	Diameter (inches)	Depth (feet)	Type of casing	Reported capacity (g. p. m.)	Time operated	Use
11	Nebraska Consolidated Mills	1936	13	74	Concrete	200	Continuous	Air conditioning and general.
12	Grand Island Creamery Co	1934	14	70	Steel	4	3/4	Boiler feed.
13	Fairmont Creamery Co	1923	18	83	Concrete	600	4/5	Cooling.
14	Golden Rod Creamery Co	1910	4	33	Steel	5	5/12	General.
15	American Crystal Sugar Co	1929	24	90	do	1,000	Oct., Nov., Dec	Do.
16	do	1932	24	90	do	1,000	do	Do.
17	do	1935	24	90	do	1,000	do	Do.
18	do	1936	30	90	Concrete	1,000	do	Do.
19	Nash Finch Grocery Co	1937	18	25	do	200	1/2	Cooling.
20	Schuff Cafeteria	1937	6	75	Steel	50	Continuous	Do.
21	Capitol Theatre	1928	8	75	Concrete	125	1/2 May to Sept	Air conditioning.
22	Union Pacific R. R	1927	30	102	do	1,000	1/2	General.
23	do	1928	30	102	do	1,000	1/2	Do.

Forty-five irrigation wells were located in an 81-square-mile area in the vicinity of Grand Island (pl. 16) by the well inventory conducted in 1931. The records of these wells, taken from the table of well records in Water-Supply Paper 779, are given in the following table. According to information collected during the inventory, 2,140 acres of crops were irrigated in 1931 by water pumped from the wells. It was estimated that the average supplemental water requirement for crops in the Platte Valley is about 10 acre-inches a year for corn, about 15 acre-inches for potatoes, and about 8 acre-inches for alfalfa. If these quantities of water are supplied to the crops from wells the annual pumpage for irrigation is computed to be about 1,800 acre-feet. It is not known whether pumpage for irrigation has increased materially since 1931.

The total pumpage from the Pleistocene sand and gravel in the area of 81 square miles covered by plate 16 is about equal to the total pumpage for city, industrial, and irrigation supplies. Pumpage for stock and for domestic use is a comparatively small quantity. It is estimated that in 1937 the pumpage for all uses averaged about 9,700,000 gallons a day and totaled about 10,850 acre-feet for the year. This represents only 2.5 inches of water over the area of 81 square miles. However, 9,100 acre-feet was pumped from about 8 square miles in and very near Grand Island, which is equivalent to about 21 inches of water over this relatively small area.

Records of wells pumped for irrigation in the vicinity of Grand Island

[From table of well records in Water-Supply Paper 779]

T. 12 N., R. 9 W.

Well No.[1]	Location	Owner or name	Year completed	Type[2]	Depth (feet)[3]	Diameter (inches)	Type of pump[4]	Size of pump (inches)	Kind of power[5]	Measuring point	Distance of measuring point above or below land surface (feet)	Depth to water level below measuring point (feet)	Date of measurement (1931)
61	NW¼SW¼ sec. 32	H. Mader	1930	Dr	57	12	T	4	E				
63	SW¼SW¼ sec. 32	F. Trout	1926	Dn	60	3	F		G				
64	SW¼SW¼ sec. 32	do	1930	Dr	30	6	Pl	2	G	Top of well casing	+1.5	8.62	June 23
65	SE¼SE¼ sec. 32	R. Menck	1931	Dn	10.6	2	R	2	A	Top of 18-inch casing	−3.6	3.77	Do.
68	NW¼SE¼ sec. 34	J. Erion	1927	Dr	44.9	24	C	6	G	Top of 2- by 4-inch building sill.	+.3	12.06	June 17
69	SW¼SE¼ sec. 34	G. Tilly	1919	Dr		25	C	6	E	Top of concrete curb	+.7	11.98	Do.
70	SE¼NE¼ sec. 35	Hainer Land Co	1929	Dr	80	25	C		E	Top of 4- by 6-inch girder on west side.	+.6	15.83	June 12
71	SW¼NW¼ sec. 35	do		Dr	58.7	25	C		E	Top of steel pump base	+1.0	14.70	Do.
72	SW¼SW¼ sec. 35	do		Dr	58.7	25	C		E	do	+1.0	13.27	Do.
73	SW¼SE¼ sec. 35	do		Dr	66.7	25	C		E	do	+1.0	17.80	Do.
74	SW¼NE¼ sec. 36	do		Dr	72.3	25	C		E	do	+1.7	19.20	Do.
76	SW¼SW¼ sec. 36	do		Dr	77.0	25	C		E	do	+1.0	18.85	Do.
77	SW¼SE¼ sec. 36	do		Dr	66.6	25	C		E	do	+2.0	20.45	Do.

T. 11 N., R. 9 W.

Well No.[1]	Location	Owner or name	Year completed	Type[2]	Depth (feet)[3]	Diameter (inches)	Type of pump[4]	Size of pump (inches)	Kind of power[5]	Measuring point	Distance of measuring point above or below land surface (feet)	Depth to water level below measuring point (feet)	Date of measurement (1931)
79	SW¼NE¼ sec. 2	do		Dr	66.7	25	C		E	do	+1.5	19.12	June 23
80	SW¼NW¼ sec. 2	do		Dr	88.8	25	C		E	do	+1.5	17.72	Do.
81	SW¼SW¼ sec. 2	do	1919	Dr	101	25	C		E	do	+.5	21.30	Do.
82	SE¼SE¼ sec. 3	A. Cadey		Dr	30.5		C	4	E	Top of concrete curb	+2.0	21.12	June 17
83	NE¼NE¼ sec. 4	W. Cupit		Dr	26.4	8	C	3	A	Top of well casing in pit	−8.4	1.65	June 23
84	SE¼NE¼ sec. 4	P. Bullis	1930	Dn	45	2	R	2	A			[6] 16	
85	SE¼NE¼ sec. 4	M. Anderson	1927	Dn	34.1	6	C	3	A	Top of well casing in pit	−9.4	4.25	Do.
86	NW¼NW¼ sec. 4	A. Kenyon	1930	Dr	49.6	24	T	8	T	Top of well casing	+1.0	12.12	Do.
87	NE¼SE¼ sec. 4	G. Meyers	1924	Dn	51	2	R	2	G			[6] 20	
88	NE¼SE¼ sec. 4	Mrs. A. Edwards	1915	Dr	50	12	F	3½	G	Top of board over casing	−5.5	6.55	Do.
90	SE¼SE¼ sec. 4	Olson's Hatchery	1930	Dr	37.7	18	C	4	G	Top of 4- by 6-inch pump support.	−12.4	1.08	Do.
92	SW¼SW¼ sec. 5	Soldiers' Home	1929	Dr		12	T	10	E				
93	SW¼SW¼ sec. 5	do	1927	Dr		7	C	5	E				
94	SE¼SE¼ sec. 5	do	1927	Dr		7	C	5	E				
95	SW¼NE¼ sec. 10	Hainer Land Co.	1921	Dr		25	C		E	Top of concrete pump base	+1.0	21.28	June 12
97	SW¼SW¼ sec. 12	F. Meyer	1928	Dr	27.8	15	C	5	E	Top of well casing	−5.3	.65	June 15
98	NE¼NW¼ sec 13	E. Roush	1927	Dr	19.2	8	C	3	E	do	+.2	5.93	Do.

99	SW¼SW¼ sec. 14	D. Stelk	1931	Dr	39.7	24	C	6	T	do	−2.0	4.95	June 16
103	NW¼NW¼ sec. 27	G. Thavenet	1930	Dn	15	2	R	2	A			[6] 6	
105	NE¼NW¼ sec. 28	A. Anderson	1930	Dr	12.1	24	R	1½	G	Top of wood curb	+1.7	7.50	June 27
106	NE¼NW¼ sec. 28	F. Mehring	1930	Dr	29	12	C	3	G				
107	NW¼NW¼ sec. 28	E. Roeser	1930	Dr	19.4	9	R	1¼	A	Top of well casing	−1.9	4.08	Do.
108	NW¼NW¼ sec. 28	C. Palmer	1930	Dr	38	10	R	2	E				
112	NE¼SE¼ sec. 29	F. Huston	1920	Dr	35	24	R	5	T	Top of well casing	+.5	6.52	June 26
113	NE¼SE¼ sec. 29	do	1918	Dr	64.2	25	C	10	T	Top of well platform	.0	6.86	Do.
114	NW¼NE¼ sec. 32	W. Munson	1931	Dn	15	2	R	1¼	G				
115	SW¼SW¼ sec. 32	Mrs. L. Galyean	1925	Dr		25	C	6	E	Top of concrete curb	.0	6.16	June 24
						T. 10 N., R. 9 W.							
126	NW¼NW¼ sec. 10	P. Herman	1930	Dr	16	16	C	3	A				
						T. 11 N., R. 10 W.							
144	NE¼SE¼ sec. 12	H. Hinrichs	1930	Dr	41.2	12	C	3	A	Top of concrete curb in pit	.0	11.64	June 24
145	SW¼SE¼ sec. 12	L. Pope	1924		51		F		G			[6] 12	
146	NE¼NE¼ sec. 14	J. H. & J. A. Still	1931	Dr	20.3	8	C	2	A	Top of well casing	−1.5	9.28	Do.
						T. 10 N., R. 10 W.							
159	NW¼NW¼ sec. 2	W. Schultz	1928	Dn	12	2	Pl		G	Top of 6- by 8-inch tie on north side.	.0	7.00	June 24

[1] Number in Water-Supply Paper 779 and in this report.
[2] Dr, drilled; Dn, driven.
[3] Reported depths below land surface are given in feet; measured depths, in feet and tenths below measuring points.
[4] C, centrifugal; F, force; Pl, plunger; R, rotary; T, turbine.
[5] A, automobile engine; E, electric motor; G, gasoline engine; T, tractor.
[6] Reported.

Records of observation wells in Grand Island and vicinity

[All wells except 245 constructed and owned by City Water Department; diameter, 1¼ inches; measuring point, top of pipe, 6 inches above land surface]

Well No. in this report	City No.	Location	Depth (feet)	Altitude of measuring point (feet)	Depth to water level below measuring point (feet)	Date (1935)	Remarks
		T. 11 N., R. 8 W.					
200	56	NW¼NE¼ sec. 18	11.0	1,822.30	6.05	Dec. 28	
201	55	SW¼SE¼ sec. 19	13.1	1,824.23	9.97	Dec. 28	3 feet southeast of corner fence post.
		T. 12 N., R. 9 W.					
202	36	NW¼SW¼ sec. 27	16.9	1,844.74	7.05	Dec. 28	
203	38	NE¼NE¼ sec. 32	13.6	1,858.60	10.75	Dec. 28	
204	39	SW¼SW¼ sec. 32	12.4	1,864.47	10.17	Dec. 28	
205	37	NW¼SW¼ sec. 34	14.6	1,847.67	8.80	Dec. 28	
		T. 11 N., R. 9 W.					
206	58	NE¼NE¼ sec. 2	24.5	1,841.49	19.15	Dec. 28	
207	1	SW¼NW¼ sec. 3	18.2	1,852.01	13.20	Dec. 27	East side of St. Paul Road, about ½ mile north of Capital Ave.
208	4	SE¼SW¼ sec. 4	22.0	1,856.20	14.25	Dec. 27	
209	5	SW¼SW¼ sec. 4	19.4	1,859.82	15.95	Dec. 27	Between two trees on east side of Broadwell Ave., just north of Capital Ave.
210	7	NE¼SE¼ sec. 8	24.0	1,862.42	17.30	Dec. 27	5 feet southwest of post, corner Broadwell Ave. and 18th St.; 390 feet north of Broadwell well (7).
211	6	NW¼SE¼ sec. 8	19.4	1,864.07	14.82	Dec. 27	State St. and Kruze Ave.
212	3	NE¼NE¼ sec. 9	29.0	1,857.06	20.85	Dec. 27	7.3 feet southwest of power pole on southwest corner of St. Paul Ave. and Capital Ave.
213	9	NE¼NE¼ sec. 9	24.0	1,858.77	21.20	Dec. 27	7.8 feet southeast of power pole on northeast corner of Illinois Ave. and Ohio St.
214	8	SE¼NW¼ sec. 9	19.5	1,860.71	17.10	Dec. 27	17th St. and Wheeler Ave.
215	15	SW¼SW¼ sec. 9	24.0	1,864.41	21.90	Dec. 27	13th St. and Broadwell Ave.
216	10	NE¼SE¼ sec. 9	33.1	1,861.77	28.92	Dec. 27	10th St. east from railroad tracks.
217	13	SE¼SE¼ sec. 9	36.1	1,860.83	29.35	Dec. 27	East side of Oak St., south from 7th St.
218	2	NE¼NE¼ sec. 10	30.1	1,851.87	22.15	Dec. 28	
219	57	SW¼SE¼ sec. 12	11.0	1,828.98	7.57	Dec. 28	2 feet southeast of corner fence post.
220	11	NW¼NE¼ sec. 14	12.6	1,835.15	6.90	Dec. 28	
221	19	NW¼NW¼ sec. 15	38.8	1,860.75	30.80	Dec. 28	770 feet northeast of Ice Plant well (1).
222	12	NW¼NW¼ sec. 15	37.2	1,858.52	27.30	Dec. 28	
223	29	SW¼SW¼ sec. 15	18.2	1,846.93	13.97	Dec. 27	10.8 feet south of tree, east side of Locust St., south of Charles St.
224	30	NW¼SE¼ sec. 15	12.5	1,842.13	9.25	Dec. 27	4 feet east of hydrant, Poplar and Groff Sts.
225	31	SE¼SE¼ sec. 15	10.5	1,841.77	8.50	Dec. 28	

