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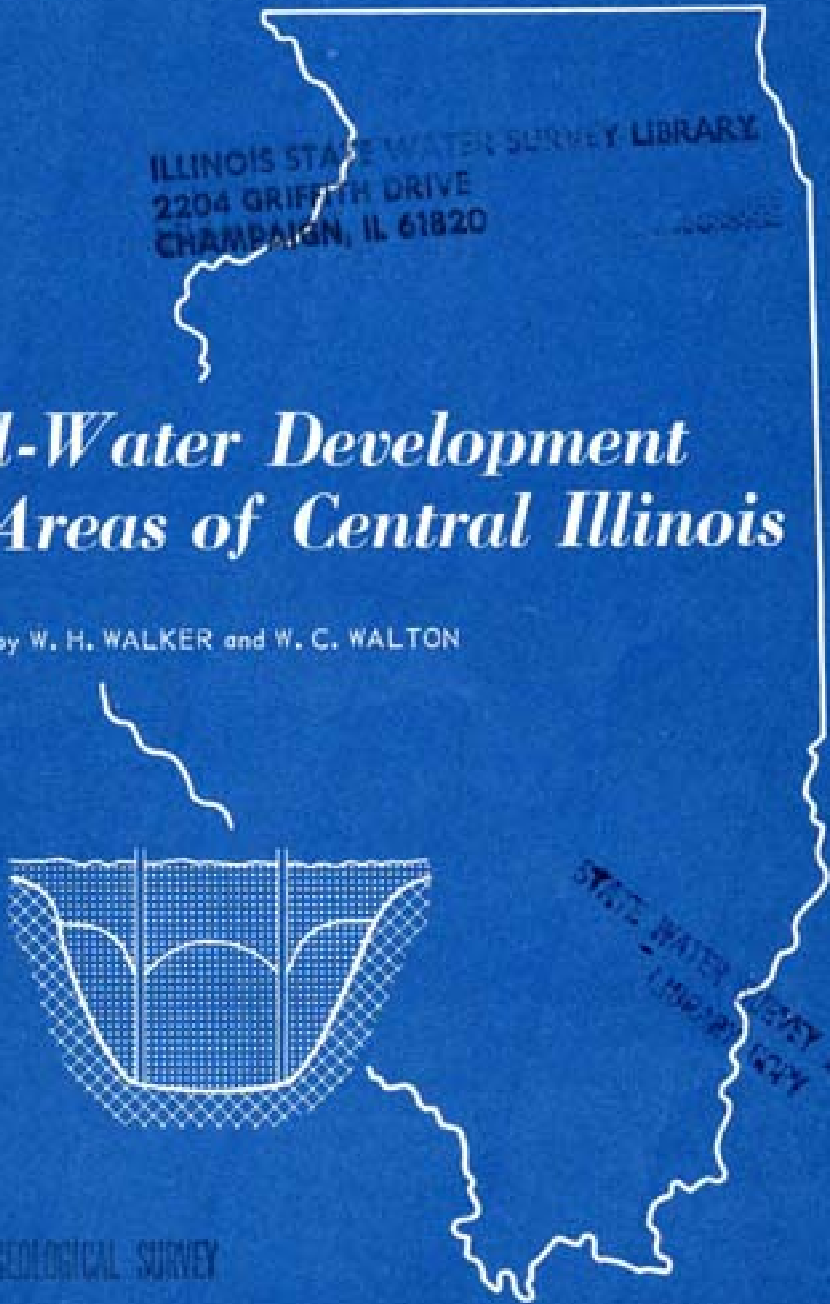
WILLIAM SYLVESTER WHITE, Director