226	20	SE¼NE¼ sec. 16	44.2	1,864.08	34.90	Dec. 27	500 feet southwest of Ice Plant well (1); 800 feet east of Cedar well (2).
227	18	SW¼NW¼ sec. 16	37.8	1,864.69	32.27	Dec. 27	8 feet north of alley, Greenwich Ave.; 1,480 feet from Lincoln well (5); 1,600 feet from Cleburn well (3).
228	21	SE¼NW¼ sec. 16	43.5		27.30	Dec. 20	14 feet east of hydrant, North Front and Clark Sts.; 840 feet northeast of Lincoln well (5); 590 feet southwest of Cleburn well (3).
229	22	NE¼SW¼ sec. 16	43.8	1,869.00	39.32	Dec. 27	20 feet west of barn, North Front and Washington Sts.; 220 feet south of Lincoln well (5).
230	23	NW¼SW¼ sec. 16	38.9	1,869.53	32.67	Dec. 27	North Front St. and Broadwell Ave.; 1,960 feet southwest from Lincoln well (5).
231	28	NW¼SE¼ sec. 16	39.0	1,864.91	33.05	Dec. 27	14.6 feet north of tree, 1st and Clark Sts.
232	16	NE¼NW¼ sec. 17	21.6	1,866.61	17.12	Dec. 27	13th St. and Custer Ave.
233	17	SE¼NW¼ sec. 17	28.3	1,868.53	22.15	Dec. 27	7th St. and Custer Ave.
234	24	SE¼SW¼ sec. 17	31.4	1,870.02	31.40	Dec. 20	75 feet northwest of Hart well (6).
235	26	SW¼NW¼ sec. 20	16.3	1,869.71	14.97	Dec. 27	6 feet northeast of hydrant, Division and Ingals Sts.
236	25	NW¼NW¼ sec. 20	28.5	1,874.23	23.35	Dec. 27	Potash Highway, northwest of race track.
237	27	NW¼NW¼ sec. 21	34.8	1,868.59	29.62	Dec. 27	16 feet north of tree on Jackson St., north of Koenig St.
238	33	SE¼NW¼ sec. 21	34.2	1,869.62	29.30	Dec. 27	26 feet east of Jackson St., 14 feet north of John St.; 215 feet north of Jackson well (8).
239	32	NW¼SW¼ sec. 22	11.0	1,846.84	8.13	Dec. 28	4 feet southwest of hydrant, Driesbach's corner.
240	54	NE¼NE¼ sec. 26	10.0	1,837.41	5.88	Dec. 28	3 feet northwest of corner fence post at intersection.
241	34	NE¼NW¼ sec. 28	10.7	1,853.16	7.47	Dec. 28	21.6 feet south and 30.7 feet west of intersection.
242	35	NW¼NW¼ sec. 29	23.8	1,875.72	21.95	Dec. 28	At cemetery.
243	45	SW¼SW¼ sec. 32	9.9	1,867.18	4.90	Dec. 28	
244	53	NE¼NE¼ sec. 34	10.3	1,846.39	5.47	Dec. 28	2 feet east of pole, southwest corner of intersection.
245	245	NW¼SW¼ sec. 27	12.1		7.62	Dec. 21	Owned and constructed by Univ. of Nebraska. Diameter, 1 inch. Measuring point, top of pipe, 2.0 feet above land surface.
246	49	NW¼SW¼ sec. 34	10.4	1,853.67	5.57	Dec. 28	2 feet north of east-west fence, east of road.
247	52	SW¼SE¼ sec. 35	10.7	1,846.74	4.73	Dec. 28	
T. 10 N., R. 9 W.							
248	50	NW¼SW¼ sec. 3	10.4	1,857.51	5.55	Dec. 28	
249	47	NW¼SW¼ sec. 4	10.4	1,863.18	5.70	Dec. 28	
250	46	SW¼SW¼ sec. 8	10.5	1,873.97	5.15	Dec. 28	
T. 12 N., R. 10 W.							
251	40	SW¼SW¼ sec. 1	12.6	1,871.21	8.65	Dec. 28	
252	41	SW¼SE¼ sec. 11	10.5	1,875.66	8.55	Dec. 28	
T. 11 N., R. 10 W.							
253	42	NW¼NE¼ sec. 13	15.5	1,872.95	11.70	Dec. 28	
254	43	NW¼SW¼ sec. 24	23.0	1,881.20	15.45	Dec. 28	
255	44	SE¼SE¼ sec. 26	19.6	1,875.72	9.20	Dec. 15	

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FLUCTUATIONS OF WATER LEVEL IN OBSERVATION WELLS

In 1935, the Grand Island Water Department constructed 55 observation wells in the city and vicinity, and in December of that year the Department began periodic observations of the water levels in them. The records of these wells are given in the preceding table, and the water-level measurements are recorded at the end of this report. As a part of the investigation in south-central Nebraska periodic measurements were made of the water level in an observation well about 2 miles south of Grand Island. Since the conclusion of that investigation, observations of the well have been continued as a part of a state-wide program of measurements of ground-water levels. The record of this well, No. 245, is given in the accompanying table and measurements of the water level in it are given in annual reports of the Geological Survey.[14] The location of all observation wells in the area covered by this report is shown on plate 16.

The fluctuations of water level in a well may indicate recharge and discharge of ground water in that part of the underground reservoir tapped by the well and consequently furnish data on changes in ground-water storage and on the nature of the factors that cause the changes. The water levels in wells at Grand Island fluctuate almost constantly as the result of precipitation and of the use of water by plants, evaporation, pumpage from wells, and other causes. The nature and magnitude of these fluctuations are described in detail in Water-Supply Paper 779.

Because the factors that cause many of the water-level fluctuations are operative only at certain times in the year or vary in magnitude through the year, the ground-water level usually undergoes a seasonal fluctuation. Recharge from precipitation is most likely to occur in the winter and spring, and discharge through transpiration, evaporation, and pumpage is greatest in the summer. As a result the water table normally reaches its highest level in the spring and its lowest stage in the fall. The highest and lowest stages reached each year vary considerably with the relative magnitude of the recharge and discharge, and if one or the other of these factors is persistently greater than the other over a period of years, the water table will rise to successively higher levels or decline to successively lower stages.

The precipitation recorded at the United States Weather Bureau station at Grand Island and the accumulative departure from normal

[14] Water levels and artesian pressure in observation wells in the United States in 1936: U. S. Geol. Survey Water-Supply Paper 817, pp. 131-132, 1937. Water levels and artesian pressure in observation wells in the United States in 1937: U. S. Geol. Survey Water-Supply Paper 840, p. 205, 1938.

precipitation for the period 1895–1937 are graphically shown in figure 44. The precipitation has been below normal each year since 1930, and in only 2 years in the last 18 has it exceeded normal. Doubtless the water table in the vicinity of Grand Island has declined somewhat in the recent dry years, yet at many places in the area it still stands comparatively close to the land surface—less than 5 feet, south and east of the city—and hence the regional decline has not been great. The recharge to the zone of saturation from any one

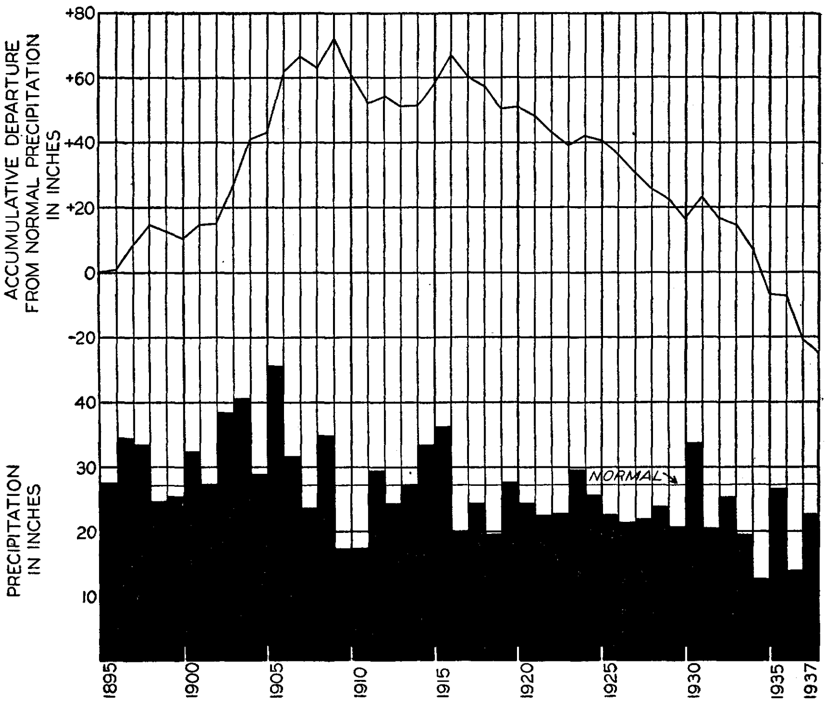


FIGURE 44.—Annual precipitation and accumulative departure from normal precipitation at Grand Island for the period 1895–1937.

rain in the Platte Valley depends to a large extent on the deficit of soil moisture that exists in the root zone at the time of the rain. (See Water-Supply Paper 779, pp. 149–151.) This deficit, which is created by use of water by plants, must be satisfied by infiltration from rains before much water can move downward to the water table. Where the water table stands close to the land surface the roots of many plants reach to the zone of saturation and a part of the water required for their growth is derived from this source. The draft on the moisture in the root zone thus is somewhat less than the draft in areas where the water table is below the reach of plant roots. In addition, the root zone in shallow water areas is confined essentially between the water table and the land surface and thus is limited in thickness, but in deep water areas the root zone may extend to a considerable depth. The maximum possible deficit in soil moisture that may be reached where the root zone is comparatively thick, is, of course, greater than where the thickness of the root zone is less. As the result of the comparative thinness of the root zone and the smaller draft on the moisture in the zone the deficit in soil moisture in shallow water areas is likely to be less than that which exists at the same time in deep water areas. This is confirmed by the relatively rapid response of the water table to precipitation in shallow water areas at the end of the growing season and by the frequent rises of the water table, even in the growing season, after moderate rains. Observations on the water levels in wells indicate that the zone of saturation in some shallow water areas receives sufficient accretions from precipitation in some years of subnormal precipitation to prevent the water table from suffering net declines in those years.

The use of water from the zone of saturation by plants in shallow water areas, and, in some places, the evaporation of water directly from the capillary fringe, create a comparatively high discharge that in such areas balances the frequent recharge from precipitation. However, in very dry years, the water table may be lowered below the roots of most plants and at such times transpiration from the zone of saturation is greatly decreased. This materially slows up the decline of the water table and prevents it from reaching extremely low stages. This process together with moderate recharge from precipitation has probably prevented the water table near Grand Island from declining to lower stages during the recent consecutive years of subnormal precipitation.

A general correlation of water level with precipitation is indicated in figure 45, which shows a graph of the water-level fluctuations in well 245 from 1932 to 1938 and the monthly precipitation for the period at Grand Island. From 1932 through 1934 the general trend of the water level was down, as shown by successively lower fall and winter stages. In 1935, considerable recharge occurred and the water level at the end of the year stood almost 2 feet higher than at the beginning of the year. The precipitation in the following year, however, was low, and the water level lost its gain of 1935 and declined to about the low stage of 1934. In 1937 about 0.6 foot was recovered. Rather large rises of water level resulted from heavy

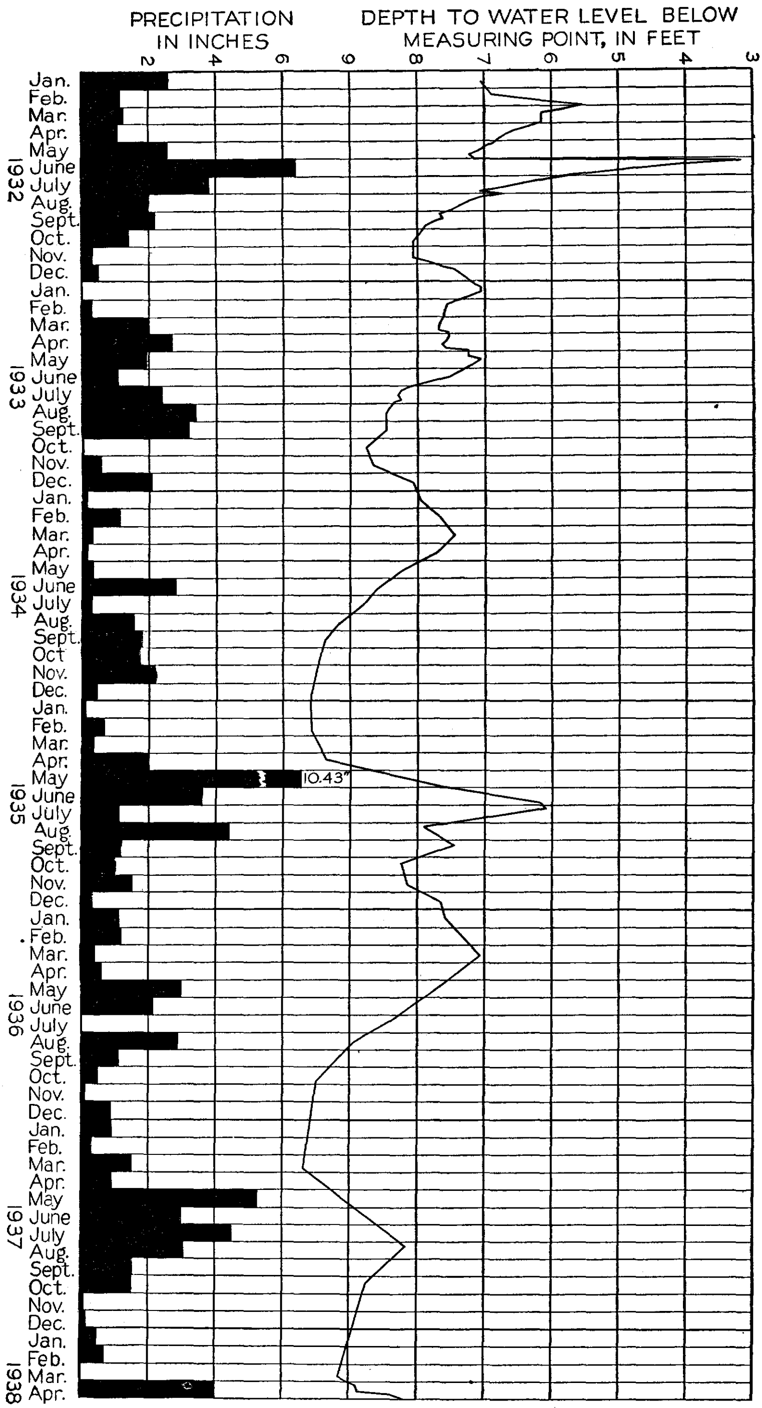


FIGURE 45.—Hydrograph showing fluctuations of water level in well 245 and the monthly precipitation at Grand Island.

precipitation in June 1932 and May 1935. In 1932, the rise was followed by a precipitous decline, but in 1935 the decline was much less rapid, owing probably to two causes. First, the rise in 1932 carried the water level to within about 1 foot of the land surface, whereas the water level in 1935 rose only to about 3 feet from the surface; thus in 1932 more plants were able to transpire water from the underground reservoir. Second, the ensuing decline in 1935 was interrupted by a rise in August, probably due to recharge from the comparatively high precipitation in that month, whereas the decline in 1932 was almost continuous from June to November.

The fluctuations of water level in well 245 probably represent in general the regional fluctuations in that part of the area where the water table is comparatively close to the land surface, although the water level in the well probably is affected to some extent by the pumpage in Grand Island. The net decline suffered by the water level in the well in the 2-year period ended January 1, 1938, suggests that the regional water table probably declined in that period and hence that the water levels in most of the observation wells might also be expected to decline.

The water levels in almost all the 55 observation wells in Grand Island and vicinity were lower in January 1938 than in January 1936 (see table of well measurements at end of this report). To what extent these declines represent a regional lowering caused by the low precipitation and to what extent they are the result of a local overdevelopment may be judged by an inspection of the records of individual wells. Some of the wells are definitely outside the area where the water table is seriously affected by the pumpage in Grand Island, whereas other wells are within a clearly defined cone of depression created by the pumping. (See pl. 16.) Hence the wells may be segregated into two general groups according to this classification. Wells 243 to 250, inclusive, are south of Grand Island and probably are affected little, if any, by the pumpage in the city. The water levels in these wells averaged 4.88 feet below the land surface on January 1, 1936, and 5.40 feet below the land surface on January 1, 1938. The average net decline for the 2-year period was only 0.52 foot—equivalent to about 1.5 inches of water over that area.