Ground-Water Development in Three Areas of Central Illinois

by W. H. WALKER and W. C. WALTON

ILLINOIS STATE WATER SURVEY
WILLIAM C. ACKERMANN, Chief

URBANA
1961

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SEAL OF THE STATE OF ILLINOIS
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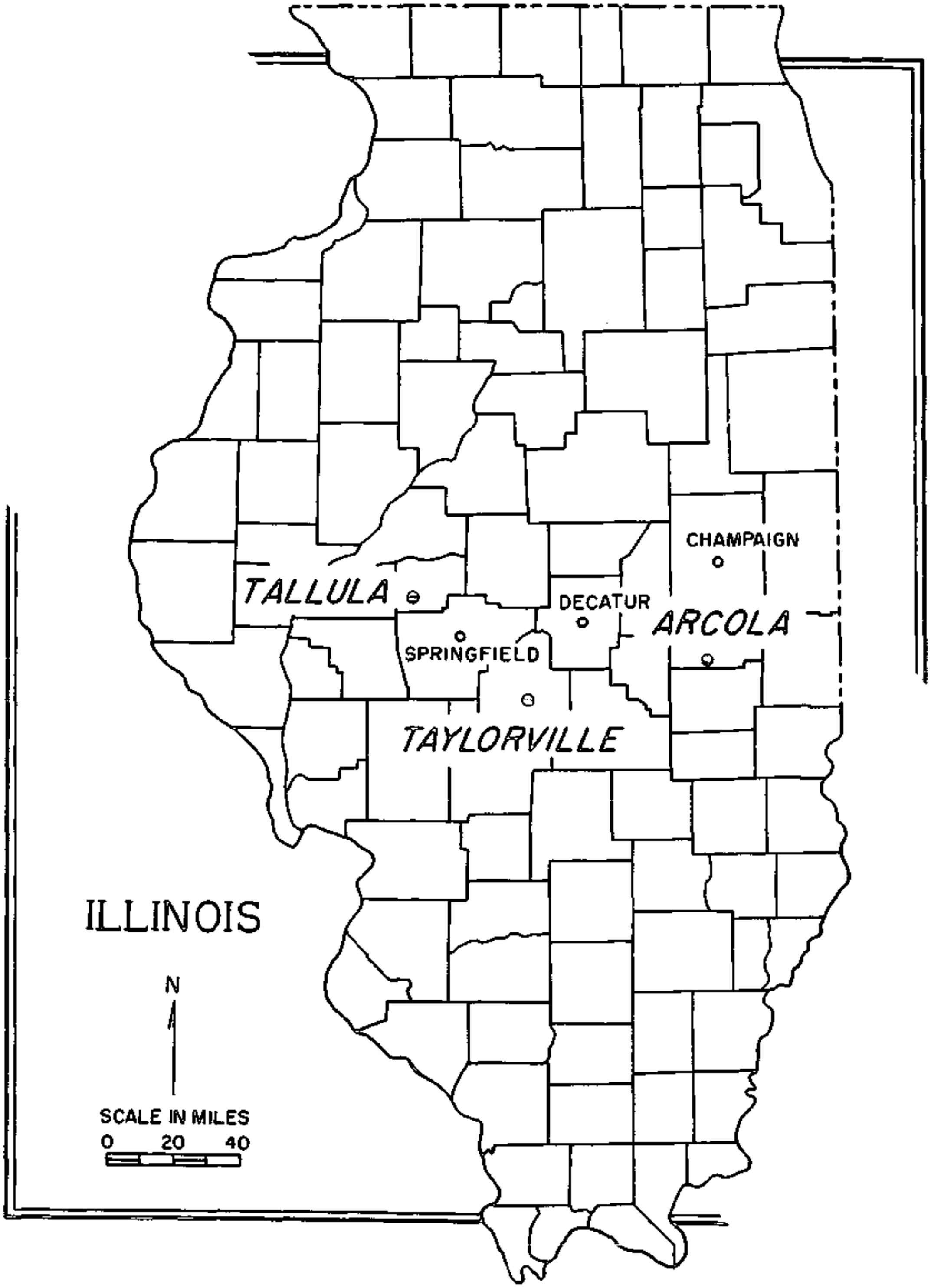