Wells 200, 201, 218, 219, 220, 225, and 240 are east of Grand Island. Of these wells, 218, 220, and 225 are near the city and probably are influenced by the pumpage, whereas the other wells are farther east and probably are not so affected. The water levels in wells 218, 220, and 225 suffered net declines of 1.0 foot to 1.8 feet from January 1, 1936, to January 1, 1938, and averaged 1.30 feet lower on the latter date, whereas the water levels in wells 200, 201, 219, and 240 declined from 0.25 to 0.55 foot in the 2-year period and averaged 0.38 foot lower on January 1, 1938. The average depth to water level in wells

218, 220, and 225 on January 1, 1938, was 13.3 feet; in the other wells, 6.8 feet.

Wells 202, 203, 204, 205, 206, 207, and 251 are north of the city and all of them probably are affected by the pumpage in Grand Island or by pumpage for irrigation. The water levels in them declined 1.0 to 2.4 feet from January 1, 1936, to January 1, 1938, the largest declines, 2.40 and 2.00 feet, occurring in wells 207 and 251, respectively. The water levels in the wells declined 1.5 feet on the average in the 2-year period and on January 1, 1938, averaged 12.1 feet below the land surface. That the net decline of the water level north of Grand Island is greater than that east and south of the city is probably due to less recharge from precipitation, because of a deeper-lying water table, and more pumpage, especially for irrigation, in the vicinity of the wells.

The water levels in all the observation wells in and very near Grand Island and in those to the west are affected by pumpage in the city. The water levels in 26 out of 29 of these wells declined 1 foot or more between January 1, 1936, and January 1, 1938, and the water levels in 9 of them declined more than 2 feet. The water levels in 19 wells in the city declined an average of 1.7 feet in the 2-year period and on January 1, 1938, averaged 26.9 feet below the land surface. The water levels in six wells west of Grand Island declined an average of 2.0 feet in the period and stood 17.5 feet below the surface on January 1, 1938.

The foregoing comparison of net changes in water level between January 1, 1936, and January 1, 1938, in different parts of the area covered by this report suggests that local overdevelopment exists in Grand Island. Average net declines of only 0.52 foot and 0.38 foot occurred in wells south and east of the city where the influence of the pumpage is negligible in comparison to average net declines of 1.7 feet in the city and 2.0 feet west of the city where the pumpage is known definitely to affect the water level. North of Grand Island the water levels in wells declined an average of 1.5 feet, but an average net decline of only 1.07 feet occurred in the three wells situated farthest north of the city (202, 203, and 205). The comparatively large declines near the city and up-gradient to the west indicate a gradual spreading out of the cone of depression, and the declines within the city indicate a deepening of the depression. Although the average net decline of the water levels in wells in the city—1.7 feet—was not exceptionally large in comparison to the declines that occurred in some of the wells farther from the area of pumping, the decline is significant because the total pumpage for public supply in 1936 and 1937 was about 240,000,000 gallons less than in 1934 and 1935 and the water level in the city might have been expected to recover somewhat as the result.

The fluctuations of the water level in the observation wells south of Grand Island, 243 to 250, inclusive, in 1936 and 1937 were very similar. Appreciable rises occurred in the spring months of 1936 and 1937 and subsequent declines followed in the summer months. The declines in 1936 were relatively large and the water levels in all the wells were lower at the end of the year than they were at the beginning. The seasonal decline in 1937, however, was less severe and the water levels in all the wells at the end of the year were at stages above those at the end of 1936. The net rises in 1937 indicate strongly that recharge from precipitation in the area south of Grand Island where the water table is close to the land surface is ample in some dry years, such as 1937, to maintain the water table near the surface or to raise it when preceded by years of very low precipitation during which the water table has declined to low levels.

The fluctuations of water level in wells 200, 201, 219, and 240, east of Grand Island, were similar in 1936 and 1937 to the fluctuations in the wells south of the city. All show seasonal rises and declines in 1936 and 1937, net declines in 1936, and small net rises in 1937. The fluctuations of water level in wells 218, 220, and 225, situated to the east but near Grand Island, were somewhat different. The water levels in wells 220 and 225 rose in the springs of 1936 and 1937 but declines during both summers were sufficient to cancel the preceding rises and the water levels suffered net declines in both years. The water level in well 218, which on January 1, 1938, stood about 23.5 feet below the land surface, rose very little in the springs of 1936 and 1937 and suffered net declines in both years. Apparently very little recharge to the ground-water reservoir occurred near well 218 in the 2-year period, probably because the water table in the vicinity is comparatively deep and the plants used most of the precipitation that seeped into the ground.

The water levels in wells north of Grand Island fluctuated in the same general manner as those in wells 218, 220, and 225. Net declines occurred in both 1936 and 1937 but the declines in the former year were most severe. The spring rises of water level in both years were small. The water level in well 251 declined persistently throughout 1936 and 1937 at about a constant rate, indicating that little if any recharge from precipitation occurred.

The water levels in most of the wells in Grand Island and some of the wells west of the city fluctuate with changes in pumpage—as a result the effect of recharge from precipitation is rather effectively masked. The lowest water levels in many of the wells are reached in the summer when the pumpage is at a maximum and rises occur in the fall and winter when the pumpage is less. A severe net decline in water level was registered in almost all of the wells in 1936 followed by a moderate net decline in 1937. Sharp declines occurred in wells 236 and 242, situated just west of Grand Island, in December 1935 and to a lesser extent in the falls of 1936 and 1937. The unseasonable lowering of the water levels in these wells probably was caused by the pumping of nearby wells at the plant of the American Crystal Sugar Co., which usually operates its wells only during October, November, and December.

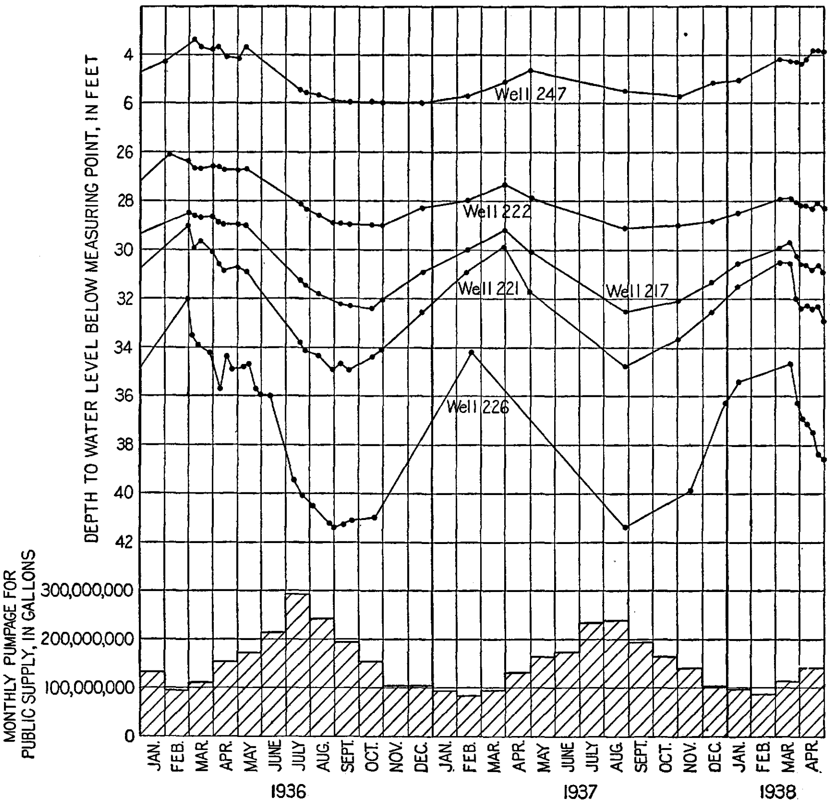


FIGURE 46.—Hydrographs showing fluctuations of water level in observation wells and monthly pumpage for public supply at Grand Island.

The general fluctuations in water level that result from seasonal variations in pumpage in Grand Island are shown by the lower four hydrographs in figure 46. Well 226 is situated about 1,000 feet from the probable apex of the cone of depression in the heart of the city; well 221 at about 2,100 feet; well 217 at about 3,000 feet; and well 222 at about 3,300 feet. Well 247 is about 4 miles southeast of the pumping area and the water level in it is not affected by the pumpage in the city. A comparison of the hydrographs with the monthly pumpage shows that the water levels in wells 226, 221, 217, and 222, in general, fluctuate inversely with the pumpage. The highest yearly stages in the wells are reached in February or March, when the pumpage is low, and the lowest stages are reached in August or September, when the pumpage is high. Each of the wells probably is influenced most by the pumpage from the nearest well, and hence the lowest levels do not correspond exactly with the highest total pumpage of all of the city wells. Moreover, the water levels in some of the wells doubtless are affected by pumpage from private wells. The general magnitude of the annual fluctuations of water level are, as might be expected, about proportional to the nearness of the observation well to the pumping area. Thus the water level in well 226 fluctuated through a range of about 9 feet in 1936, the water level in well 221 fluctuated through a range of about 6 feet, the water level in well 217 through a range of about 4 feet, and the water level in well 222 fluctuated through a range of about 3 feet. A lag in response to changes in the rate of pumping is also indicated by the hydrographs of these wells. The water levels in wells close to the area of pumping began to decline as soon as the pumpage was increased, whereas the water levels in more distant wells maintained their stages until the effect of the increased pumpage was gradually transmitted to them. Also, the water levels in wells close to the pumping area rose quickly in response to a decrease in the pumping rate but the water levels in the more distant wells continued to decline for some time. This lag or delay is produced by changes in underground storage. When the pumping rate is increased, the additional water is taken for a time from storage close to the pumped wells and then, as a hydraulic gradient capable of transmitting the required quantity of water to the wells is developed, the additional water is taken from storage at increasing distances. When the pumping rate is decreased, more water than is pumped continues to flow toward the pumped wells under the existing hydraulic gradient, but instead of being discharged from the wells it gradually fills the interstices of the material. As the material fills, the hydraulic gradient is decreased, less water percolates toward the wells, and the water table rises at increasing distances. This lag was shown clearly by the pumping test made near Grand Island in 1931 to determine the permeability and specific yield of the Pleistocene sand and gravel.[15]

In general, the seasonal fluctuations of water level in well 247 are about of the same form as those in the wells situated in the city, because the use of water by the vegetation in the vicinity of well 247 affects the water level in that well in about the same manner as the

[15] Wenzel, L. K., The Thiem method for determining permeability of water-bearing materials and its application to the determination of specific yield: U. S. Geol. Survey Water-Supply Paper 679, pp. 34-35, 50-51, 1936.

increase in city pumpage affects the other wells. There are, however, several significant differences. Because transpiration does not become especially effective until late April or May and because recharge from precipitation often occurs in March, April, and May, the water level in well 247 usually maintains a high stage much later in the year than do the water levels in the wells affected by the city pumpage. The low annual stage of the water level in well 247 usually is not reached until October or November because plants withdraw water to some extent from the underground reservoir until frost halts their growth. The fall and winter recovery is usually less in well 247 than in the other wells because the magnitude of the rise depends chiefly on the amount of recharge from precipitation, which during these months generally is small.

The water levels in several of the observation wells show individual fluctuations caused by the pumping of city wells. The water level in well 210 responds considerably to the pumpage from city well 7, which is situated 390 feet to the south. Well 7 was not operated in 1936 until April 18 (see fig. 43), when it was pumped for 9½ hours. The well was operated 3 hours on April 22, 10 hours on April 23, and 9½ hours on April 24. The water level in well 210 rose slowly from 17.55 feet below the measuring point on January 25, 1936, to 17.15 feet below the measuring point on April 18. Presumably, well 7 had not been pumped before well 210 was measured on April 18. Another measurement of water level in well 210 was made on April 24 when well 7 was pumping and the water level stood 20.30 feet below the measuring point, a decline of 3.15 feet from April 18. Well 7 was not pumped on May 12 and the water level in well 210 was 17.55 feet below the measuring point, a rise of 2.60 feet from April 24. Well 7 was pumped on May 15, and the water level in well 210 declined to 19.00 feet. On June 12, when the well was not operating, the water level in well 210 was 17.65 feet below the measuring point. Well 7 was pumped almost every day from June 13 to September, and the water level in well 210 on June 20 was 20.85 feet; on June 27, 21.45 feet; on August 4, 21.90 feet; and on September 1, 21.60 feet below the measuring point. A measurement on October 20, when well 7 was not in operation, indicated that the water level in well 210 had recovered to 19.25 feet, and by February 19, 1937, the water level stood 18.52 feet below the measuring point.

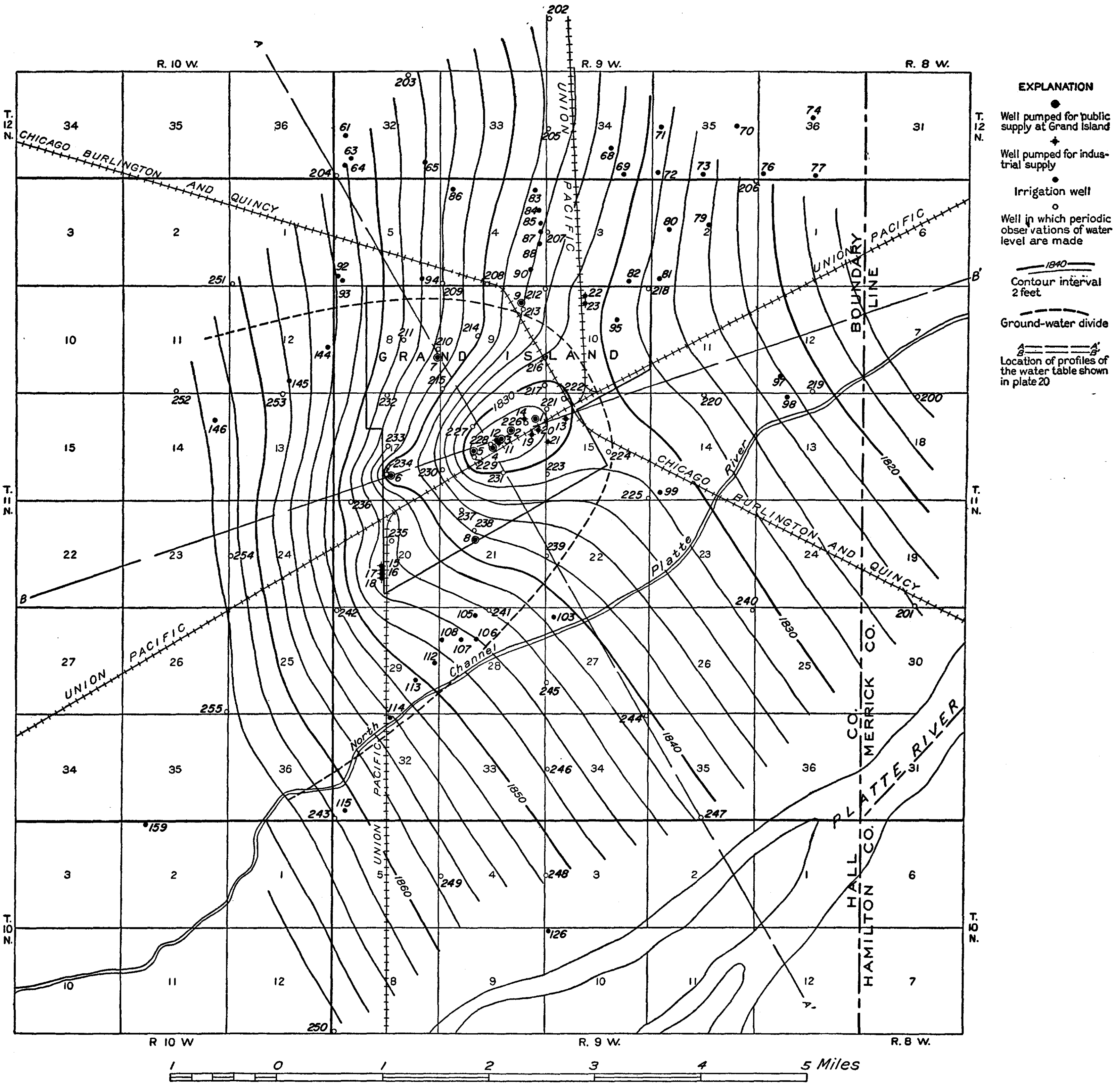
City well 5 was pumped almost every day from January 1, 1936, to October 6, 1936 (see fig. 43), and the water level in well 229, situated 220 feet south of well 5, fluctuated in that period through a range of from 37.90 to 39.65 feet below the measuring point. On October 20, 14 days after operation of well 5 had stopped, the water level in well 229 stood 36.35 feet below the measuring point, the highest level observed in 1936. Well 5 was operated 9 days in December 1936, 1 day in February 1937, and daily after March 11. The water level in well 229 stood 33.40 feet below the measuring point on February 19, 1937, indicating a recovery of more than 6 feet as the result of the 5-month shut-down of well 5. Well 5 was pumped almost continuously for the remainder of 1937, and the water level in the observation well dropped to 41.10 feet below the measuring point by December 28.

MOVEMENT OF THE GROUND WATER

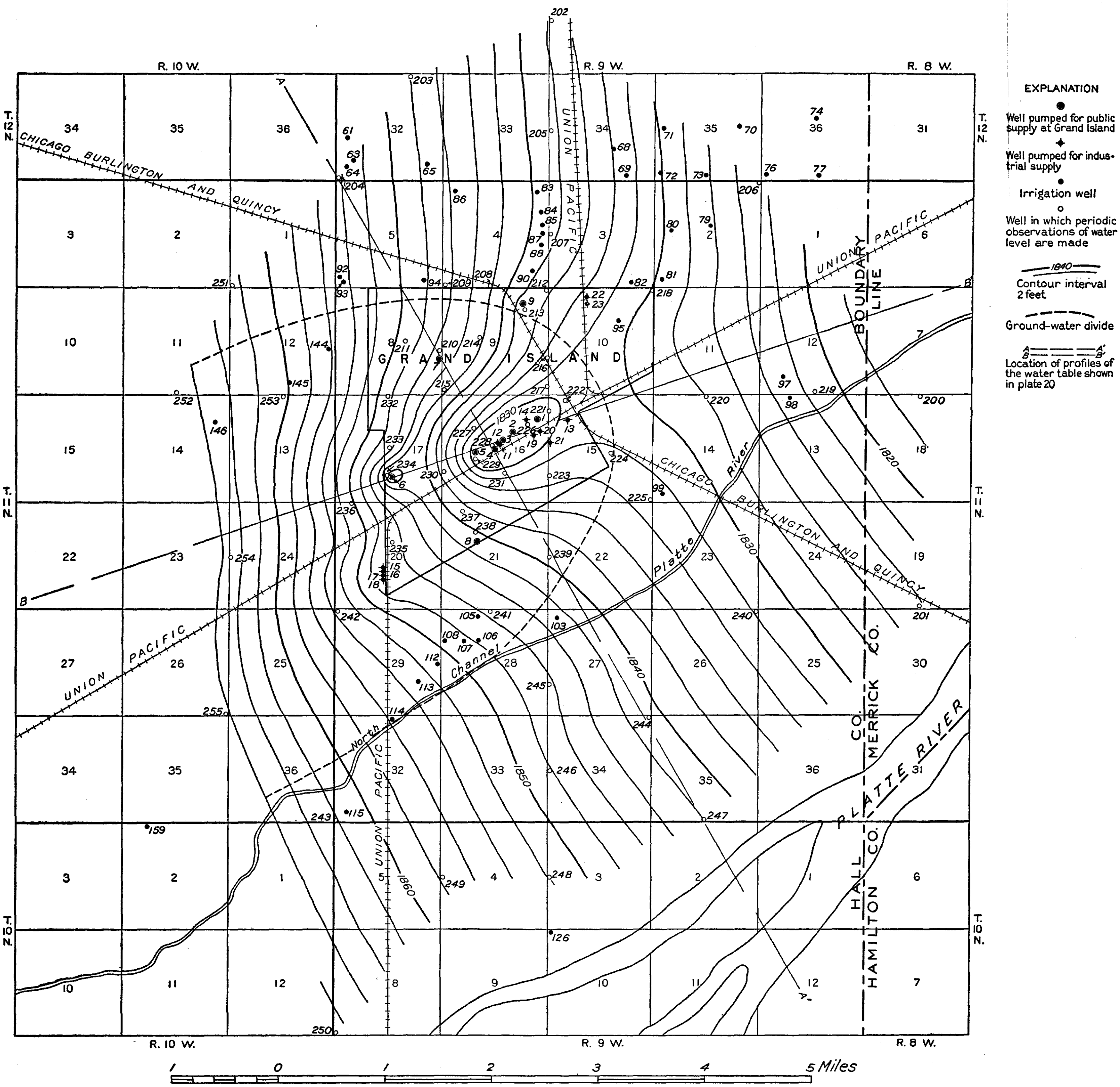
The movement of ground water depends on two conditions: First, the saturated material must be permeable in order that water can percolate through it; and second, there must be a force (hydraulic gradient) to cause the water to move. The flow of the ground water is directly proportional to the permeability of the water-bearing material, the hydraulic gradient, and the cross-sectional area of the material through which the water moves.

The altitudes of the measuring points of the observation wells at Grand Island were instrumentally determined by the Grand Island Water Department. (See table of well records.) Using these altitudes and the water levels in the wells on January 1, 1936, interpolated from depth to water-level measurements, a map showing contours (lines of equal altitude) on the water table with a 2-foot interval was constructed (pl. 16). In a similar manner, maps were drawn showing contours on the water table for August 1, 1936 (pl. 17), and for January 1, 1938 (pl. 18). Where the water table is a flat, sloping surface the contours can be constructed by direct interpolation between the altitudes of the water levels in the observation wells, but where the water table is an irregular surface, as it is beneath Grand Island, considerable judgment must be exercised in drawing the lines. There doubtless is a cone of depression around each well in Grand Island during the time that water is being pumped from it and for some time after pumping is stopped, but these individual depressions, with a few exceptions, are not indicated on the maps. The general form of the contours is well established by the water levels in the observation wells, but their precise location at all places cannot be ascertained without a greater number of points of observation. It is believed that the contours shown on the maps indicate with reasonable accuracy the direction of movement of the ground water and the hydraulic gradients under which the water moves.

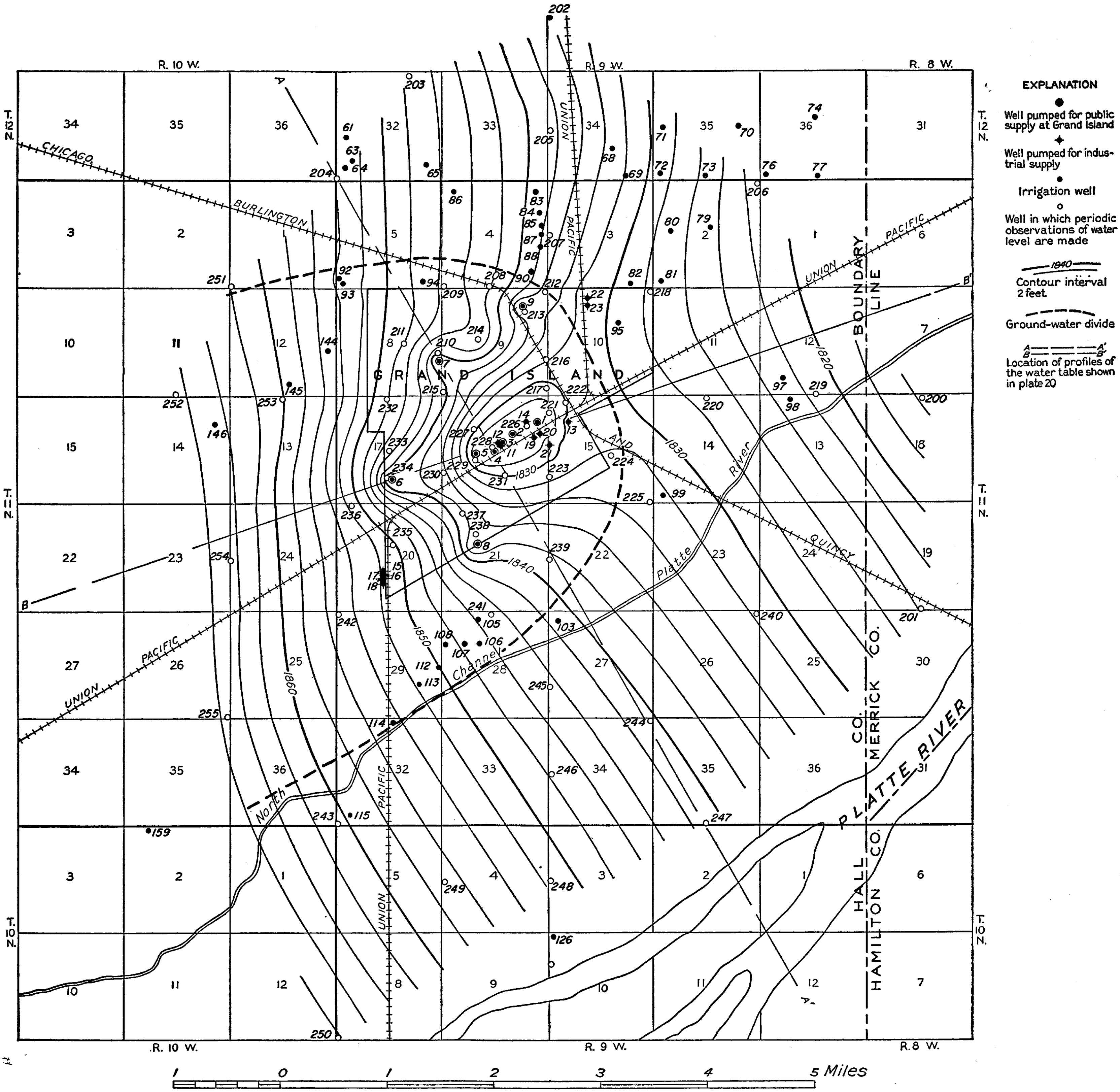
A map showing contours on the water table for the vicinity of Grand Island was published in Water-Supply Paper 779 (p. 135). The contours were based on measurements of the altitudes of the water



MAP SHOWING CONTOURS ON THE WATER TABLE IN THE VICINITY OF GRAND ISLAND ON JANUARY 1, 1936, AND LOCATION OF MUNICIPAL, INDUSTRIAL, AND IRRIGATION WELLS.



MAP SHOWING CONTOURS ON THE WATER TABLE IN THE VICINITY OF GRAND ISLAND ON AUGUST 1, 1936.



MAP SHOWING CONTOURS ON THE WATER TABLE IN THE VICINITY OF GRAND ISLAND ON JANUARY 1, 1938.

levels in 27 wells during the month of July 1931. The form of the contours on this map is similar to that shown for the same area on plates 16, 17, and 18 of this report, but the contours indicate that the water table in 1931 was about 5 feet higher than in 1936 to 1938. This difference in water level probably is more apparent than real and is due chiefly to use of different datum planes for sea level.

The direction of movement of the ground water is at right angles to the contour lines. Thus south of Grand Island the movement is to the northeast, about parallel to the Platte River, and north of Grand Island the movement is more to the east and toward the river. There is shown on each map one line drawn normal to the contour lines, through their points of inflection that separates the water which eventually moves on down gradient from that which percolates into the depression under Grand Island and is withdrawn through wells. As indicated by the position of the ground-water divide, the water beneath most of the area west of Grand Island is tributary to the city. Ground water percolates to the city through an area whose cross-section is approximately 4 miles wide. The extensive area enclosed by the divide suggests that the depression has been expanding for many years.

The form of the contours on the water table on January 1, 1936, August 1, 1936, and January 1, 1938, is nearly the same. There are, however, specific differences due to the comparatively high pumpage in August 1936 and the net decline in water level from January 1, 1936, to January 1, 1938. The pumping of city wells 6, 7, 8, and 9 during the summer somewhat alters the contours from those shown on plate 16. Four individual cones of depression are indicated on plate 17, three of which do not exist in the winter. The pumping of well 9 apparently moves the ground-water divide about a quarter of a mile north of the position it occupies when the well is not being operated and thus increases the area tributary to the main cone of depression. An inspection of the three maps shows that, with the exception of well 9, the municipal wells in the outlying sections of the city are within the area outlined by the ground-water divide and hence the pumping of them probably reduces the percolation of ground water to the five centrally located wells.

The net lowering of the water table in 1936 and 1937 is shown by the increase in size of the areas enclosed by the contours in Grand Island and by the general shift to the west of the other contour lines. Because the water table south of the north channel of the Platte River declined very little in the 2-year period the position of the contour lines in that area are about the same on both plates 16 and 18. The larger decline of the water table west and northwest of Grand Island shifted the contours in those areas to the west, and as a result the contours on plate 18 have more curvature and indicate more clearly that the area west of the city is influenced by the pumpage in Grand Island.

An estimate can be made of the quantity of water that percolates to Grand Island through the Pleistocene sand and gravel just west of the city. The average thickness of the Pleistocene deposits encountered in and near Grand Island in test holes and city wells is 137 feet. Of this thickness about 120 feet is saturated. The hydraulic gradient, which did not change appreciably in this area from 1936 to 1938, averages about 11 feet to a mile. If the permeability of the material is assumed to be 1,000 (see p. 243) the flow through a 4-mile-wide section of water-bearing material just west of Grand Island is computed to be 5,300,000 gallons a day, or 5,900 acre-feet a year. A similar computation of this kind was made for the flow of ground water down the entire width of the Platte Valley at Grand Island as a part of the investigation of south-central Nebraska.[16] The thickness of the Pleistocene sand and gravel in test holes drilled across the 14-mile width of valley averaged 123 feet and the hydraulic gradient was taken as 7 feet to a mile (the gradient for the part of the valley unaffected by the pumpage at Grand Island). Using a coefficient of permeability of 1,000, the flow down the entire width of valley was computed to be about 12,000,000 gallons a day. The average velocity of the ground water through this section was computed to be about 0.63 foot a day, assuming a porosity of 28 percent for the water-bearing material. Making the same assumption for porosity, the average velocity of the ground water just west of Grand Island is computed to be about 1 foot a day. The velocity is, of course, greater in the city where the hydraulic gradient is steeper.

SOURCE OF THE GROUND WATER

The maps showing contours on the water table (plates 16, 17, and 18) indicate clearly that the water pumped from wells in Grand Island is derived from underflow from the west and from precipitation on the area within the ground-water divide. It was pointed out in Water-Supply Paper 779 (p. 183) that the ground water in the Platte Valley is derived from precipitation in the valley, loss from streams, seepage of irrigation water, and underflow. Insofar as the Grand Island supply is concerned, only the first and last factors are important. In addition, some of the Grand Island supply is being taken from storage.

The entire area in the vicinity of Grand Island is one of recharge and discharge of ground water. Recharge from precipitation occurs

[16] Lugn, A. L., and Wenzel, L. K., Geology and ground-water resources of south-central Nebraska: U. S. Geol. Survey Water-Supply Paper 779, p. 136, 1938.

at times almost everywhere as does discharge through wells and transpiration. Thus it is not possible to distinguish concisely between areas of recharge and areas of discharge, but it can be done approximately by determining the areas where each of these factors is most operative. For the part of the valley covered by this report, the chief area of ground-water discharge is Grand Island and the important areas of recharge are those around the city where the water table stands comparatively near the land surface. The largest recharge area is south of Grand Island, where the water table is less than 5 feet below the surface.

For the Grand Island supply, the discharge area is in the city and the principal area of recharge is that part of the valley enclosed by the ground-water divide west of the city. Although some recharge from precipitation doubtless occurs in the city, it probably is small because buildings and pavements limit the infiltration area. Thus a large part of the water pumped in Grand Island necessarily percolates into the city from the west through the Pleistocene sand and gravel. The quantity of water that can safely be withdrawn through wells in Grand Island is, therefore, chiefly dependent on the quantity of underflow tributary to the pumped area.

The maps do not indicate that the city pumpage is supplied by percolation from the main channel of the Platte River. It is probable that some of the stream water percolates for short distances into the underground reservoir when the river rises above the level of the water table. Conversely when the surface of the river falls below the level of the water table some water undoubtedly moves into the stream from the ground-water reservoir. The ground-water divide has not as yet shifted sufficiently to the south to allow water from the Platte River to percolate into the cone of depression. The divide, however, does reach the north channel, and probably some seepage loss occurs at times from it. The north channel is narrow and usually carries water only part of the year, and hence the gain to the ground-water reservoir by seepage from the water in the channel probably is small.

ORIGINAL STATIC WATER LEVEL

According to Darton[17] the static water level in 1896 was 16 feet below the land surface at the waterworks in Grand Island, whereas the static water level is now from 30 to 40 feet below the surface at this locality. No other information regarding early water levels at Grand Island is known.

[17] Darton, N. H., Underground waters of a portion of southeastern Nebraska: U. S. Geol. Survey Water-Supply Paper 12, p. 37, 1898.

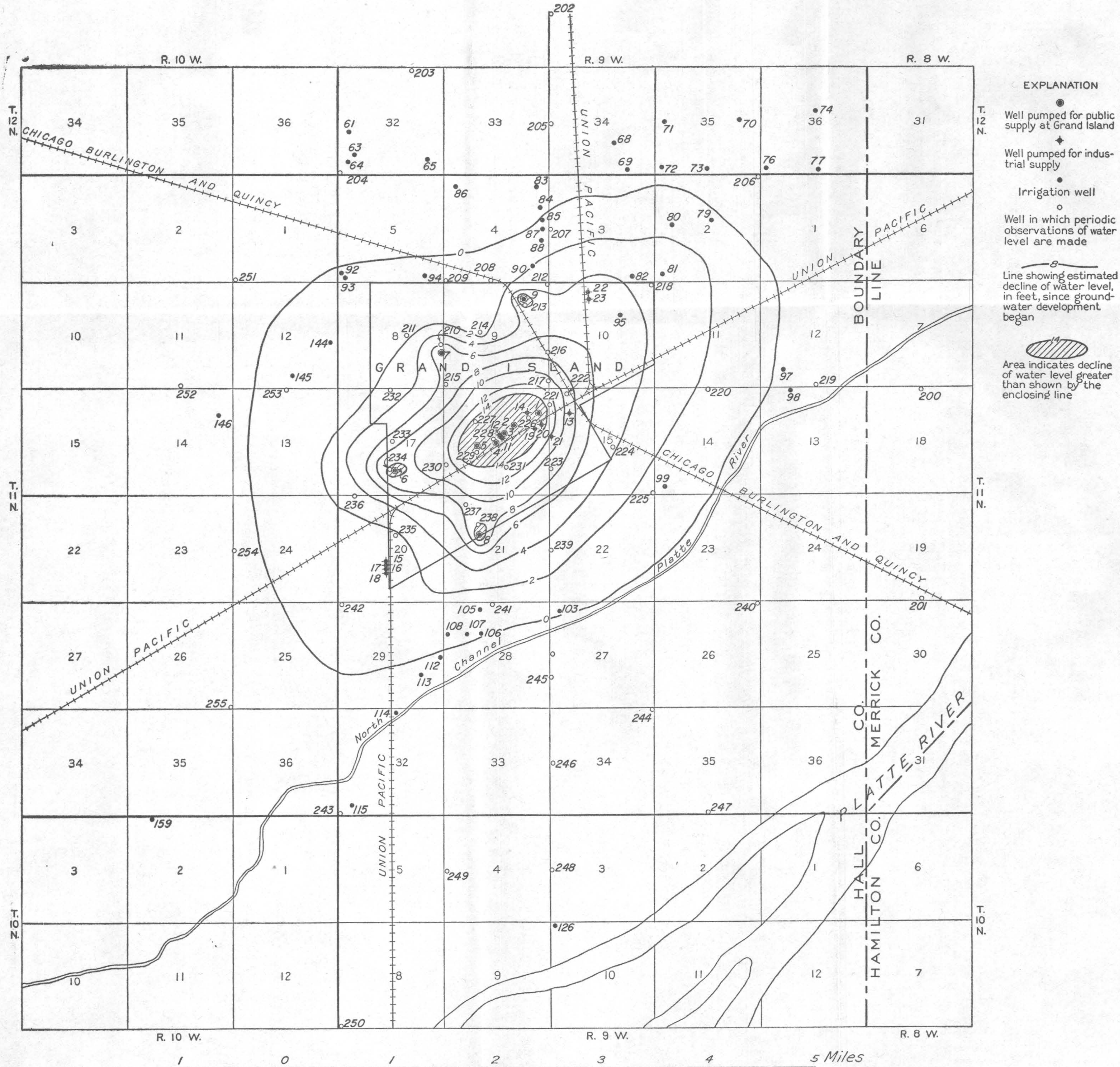
The original static level in Grand Island can be approximated if the present water levels north and south of the city are assumed to be about the same as the original levels. Because the water table stands very near the land surface south of Grand Island—less than 5 feet over a large area—it is believed that the water level has not declined materially in this area. North of the city the water table is somewhat deeper—7 to 10 feet or more—and the assumption that the present stage of the water table is the same as the stage before development began must be made with less confidence. However, the present levels cannot differ greatly from the original levels in areas where the water table is very close to the surface.

Contour lines were constructed on the estimated original water table by extending the lines on plate 17 in smooth curves from their positions on August 1, 1936, south of Grand Island across the city to their corresponding positions on that date north of Grand Island. The intersections of the two sets of contour lines were connected with lines showing the depth of the present water level below the estimated original level, and these lines of equal decline were reconstructed on plate 19. This figure indicates that since the first development was made there has been a net decline in water level of more than 14 feet in the central part of Grand Island and of 6 feet or more over a large area in the city.

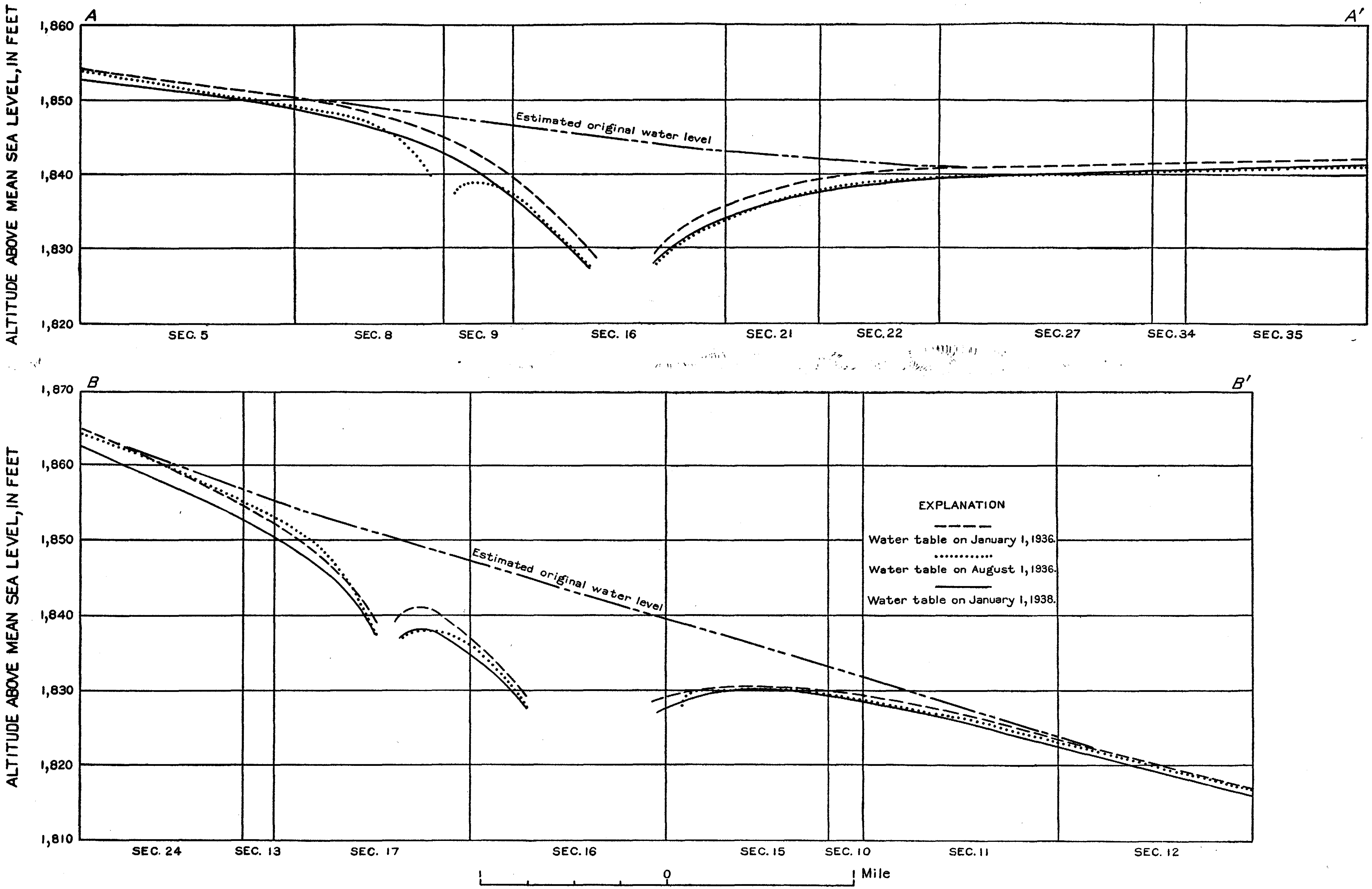
The water levels on January 1, 1936, August 1, 1936, and January 1, 1938, and the estimated original water level are shown in two profiles of the water table on plate 20. Profile *A–A′* is taken in a northwest-southeast direction and profile *B–B′* in a southwest-northeast direction. (See pls. 16, 17, and 18.) The large depression of the water table under Grand Island is shown clearly by the profiles as are the smaller depressions caused by the pumping of individual wells.

QUANTITATIVE ESTIMATES

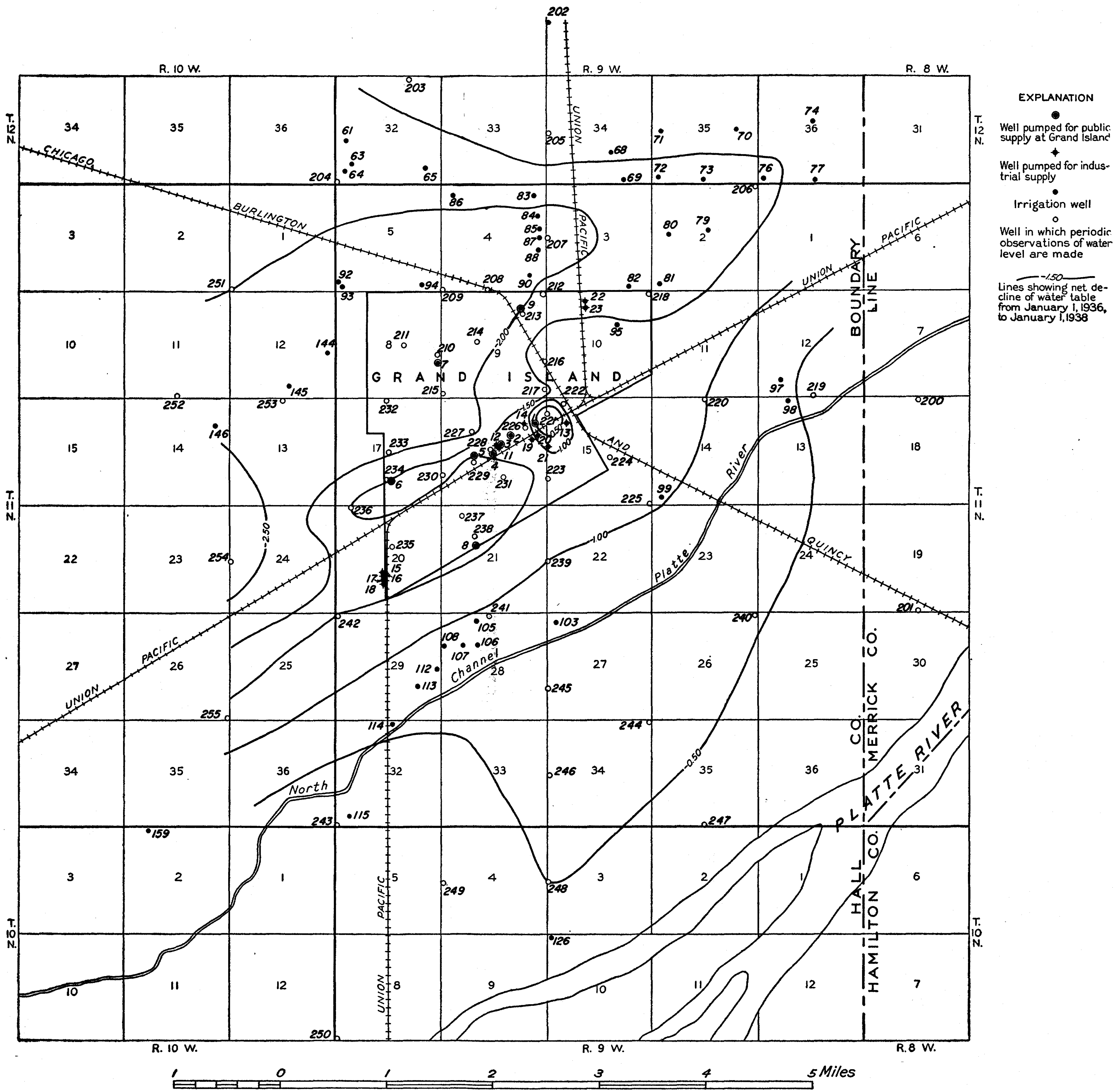
The underflow into Grand Island through the Pleistocene sand and gravel has been computed to be about 5,900 acre-feet a year. The pumpage for public supply was 6,080 acre-feet in 1936 and 5,590 acre-feet in 1937. The total pumpage for industrial supply amounts to 3,470 acre-feet a year, but not all of this water is withdrawn from the main depression of the water table. The wells of the Union Pacific Railroad (22 and 23) are down-gradient from the ground-water divide, and most of the water pumped from them must percolate to the wells from the northwest. Omitting the pumpage from these wells, the annual industrial pumpage in the city is computed to be about 2,270 acre-feet. Inasmuch as the pumpage for irrigation in the area enclosed by the ground-water divide is negligible,



LINES SHOWING ESTIMATED DECLINE OF THE WATER TABLE IN THE VICINITY OF GRAND ISLAND SINCE GROUND-WATER DEVELOPMENT BEGAN



PROFILES OF THE WATER TABLE AT GRAND ISLAND.



LINES SHOWING DECLINE OF THE WATER TABLE IN THE VICINITY OF GRAND ISLAND FROM JANUARY 1, 1936, TO JANUARY 1, 1938.

the total pumpage in this area is estimated to have been 8,350 acre-feet in 1936 and 7,860 acre-feet in 1937—a total of 16,210 acre-feet in the 2-year period. According to the previous estimate, only about 11,800 acre-feet percolated into the city in this 2-year period. Thus, apparently the pumpage in the 2-year period was 4,410 acre-feet in excess of the underflow.

A part of the water withdrawn by wells in Grand Island in 1936 and 1937 was taken from storage, as is indicated by the 2-year net decline of the water levels in the observation wells. Lines indicating equal net declines of the water table between January 1, 1936, and January 1, 1938, based on the measurements made in the observation wells, are shown on plate 21. The lowering within the area enclosed by the ground-water divide east of the west line of sec. 13, T. 11 N., R. 10 W., in the 2-year period unwatered about 12,525 acre-feet of material, which, with a specific yield of 24 percent, represents a decrease in storage of about 3,000 acre-feet of water. This quantity, subtracted from 4,410, leaves the pumpage 1,410 acre-feet in excess of the underflow and unwatering.

Part or all of the 1,410 acre-feet can be attributed to recharge from precipitation, but it is likely that a part of this discrepancy represents differences between assumed and actual conditions. The total pumpage may be somewhat less than computed, the permeability may be higher than 1,000, and the thickness of saturated Pleistocene deposits may be somewhat greater than that assumed.

By using the map showing the decline of the water table since development was begun the total volume of material unwatered is computed to be 35,600 acre-feet. This represents a decrease in storage of about 8,550 acre-feet of water. Within the area enclosed by the ground-water divide, the lowering of the water table has unwatered about 29,800 acre-feet of material and the decrease in ground-water storage has been about 7,140 acre-feet.

As this decrease in storage represents only a small percentage of the water that has been pumped at Grand Island since development was begun, it is obvious that the recharge in the period has been nearly equal to the discharge. However, the present pumpage apparently is greater than can be supplied perennially under existing hydrologic conditions by percolation to the city and precipitation in the city, and the depression in the water table probably will expand to include a larger area of recharge. This, in turn, will deepen the depression and will probably necessitate the relocation of wells. Under existing conditions, the ground-water supply at Grand Island apparently is locally overdeveloped. The regional ground-water supply, however, appears to be sufficient to satisfy considerably more than the present demand. In order to solve the problem of local overdevelopment the wells must be distributed over a much larger area than at present.

RECOMMENDATIONS

The local overdevelopment that appears to exist at Grand Island has resulted from pumping water from a small area at a rate greater than the rate at which it can be replenished. The solution to the problem is to distribute the pumpage over a larger area and thus to increase the area of recharge. Less water should be pumped from city wells 1, 2, 3, 4, and 5, in the middle of Grand Island, and more water should be pumped from wells 6, 7, 8, and 9, in the outlying sections of the city. However, with the exception of well 9, the city wells are situated within the depression outlined by the ground-water divide, and the redistribution of pumpage in the present wells probably will not prove to be a final solution to the problem. Additional wells to supply a part of the pumpage should be constructed north or south of the city, especially south, where the pumpage for irrigation is small and where the water table stands close to the surface. Wells should not be drilled west of the city because such wells would chiefly withdraw water that would otherwise eventually reach one of the other wells. The maps showing contours on the water table indicate that city well 6, situated directly up-gradient from the five centrally located wells, is pumping water that would otherwise be withdrawn farther east. The best location for additional wells is from 1 to 4 miles south of Grand Island. The redistribution of pumpage in Grand Island involves private as well as city pumpage. If private pumpage increases in the city the water that can be pumped for public supply will, of course, decrease about proportionally and municipal wells will have to be located farther from the city.

Water levels in observation wells

[Location and description of wells appear in table on page 252. Water levels are given in depth below measuring point]

Well 200

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Dec. 2	5.95	1936, Mar. 31	5.05	1936, Sept. 19	6.80	1938, Jan. 16	6.20
8	5.95	Apr. 7	5.00	Oct. 17	6.75	Mar. 6	5.60
15	5.90	17	5.35	30	6.60	20	5.65
22	5.90	May 3	5.40	Dec. 18	6.55	27	5.80
28	6.05	12	5.10	1937, Feb. 13	6.45	Apr. 3	5.95
1936, Feb. 1	6.00	July 18	6.45	Mar. 30	6.05	10	5.75
28	5.50	25	6.60	Aug. 27	6.10		
Mar. 8	4.70	Aug. 11	6.55	Nov. 2	6.10		
15	4.80	29	6.80	Dec. 12	6.35		

Water levels in observation wells—Continued

[Location and description of wells appear in table on page 252. Water levels are given in depth below measuring point]

Well 201

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Dec. 2	10.20	1936, Mar. 31	9.00	1936, Sept. 19	11.05	1937, Dec. 12	10.45
8	10.10	Apr. 7	8.95	Oct. 17	11.15	1938, Jan. 16	10.10
15	9.90	17	9.15	30	10.95	Mar. 6	9.45
22	10.00	May 3	9.20	Dec. 18	10.90	20	9.60
28	9.97	12	9.10	1937, Feb. 13	10.70	27	9.70
1936, Feb. 1	9.47	July 18	10.30	Mar. 30	10.20	Apr. 3	9.70
28	9.20	25	10.50	May 2	10.25	10	9.55
Mar. 8	8.90	Aug. 11	10.65	Aug. 27	10.35		
15	9.00	29	10.95	Nov. 2	10.75		

Well 202

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Dec. 15	7.25	1936, Mar. 31	6.60	1936, Sept. 8	8.05	1937, Dec. 12	8.00
21	7.10	Apr. 7	6.55	19	8.00	1938, Jan. 15	8.10
28	7.05	14	6.65	Oct. 17	7.95	Mar. 6	8.00
1936, Feb. 1	7.00	May 2	7.00	1937, Mar. 30	7.65	20	8.10
28	6.80	12	6.60	May 2	7.80	27	8.10
Mar. 7	6.50	Aug. 11	7.85	Aug. 27	8.00	Apr. 3	8.15
15	6.60	29	9.80	Nov. 2	8.05		

Well 203

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Dec. 7	10.80	1936, Apr. 7	10.15	1936, Sept. 19	11.30	1937, Dec. 12	11.85
15	10.65	14	10.20	Oct. 17	11.45	1938, Jan. 15	11.85
21	10.75	May 2	10.23	30	11.55	Mar. 6	11.37
28	10.75	12	10.30	Dec. 18	11.65	20	11.60
1936, Feb. 1	10.55	July 18	10.85	1937, Feb. 13	11.60	27	11.75
28	10.80	25	11.00	Mar. 30	11.00	Apr. 3	11.75
Mar. 7	10.30	Aug. 11	11.00	May 2	11.40	10	11.85
15	10.20	29	11.25	Aug. 27	11.55		
31	10.20	Sept. 8	11.30	Nov. 2	11.80		

Well 204

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Dec. 2	10.25	1936, Mar. 31	10.00	1936, Sept. 8	10.90	1937, Nov. 2	11.65
7	10.20	Apr. 7	10.00	19	10.95	Dec. 12	11.70
15	10.20	14	10.05	Oct. 17	11.80	1938, Jan. 15	11.75
21	10.30	May 2	10.15	30	11.10	Mar. 6	11.75
28	10.17	12	10.10	Dec. 18	11.25	20	11.80
1936, Feb. 1	10.30	July 18	10.50	1937, Feb. 13	11.35	27	11.80
28	10.40	25	10.55	Mar. 30	11.30	Apr. 3	11.90
Mar. 7	10.10	Aug. 11	10.70	May 2	11.35	10	11.90
15	10.05	29	10.80	Aug. 27	11.40		

Well 205

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Dec. 2	8.80	1936, Mar. 15	8.30	1936, Aug. 11	9.10	1937, Feb. 13	9.60
7	8.95	31	8.35	29	9.30	Mar. 30	9.50
15	8.90	Apr. 7	8.35	Sept. 8	9.35	May 2	9.60
21	9.60	14	8.35	19	9.31	Aug. 27	9.70
28	8.80	May 2	8.40	Oct. 17	9.45	Nov. 2	9.90
1936, Feb. 1	8.64	12	8.45	30	9.50		
Mar. 7	8.50	July 25	8.95	Dec. 318	9.55		

Well 206

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Dec. 2	19.20	1936, Mar. 7	19.30	1936, July 18	19.60	1938, Jan. 15	20.80
7	19.15	15	19.40	25	22.45	Mar. 6	20.80
15	19.20	31	18.87	Aug. 11	20.70	20	20.70
21	19.05	Apr. 7	18.90	29	20.24	27	20.85
28	19.15	14	18.75	Sept. 8	20.15	Apr. 3	20.85
1936, Feb. 1	19.28	May 2	18.90	1937, Nov. 2	20.95	10	20.70
28	19.20	12	18.90	Dec. 12	20.70		

Water levels in observation wells—Continued

[Location and description of wells appear in table on page 252. Water levels are given in depth below measuring point]

Well 207

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Nov. 30	13.45	1936, Mar. 13	12.20	1936, May 30	13.65	1936, Sept. 22	14.70
Dec. 7	13.45	27	13.25	June 12	13.55	Oct. 20	14.80
13	13.45	Apr. 10	13.25	July 11	14.10	1938, Jan. 15	15.65
20	13.40	18	13.40	21	14.25	Mar. 20	15.55
27	13.20	24	13.25	Aug. 4	14.50	27	15.60
1936, Jan. 25	13.30	May 12	13.45	25	14.65	Apr. 3	15.69
Feb. 25	13.50	15	13.40	Sept. 1	14.65	10	15.95
Mar. 3	13.40	23	13.50	12	14.70		

Well 208

1935, Nov. 30	13.80	1936, Feb. 25	13.60	1936, Apr. 24	13.60	1938, Jan. 15	17.00
Dec. 7	13.90	Mar. 3	13.60	May 12	13.70	Mar. 20	16.30
13	14.60	13	12.90	15	13.70	27	16.25
20	14.35	27	13.10	23	13.80	Apr. 3	16.30
27	14.25	Apr. 10	13.35	30	13.80	10	16.30
1936, Jan. 25	13.45	18	13.40	June 12	13.81		

Well 209

1935, Nov. 30	13.70	1936, Mar. 27	13.45	1936, July 11	14.70	1937, Nov. 16	15.70
Dec. 7	13.65	Apr. 10	13.55	21	15.00	Dec. 28	15.65
13	15.95	18	13.55	Aug. 4	15.40	1938, Jan. 15	15.70
20	16.00	24	13.65	25	15.25	Mar. 20	15.55
27	15.95	May 12	13.85	Sept. 1	15.25	27	15.65
1936, Jan. 25	14.00	15	13.55	12	15.15	Apr. 3	15.65
Feb. 25	13.70	23	13.90	22	15.25	10	15.65
Mar. 3	13.60	30	13.95	Oct. 20	15.20		
13	13.40	June 12	13.85	1937, Feb. 19	14.95		

Well 210

1935, Nov. 30	18.00	1936, Mar. 27	17.10	1936, June 20	20.85	1936, Oct. 20	19.25
Dec. 7	17.85	Apr. 10	17.15	27	21.45	1937, Feb. 19	18.52
13	17.65	18	17.15	July 11	21.75	Nov. 16	19.55
20	17.20	24	20.30	21	21.85	Dec. 28	19.45
27	17.30	May 12	17.55	Aug. 4	21.90	1938, Jan. 15	19.45
1936, Jan. 25	17.55	15	19.00	25	21.75	Mar. 20	19.25
Feb. 25	17.30	23	18.10	Sept. 1	21.60	27	19.25
Mar. 3	17.40	30	17.95	12	21.10	Apr. 3	19.30
13	17.10	June 12	17.65	22	21.20	10	19.25

Well 211

1935, Nov. 30	15.05	1936, Mar. 27	14.77	1936, July 11	16.10	1937, Nov. 16	16.90
Dec. 7	14.70	Apr. 10	14.80	21	16.30	Dec. 28	16.95
13	14.80	18	14.80	Aug. 4	16.50	1938, Jan. 15	17.00
20	14.95	24	15.05	25	16.15	Mar. 20	16.90
27	14.82	May 12	15.00	Sept. 1	16.60	27	17.00
1936, Jan. 25	14.40	15	15.05	12	16.50	Apr. 3	17.00
Feb. 25	14.90	23	15.20	22	16.65	10	17.00
Mar. 3	15.00	30	15.20	Oct. 20	16.60		
13	14.80	June 12	15.15	1937, Feb. 19	16.25		

Well 212

1935, Dec. 7	20.20	1936, Apr. 10	20.76	1936, July 11	22.20	1937, Feb. 19	22.10
13	20.85	18	20.60	21	22.60	Nov. 16	22.80
20	20.95	24	20.60	Aug. 4	22.90	Dec. 28	22.70
27	20.85	May 12	20.73	25	22.85	1938, Jan. 15	22.60
1936, Feb. 25	20.60	15	20.60	Sept. 1	22.75	Mar. 20	22.45
Mar. 3	20.60	23	20.95	12	22.65	27	22.40
13	20.40	30	21.14	22	22.55	Apr. 3	22.45
27	20.40	June 12	20.85	Oct. 20	22.40	10	22.45

Water levels in observation wells—Continued

[Location and description of wells appear in table on page 252. Water levels are given in depth below measuring point]

Well 213

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Nov. 30	20.00	1936, Jan. 25	21.35	1936, Apr. 10	23.65	1936, May 23	21.85
Dec. 7	21.30	Feb. 25	21.10	18	21.25	30	22.40
13	21.05	Mar. 3	21.00	24	21.15	June 12	21.40
20	21.10	13	21.10	May 12	21.30		
27	21.20	27	20.95	15	21.15		

Well 214

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Nov. 30	17.35	1936, Mar. 13	15.90	1936, May 30	15.95	1936, Sept. 22	17.65
Dec. 7	16.85	27	15.85	June 12	15.70	Oct. 20	18.75
13	17.10	Apr. 10	15.90	July 11	16.40	1937, Nov. 16	19.25
20	16.75	18	16.10	21	16.65	Dec. 28	19.30
27	17.10	24	16.35	Aug. 4	17.20	1938, Apr. 3	18.20
1936, Jan. 25	18.10	May 12	16.70	25	16.45	10	20.70
Feb. 25	18.20	15	16.05	Sept. 1	16.50		
Mar. 3	17.90	23	16.00	12	16.95		

Well 215

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Nov. 30	22.00	1936, Feb. 29	21.80	1936, Apr. 24	22.25	1936, July 11	23.65
Dec. 7	21.90	Mar. 3	21.70	May 12	22.05	1938, Jan. 15	24.20
13	21.85	13	21.70	15	22.10	Mar. 20	23.75
20	22.05	27	21.60	23	22.40	27	23.80
27	21.90	Apr. 10	21.67	30	22.30	Apr. 3	23.90
1936, Feb. 5	-------	18	21.75	June 12	22.25	10	23.75

Well 216

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Nov. 30	28.70	1936, Mar. 27	27.85	1936, July 11	29.65	1937, Nov. 16	30.85
Dec. 7	28.65	Apr. 10	28.05	21	29.90	Dec. 28	30.40
13	28.95	18	28.10	Aug. 4	30.30	1938, Jan. 15	30.10
20	28.15	24	28.12	25	30.60	Mar. 20	29.40
27	28.92	May 12	28.20	Sept. 1	30.65	27	29.65
1936, Jan. 25	28.28	15	28.10	12	30.70	Apr. 3	29.70
Feb. 25	28.00	23	28.40	22	30.75	10	29.80
Mar. 3	28.20	30	28.55	Oct. 20	30.70		
13	27.90	June 12	28.55	1937, Feb. 19	29.40		

Well 217

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Dec. 2	30.00	1936, Apr. 7	28.85	1936, Oct. 17	32.38	1938, Jan. 15	30.55
7	29.85	14	28.95	30	32.05	Mar. 6	29.95
15	29.40	May 2	28.95	Dec. 18	30.90	20	29.70
20	29.55	12	29.00	1937, Feb. 13	30.00	27	30.30
27	29.35	July 18	31.25	Mar. 30	29.20	Apr. 3	30.60
1936, Feb. 28	28.50	25	31.45	May 2	30.10	10	30.65
Mar. 7	28.60	Aug. 11	31.80	Aug. 27	32.55		
15	28.70	Sept. 8	32.20	Nov. 2	32.10		
31	28.65	19	32.30	Dec. 12	31.35		

Well 218

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Dec. 2	22.65	1936, Mar. 31	22.15	1936, Sept. 8	23.65	1937, Nov. 2	24.25
7	22.50	Apr. 7	22.05	19	23.60	Dec. 12	24.00
15	22.20	14	22.30	Oct. 17	23.60	1938, Jan. 15	23.95
21	22.40	May 2	22.15	30	23.65	Mar. 6	23.80
28	22.15	12	22.30	Dec. 18	23.70	20	23.80
1936, Feb. 1	21.95	July 18	23.10	1937, Feb. 13	23.80	27	23.95
28	22.30	25	24.50	Mar. 30	23.65	Apr. 3	24.00
Mar. 7	22.30	Aug. 11	23.50	May 2	23.90	10	23.85
15	22.20	29	23.90	Aug. 27	26.80		

Water levels in observation wells—Continued

[Location and description of wells appear in table on page 252. Water levels are given in depth below measuring point]

Well 219

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Dec. 2	7.55	1936, Mar. 31	6.75	1936, Sept. 19	8.25	1937, Dec. 12	7.95
8	7.55	Apr. 7	6.85	Oct. 17	8.10	1938, Jan. 16	8.00
15	7.50	17	7.00	30	8.00	Mar. 6	7.75
22	7.50	May 3	7.05	Dec. 18	8.00	20	7.60
28	7.57	12	6.80	1937, Feb. 13	8.90	27	7.55
1936, Feb. 1	7.40	July 18	7.85	Mar. 30	7.20	Apr. 3	7.65
28	7.10	25	8.05	May 2	7.60	10	7.65
Mar. 8	6.40	Aug. 11	7.90	Aug. 27	7.70		
15	6.70	29	8.10	Nov. 2	7.80		

Well 220

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Dec. 2	7.20	1936, Mar. 31	6.35	1936, Sept. 19	7.95	1937, Dec. 12	7.80
8	7.15	Apr. 3	6.35	Oct. 17	7.90	1938, Jan. 16	7.90
15	6.95	17	6.40	30	7.75	Mar. 6	7.45
22	6.95	May 3	6.40	Dec. 18	7.60	20	7.60
28	6.90	12	6.30	1937, Feb. 13	7.45	27	7.60
1936, Feb. 1	6.85	July 18	7.65	Mar. 30	7.25	Apr. 3	7.45
28	6.70	25	7.70	May 2	7.27	10	7.60
Mar. 8	6.50	Aug. 11	7.50	Aug. 27	7.50		
15	6.50	29	7.75	Nov. 2	7.80		

Well 221

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Dec. 2	31.20	1936, Apr. 7	30.60	1936, Sept. 19	34.95	1937, Dec. 12	32.55
7	31.30	14	30.85	Oct. 17	34.40	1938, Jan. 15	31.55
15	31.20	May 2	30.75	30	34.10	Mar. 6	30.55
20	30.70	May 12	30.95	Dec. 18	32.55	20	30.60
27	30.80	July 18	33.80	1937, Feb. 13	30.90	27	32.00
1936, Feb. 29	29.00	25	34.15	Mar. 30	29.85	Apr. 3	32.40
Mar. 7	29.90	Aug. 11	34.35	May 2	31.70	10	32.30
15	29.60	29	34.95	Aug. 27	34.80		
31	30.05	Sept. 8	34.70	Nov. 2	33.65		

Well 222

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Dec. 2	27.70	1936, Apr. 7	26.65	1936, Sept. 19	28.95	1937, Dec. 12	28.85
7	27.80	14	26.75	Oct. 17	28.95	1938, Jan. 15	28.50
15	27.85	May 2	26.75	30	29.00	Mar. 6	27.95
21	27.35	May 12	26.70	Dec. 18	28.25	20	27.90
28	27.30	July 18	28.15	1937, Feb. 13	28.00	27	28.10
1936, Feb. 28	26.40	25	28.35	Mar. 30	27.35	Apr. 3	28.20
Mar. 7	26.70	Aug. 11	28.60	May 2	27.90	10	28.20
15	26.70	29	28.85	Aug. 27	29.10		
31	26.65	Sept. 8	28.90	Nov. 2	29.00		

Well 223

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Nov. 30	14.45	1936, Apr. 10	13.40	1936, July 11	14.55	1937, Nov. 16	15.65
Dec. 7	14.30	18	13.30	21	14.90	Dec. 28	15.35
13	14.35	24	13.35	Aug. 4	15.25	1938, Jan. 15	15.20
20	14.30	May 3	13.40	25	15.55	20	14.55
27	13.97	12	13.45	Sept. 1	15.60	Mar. 27	14.65
1936, Feb. 29	13.60	15	13.45	12	15.65	Apr. 3	14.75
Mar. 3	13.40	23	13.50	22	15.90	10	14.85
13	13.40	30	13.60	Oct. 20	15.90		
27	13.20	June 12	13.75	1937, Feb. 19	14.25		

Water levels in observation wells—Continued

[Location and description of wells appear in table on pages 252–253. Water levels are given in depth below measuring point]

Well 224

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Nov. 30	9.55	1936, Mar. 27	8.90	1936, June 12	8.90	1937, Feb. 19	9.95
Dec. 7	9.50	Apr. 10	8.80	July 11	9.60	Nov. 16	10.65
13	9.30	18	8.70	21	9.75	Dec. 28	10.65
20	9.20	24	8.80	Aug. 4	9.90	1938, Jan. 15	10.60
27	9.25	May 3	8.70	25	10.05	Mar. 20	10.20
1936, Feb. 5	9.31	9	8.80	Sept. 1	10.15	27	10.30
29	9.00	15	8.78	12	10.25	Apr. 3	10.35
Mar. 3	8.80	23	8.70	22	10.45	10	10.25
13	8.80	30	8.80	Oct. 20	10.50		

Well 225

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Dec. 2	8.45	1936, Mar. 31	7.80	1936, Sept. 19	9.15	1937, Dec. 12	9.35
8	8.15	Apr. 7	7.85	Oct. 17	9.25	1938, Jan. 15	9.60
15	7.45	17	7.95	30	9.25	Mar. 20	9.40
22	8.50	May 3	8.00	Dec. 18	9.45	27	9.50
28	8.50	12	7.80	1937, Feb. 13	9.35	Apr. 3	9.50
1936, Feb. 1	8.36	July 18	8.60	Mar. 30	9.20	10	9.35
28	8.10	25	8.80	May 2	9.20		
Mar. 8	7.80	Aug. 11	8.65	Aug. 27	8.80		
15	7.80	29	8.95	Nov. 2	8.95		

Well 226

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Nov. 30	34.40	1936, Apr. 10	35.70	1936, July 21	40.10	1937, Nov. 16	39.85
Dec. 7	35.60	18	34.35	Aug. 4	40.50	Dec. 28	36.30
13	35.25	24	34.90	25	41.25	1938, Jan. 15	35.40
20	34.95	May 9	34.80	Sept. 1	41.40	Mar. 20	34.70
27	34.90	15	34.75	12	41.25	27	36.35
1936, Feb. 29	32.00	23	35.73	22	41.15	Apr. 3	37.00
Mar. 3	33.50	30	35.95	Oct. 20	41.00	10	37.15
13	33.90	June 12	36.00	1937, Feb. 19	34.20		
27	34.20	July 11	39.55	Aug. 27	41.40		

Well 227

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Nov. 30	30.20	1936, Mar. 27	30.55	1936, July 21	33.65	1937, Dec. 28	34.25
Dec. 7	32.60	Apr. 10	30.85	Aug. 4	34.10	1938, Jan. 15	34.30
13	32.30	18	31.10	25	34.40	Mar. 20	33.30
20	32.35	24	31.30	Sept. 1	34.40	27	33.35
27	32.27	May 12	31.70	12	34.35	Apr. 3	33.60
1936, Feb. 5	31.83	15	31.70	22	34.35	10	33.45
29	31.50	23	31.90	Oct. 20	33.85		
Mar. 3	31.80	30	32.00	1937, Feb. 19	30.45		
13	31.20	July 11	33.15	Nov. 16	34.50		

Well 228

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1936, Mar. 13	36.65	1936, May 30	40.25	1936, Sept. 12	43.05	1938, Mar. 20	41.20
Apr. 10	37.20	June 12	40.05	22	43.00	27	41.50
18	38.85	July 11	42.79	Oct. 20	41.55	Apr. 3	41.70
24	39.30	21	43.20	1937, Feb. 19	37.30	10	41.55
May 12	39.95	Aug. 4	43.40	Nov. 16	42.80		
15	40.00	25	43.05	Dec. 28	42.30		
23	40.15	Sept. 1	43.00	1938, Jan. 15	42.10		

Water levels in observation wells—Continued

[Location and description of wells appear in table on page 253. Water levels are given in depth below measuring point]

Well 229

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Nov. 30	39.75	1936, Mar. 27	37.90	1936, July 11	39.90	1937, Nov. 16	39.40
Dec. 7	39.30	Apr. 10	38.00	21	40.40	Dec. 28	41.10
13	39.50	18	38.25	Aug. 4	40.10	1938, Jan. 15	40.90
20	39.35	24	38.40	25	40.05	Mar. 20	40.30
27	39.32	May 12	38.90	Sept. 1	39.90	27	40.40
1936, Feb. 5	39.65	15	38.90	12	39.30	Apr. 3	40.55
29	38.60	23	38.95	22	39.35	10	40.30
Mar. 3	39.90	30	39.10	Oct. 20	36.35		
13	38.10	June 12	39.15	1937, Feb. 19	33.40		

Well 230

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Nov. 30	33.70	1936, Mar. 27	31.30	1936, July 11	32.50	1937, Nov. 16	33.75
Dec. 7	32.00	Apr. 10	31.53	21	32.75	Dec. 28	34.00
13	31.90	18	31.50	Aug. 4	33.00	1938, Jan. 15	33.85
20	32.25	24	31.65	25	33.10	Mar. 20	33.25
27	32.67	May 12	31.90	Sept. 1	33.10	27	33.20
1936, Feb. 5	32.14	15	31.80	12	33.05	Apr. 3	33.35
29	31.20	23	31.85	22	33.10	10	33.25
Mar. 3	31.50	30	31.85	Oct. 20	32.65		
13	31.40	June 12	31.95	1937, Feb. 19	31.10		

Well 231

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Nov. 30	33.90	1936, Mar. 27	31.75	1936, July 11	34.50	1937, Nov. 16	35.35
Dec. 7	33.85	Apr. 10	31.95	21	34.90	Dec. 28	35.20
13	33.70	18	32.40	Aug. 4	35.25	1938, Jan. 15	34.85
20	33.05	24	32.50	25	35.35	Mar. 20	34.25
27	33.05	May 12	32.85	Sept. 1	35.25	27	34.45
1936, Feb. 5	--------	15	32.85	12	35.25	Apr. 3	34.50
29	32.30	23	33.05	22	35.35	10	34.55
Mar. 3	32.80	30	33.10	Oct. 20	34.85		
13	32.40	June 12	33.25	1937, Feb. 19	31.90		

Well 232

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Nov. 30	16.95	1936, Mar. 27	17.00	1936, July 11	18.85	1937, Nov. 16	19.25
Dec. 7	17.00	Apr. 10	17.10	21	18.65	Dec. 28	19.35
13	16.90	18	17.15	Aug. 4	18.60	1938, Jan. 15	19.45
20	17.10	24	17.30	25	19.35	Mar. 20	19.25
27	17.12	May 12	17.35	Sept. 1	18.70	27	19.25
1936, Jan. 25	17.40	15	17.30	12	18.50	Apr. 3	19.35
Feb. 25	16.90	23	17.45	22	18.70	10	19.25
Mar. 3	17.50	30	17.55	Oct. 20	18.65		
13	17.00	June 12	17.45	1937, Feb. 19	18.60		

Well 233

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Nov. 30	21.70	1936, Apr. 10	22.25	1936, July 11	23.00	1937, Feb. 19	23.60
Dec. 7	21.55	18	22.25	21	23.20	Nov. 16	24.45
13	22.05	24	22.24	Aug. 4	23.35	Dec. 28	24.25
20	22.05	May 12	22.30	25	23.50	1938, Jan. 15	24.20
27	22.15	15	22.45	Sept. 1	23.50	Mar. 20	23.80
1936, Feb. 25	21.00	23	22.50	12	23.50	27	23.80
Mar. 3	21.10	30	22.40	22	23.60	Apr. 3	23.75
13	21.80	June 12	22.55	Oct. 20	23.85	10	23.55
27	22.10						

Water levels in observation wells—Continued

[Location and description of wells appear in table on page 253. Water levels are given in depth below measuring point]

Well 234

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Nov. 30	31.00	1936, Mar. 3	24.20	1936, Apr. 24	31.15	1938, Jan. 15	31.20
Dec. 7	29.90	13	30.70	May 15	31.20	Mar. 20	28.09
13	31.40	27	31.15	23	31.20	27	32.00
20	31.40	Apr. 10	31.20	30	31.20	Apr. 3	30 80
1936, Jan. 25	31.38	17	31.15	July 21	31.20	10	27.00
Feb. 25	24.50						

Well 235

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Nov. 30	14.55	1936, Feb. 25	16.10	1936, Apr. 24	17.30	1936, July 11	18.10
Dec. 7	14.50	Mar. 3	16.00	May 12	17.45	21	18.25
13	14.70	13	16.50	15	17.50	Aug. 4	18.45
20	14.65	27	16.70	23	17.55	25	18.70
27	14.97	Apr. 10	17.13	30	17.65		
1936, Jan. 25	15.03	18	17.20	June 12	17.65		

Well 236

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Nov. 30	22.70	1936, Mar. 27	22.20	1936, July 11	22.55	1937, Dec. 28	25.30
Dec. 7	22.50	Apr. 10	22.30	21	22.60	1938, Jan. 15	24.85
13	23.00	17	22.25	Aug. 4	22.75	Mar. 20	24.00
20	22.60	24	22.24	25	22.85	27	24.00
27	23.35	May 12	22.25	Sept. 1	22.90	Apr. 3	24.10
1936, Jan. 25	23.70	15	22.15	22	23.05	10	23.95
Feb. 25	22.20	23	22.20	Oct. 20	23.65		
Mar. 3	22.10	30	22.25	1937, Feb. 19	23.85		
13	22.10	June 12	22.25	Nov. 16	25.25		

Well 237

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Nov. 30	29.55	1936, Mar. 27	29.05	1936, July 21	30.85	1937, Dec. 28	31.50
Dec. 7	29.50	Apr. 10	29.02	Aug. 4	31.00	1938, Jan. 15	31.50
13	29.40	18	29.30	25	31.05	Mar. 20	30.90
20	29.15	May 12	29.35	Sept. 1	31.10	27	30.75
27	29.62	15	29.25	12	30.90	Apr. 3	31.05
1936, Feb. 5	29.44	23	29.40	22	31.15	10	30.80
25	29.20	30	29.65	Oct. 20	30.70		
Mar. 3	29.20	June 12	29.70	1937, Feb. 19	29.45		
13	29.20	July 11	30.60	Nov. 16	31.25		

Well 238

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Nov. 30	29.10	1936, Mar. 27	28.80	1936, July 11	32.40	1937, Nov. 16	31.00
Dec. 7	29.20	Apr. 10	28.85	21	32.35	Dec. 28	31.15
13	29.05	18	29.65	Aug. 4	32.30	1938, Jan. 15	30.95
20	29.15	24	31.20	25	32.25	Mar. 20	30.55
27	29.30	May 12	29.30	Sept. 1	32.10	27	30.50
1936, Feb. 5	29.52	15	28.95	12	32.15	Apr. 3	31.00
25	29.20	23	29.35	22	32.15	10	30.70
Mar. 3	29.10	30	31.05	Oct. 20	30.85		
13	28.90	June 12	30.65	1937, Feb. 19	29.80		

Well 239

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Dec. 2	8.05	1936, Mar. 31	7.50	1936, Oct. 17	8.95	1938, Jan. 15	9.25
8	8.05	Apr. 17	7.50	30	9.00	Mar. 6	9.25
15	8.05	May 3	7.50	Dec. 18	9.15	20	9.25
22	8.15	12	7.45	1937, Feb. 13	9.20	27	9.25
28	8.13	July 18	8.10	Mar. 30	8.95	Apr. 3	9.15
1936, Feb. 1	8.00	25	8.30	May 2	8.90	10	9.20
28	7.90	Aug. 11	8.35	Aug. 27	8.65		
Mar. 7	7.60	29	8.65	Nov. 2	9.00		
15	7.80	Sept. 19	8.75	Dec. 12	9.00		

Water levels in observation wells—Continued

[Location and description of wells appear in table on page 253. Water levels are given in depth below measuring point]

Well 240

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Dec. 2	5.95	1936, Mar. 31	4.90	1936, Sept. 19	6.50	1937, Dec. 12	6.40
8	5.95	Apr. 7	4.95	Oct. 17	6.55	1938, Jan. 16	6.40
15	5.85	17	5.05	30	6.60	Mar. 6	6.15
22	5.80	May 3	5.05	Dec. 18	6.70	20	6.15
28	5.88	12	4.95	1937, Feb. 13	6.70	27	6.20
1936, Feb. 1	5.76	July 18	5.85	Mar. 30	6.50	Apr. 3	6.20
28	5.30	25	5.95	May 2	6.40	10	6.15
Mar. 8	5.20	Aug. 11	6.15	Aug. 27	5.90		
15	5.10	29	6.35	Nov. 2	6.25		

Well 241

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Dec. 2	7.30	1936, Mar. 31	6.65	1936, Sept. 19	8.05	1937, Nov. 2	8.10
8	7.30	Apr. 14	6.70	Oct. 17	8.05	Dec. 12	8.35
15	7.30	May 2	6.65	30	8.20	1938, Jan. 15	8.55
28	7.47	12	6.70	Dec. 18	8.50	Mar. 6	8.18
1936, Feb. 1	7.25	July 18	7.40	1937, Feb. 13	8.40	20	8.30
28	6.70	25	7.60	Mar. 30	8.10	27	8.40
Mar. 7	6.90	Aug. 11	7.70	May 2	8.00	Apr. 3	8.35
15	6.80	29	8.00	Aug. 27	7.90	10	8.20

Well 242

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Dec. 2	20.10	1936, Mar. 15	20.50	1936, Aug. 29	21.50	1937, Aug. 27	22.00
8	20.95	31	20.45	Sept. 19	21.40	Nov. 2	22.95
15	21.20	Apr. 14	20.55	Oct. 17	21.85	Dec. 12	23.55
22	21.60	May 2	20.65	30	21.85	1938, Jan. 15	23.35
28	21.95	12	20.60	Dec. 18	23.05	Mar. 6	22.83
1936, Feb. 1	21.15	July 18	21.05	1937, Feb. 13	22.80	20	22.09
28	21.00	25	21.00	Mar. 30	22.60	27	22.90
Mar. 7	20.70	Aug. 11	21.25	May 2	22.45	Apr. 3	22.95
						10	22.08

Well 243

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Dec. 2	4.95	1936, Mar. 31	3.00	1936, Sept. 8	6.35	1937, Nov. 2	4.70
8	3.95	Apr. 7	3.05	19	6.40	Dec. 12	4.90
15	4.70	14	3.10	Oct. 17	6.55	1938, Jan. 16	4.90
21	5.00	May 2	3.30	30	6.30	Mar. 6	4.30
28	4.90	12	3.00	Dec. 18	5.55	20	4.15
1936, Feb. 1	4.60	July 18	5.35	1937, Feb. 13	6.35	27	4.25
28	4.20	25	5.55	Mar. 30	4.45	Apr. 3	4.30
Mar. 7	2.50	Aug. 11	5.80	May 2	4.25	10	4.20
15	2.80	29	6.20	Aug. 27	4.80		

Well 244

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Dec. 2	5.60	1936, Mar. 31	4.70	1936, Sept. 19	6.15	1937, Nov. 2	6.10
8	5.55	Apr. 7	4.65	Oct. 17	6.35	Dec. 12	6.20
15	5.30	17	4.85	30	6.40	1938, Jan. 16	6.25
22	5.50	May 3	4.85	Dec. 18	6.65	Mar. 6	6.10
28	5.47	12	4.70	1937, Feb. 13	6.75	20	6.00
1936, Feb. 1	5.16	July 18	5.55	Mar. 30	6.55	27	6.00
28	5.30	25	5.70	May 2	6.40	Apr. 3	5.95
Mar. 8	4.90	Aug. 11	5.80	Aug. 27	5.60	10	5.90
15	4.80	29	6.05				

Water levels in observation wells—Continued

[Location and description of wells appear in table on page 253. Water levels are given in depth below measuring point]

Well 246

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Dec. 2	5.70	1936, Mar. 31	4.60	1936, Sept. 8	6.15	1937, Nov. 2	6.10
8	5.75	Apr. 7	4.65	19	6.15	Dec. 12	6.20
15	5.60	14	4.75	Oct. 17	6.30	1938, Jan. 16	6.20
22	5.75	May 2	4.85	30	6.40	Mar. 6	5.95
28	5.57	12	4.70	Dec. 18	6.60	20	6.00
1936, Feb. 1	5.30	July 18	5.55	1937, Feb. 13	6.70	27	5.55
28	5.20	25	5.60	Mar. 30	6.45	Apr. 3	6.00
Mar. 7	5.00	Aug. 11	5.85	May 2	6.35	10	5.90
15	4.70	29	6.00	Aug. 27	5.70		

Well 247

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Dec. 2	4.90	1936, Apr. 7	3.70	1936, Oct. 17	5.95	1937, Dec. 12	5.20
8	4.80	17	4.10	30	6.00	1938, Jan. 16	4.85
15	4.65	May 3	4.15	Dec. 18	6.00	Mar. 6	4.20
22	4.75	12	3.65	1937, Feb. 13	5.85	20	4.25
28	4.73	July 18	5.45	Mar. 30	5.10	27	4.30
1936, Feb. 1	4.30	25	5.55	May 2	4.65	Apr. 3	4.40
Mar. 8	3.40	Aug. 11	5.65	Aug. 27	5.50	10	4.20
15	3.70	29	5.87	Nov. 2	5.75		
31	3.80	Sept. 19	6.00				

Well 248

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Dec. 2	5.90	1936, Mar. 31	4.70	1936, Sept. 8	6.35	1937, Nov. 2	6.40
8	5.85	Apr. 7	4.70	19	6.35	Dec. 12	6.20
15	5.50	14	4.85	Oct. 17	6.55	1938, Jan. 16	5.90
21	5.60	May 2	4.90	30	6.60	Mar. 6	5.45
28	5.55	12	4.65	Dec. 18	6.70	20	5.50
1936, Feb. 1	5.30	July 18	5.75	1937, Feb. 13	6.60	27	5.50
28	5.00	25	5.90	Mar. 30	6.20	Apr. 3	5.50
Mar. 7	4.80	Aug. 11	6.10	May 2	5.90	10	5.40
15	4.80	29	6.25	Aug. 27	6.00		

Well 249

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Dec. 2	5.85	1936, Mar. 31	4.70	1936, Sept. 8	6.55	1937, Nov. 2	6.15
8	5.70	Apr. 7	4.65	19	6.50	Dec. 12	5.95
15	5.60	14	4.78	Oct. 17	6.65	1938, Jan. 16	5.85
21	5.60	May 2	4.80	30	6.60	Mar. 6	5.45
28	5.70	12	4.65	Dec. 18	6.60	20	5.45
1936, Feb. 1	5.30	July 18	6.00	1937, Feb. 13	6.55	27	5.50
28	5.20	25	6.15	Mar. 30	6.20	Apr. 3	5.45
Mar. 7	4.80	Aug. 11	6.20	May 2	5.95	10	5.50
15	4.70	29	6.40	Aug. 27	6.00		

Well 250

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Dec. 2	5.65	1936, Mar. 7	4.10	1936, May 12	3.85	1938, Jan. 16	5.30
8	5.60	15	4.10	July 18	5.70	Mar. 6	4.70
15	5.35	31	4.30	25	5.80	20	4.75
21	5.35	Apr. 7	4.20	1937, May 2	5.24	27	4.85
28	5.15	14	4.45	Nov. 2	6.30	Apr. 3	4.95
1936, Feb. 1	4.80	May 2	4.60	Dec. 12	5.60	10	4.75
28	4.50						

Water levels in observation wells—Continued

[Location and description of wells appear in table on page 253. Water levels are given in depth below measuring point]

Well 251

Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)	Date	Water level (feet)
1935, Dec. 2	8.50	1936, Mar. 31	8.65	1936, Sept. 8	9.50	1937, Nov. 2	10.50
7	8.50	Apr. 7	8.75	19	9.50	Dec. 12	10.60
15	8.65	14	8.80	Oct. 17	9.65	1938, Jan. 15	10.70
21	8.65	May 2	8.80	30	9.75	Mar. 6	10.74
28	8.65	12	8.90	Dec. 18	9.95	20	10.70
1936, Feb. 1	8.75	July 18	9.15	1937, Mar. 30	10.10	27	10.80
28	8.90	25	9.30	May 2	10.20	Apr. 3	10.80
Mar. 7	8.60	Aug. 11	9.35	Aug. 27	10.25	10	10.85
15	8.70	29	9.45				

Well 252

1935, Dec. 2	8.60	1936, Mar. 15	8.80	1936, Aug. 11	9.30	1937, Feb. 13	10.12
7	8.50	31	8.75	29	9.40	Mar. 30	10.20
15	7.80	Apr. 7	8.85	Sept. 8	9.50	May 2	10.30
21	8.55	14	8.95	19	9.40	Aug. 27	10.30
28	8.55	May 2	9.00	Oct. 17	9.60	Nov. 2	10.40
1936, Feb. 1	8.70	12	9.00	30	9.65	1938, Apr. 3	10.10
28	8.60	July 18	9.10	Dec. 18	9.95	10	11.00
Mar. 7	8.70	25	9.20				

Well 253

1935, Dec. 2	11.65	1936, Apr. 7	11.90	1936, Sept. 19	12.80	1937, Nov. 2	13.70
7	11.70	14	12.00	Oct. 17	12.90	Dec. 12	13.85
15	11.70	May 2	12.05	30	12.95	1938, Jan. 15	13.95
21	11.80	12	12.05	Dec. 18	13.10	Mar. 6	14.00
28	11.70	July 18	12.30	1937, Feb. 13	13.05	20	14.00
1936, Feb. 28	11.90	25	12.45	Mar. 30	13.20	27	14.10
Mar. 7	11.80	Aug. 11	12.60	May 2	13.30	Apr. 3	14.10
15	11.80	29	12.78	Aug. 27	13.50	10	14.05
31	11.85	Sept. 8	12.80				

Well 254

1935, Dec. 2	15.30	1936, Mar. 7	14.70	1936, July 18	16.10	1938, Jan. 15	18.40
7	15.20	15	15.00	25	16.20	Mar. 6	18.30
15	15.30	31	15.25	Aug. 11	16.25	20	18.40
21	15.40	Apr. 7	15.35	29	16.30	27	18.45
28	15.45	14	15.60	1937, Nov. 2	18.00	Apr. 3	18.45
1936, Feb. 1	15.70	May 2	15.80	Dec. 12	18.30	10	18.45
28	16.00	12	15.80				

Well 255

1935, Dec. 2	9.20	1936, Mar. 31	8.85	1936, Sept. 8	10.75	1937, Nov. 2	10.55
8	9.40	Apr. 7	8.85	19	10.79	Dec. 12	10.55
15	9.20	14	8.90	Oct. 17	10.75	1938, Jan. 15	10.60
21	14.70	May 2	9.05	30	10.70	Mar. 6	10.50
28	18.20	12	8.90	Dec. 18	10.70	20	10.50
1936, Feb. 1	9.30	July 18	10.15	1937, Feb. 13	10.65	27	10.50
28	9.30	25	10.25	Mar. 30	10.50	Apr. 3	10.50
Mar. 7	8.80	Aug. 11	10.45	May 2	10.45	10	10.30
15	8.90	29	10.60	Aug. 27	10.65		

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