Figure 1. Mop showing location of Taylorville. Arcola, and Tallula

GROUND-WATER DEVELOPMENT IN THREE AREAS OF CENTRAL ILLINOIS

by W. H. Walker and W. C. Walton

ABSTRACT

In many parts of central Illinois, ground water is obtained for municipal, institutional, commercial, and industrial supplies from glacial sand and gravel aquifers which are often thin and greatly limited in areal extent. Case histories of the development of glacial aquifers in three areas in central Illinois are presented in this report. Complex aquifer conditions are simulated with simplified model aquifers. Model aquifers and existing ground-water. formulas are used to evaluate the practical sustained yields of well fields and aquifers at Taylorville, Arcola, and Tallula.

The aquifer at Taylorville is a strip of sand and gravel approximately 3/4-mile wide and 50 feet thick, bounded on the sides and bottom by relatively impermeable deposits of till or shale. The coefficients of transmissibility and storage of the aquifer are 70,000 gpd/ft and 0.20, respectively. Water occurs under water-table conditions and the aquifer is recharged from precipitation. Computations indicate that the practical sustained yield of the part of the aquifer within a 3-mile radius of Taylorville is 1,400,000 gallons per day.

The aquifer at Arcola is a strip of sand and gravel approximately 400 feet wide and 20 feet thick, bounded on the sides and bottom by relatively impermeable deposits of till or shale, and overlain by clayey materials (confining bed) 70 feet thick. The coefficient of transmissibility of the aquifer and the vertical permeability of the confining bed are 10,000 gpd/ft and 0.04 gpd/sq ft, respectively. Water occurs under leaky artesian conditions and the aquifer is recharged by the vertical leakage of water through the confining bed. Computations indicate that the practical sustained yield of 3 wells widely spaced within a 2-mile radius of Areola is 200,000 gallons per day.

The aquifer at Tallula is a strip of sand and gravel approximately 300 feet wide and 3.5 feet thick, bounded on the sides and bottom by relatively impermeable deposits of till or shale, and overlain by silty and sandy materials (confining bed) 10 feet thick. The coefficient of transmissibility of the aquifer and the coefficient of storage of the confining bed are 2750 gpd/ft and 0.05, respectively. Water occurs under leaky artesian conditions and the aquifer is recharged naturally by the vertical leakage of water through the confining bed and artificially through a recharge well connected to a lagoon. Computations indicate that the practical sustained yield of a horizontal collector is 16,000 gallons per day during extended dry periods and 25,000 gallons per day during periods of normal precipitation.

INTRODUCTION

Purpose and Scope of Study

Records of experience in ground-water development are important sources of hydrologic data. Actual performance data studied in relation to geohydrologic theory can be a guide to sound evaluation of untapped aquifers and to proper design of ground-water systems. Case histories of ground-water development in three areas in central Illinois are presented in this report to facilitate the future planning and management of ground-water supplies.

Large areas in central, western, south central, and southern Illinois are covered by glacial drift of Illinoian age. The drift cover is relatively thin and seldom exceeds 75 feet in thickness. The bedrock beneath the drift is shale, sandstone, and limestone of Pennsylvanian age which yield only small amounts of water to wells. Large deposits of water-yielding sand and gravel are scarce in the glacial drift and they occur chiefly in existing or buried valleys and as lenticular and discontinuous layers. In the area of the Wisconsinan glacial drift in the east-central and northern parts of Illinois, drift is thicker and consequently may contain more aquifers.

In many parts of central Illinois, ground water is obtained for municipal, institutional, commercial, and industrial supplies from glacial sand and gravel deposits which are often thin and greatly limited in areal extent. The aquifers are commonly overlain by deposits of till that contain a high percentage of silt and clay and have a low permeability. In many areas, recharge to the aquifers is derived from vertical leakage of ground water through the till. The permeability and sustained yield of the aquifers often are not great.

The practical sustained yields of glacial sand and gravel aquifers underlying the cities of Taylorville and Arcola and near the village of Tallula are evaluated in this report. Available information concerning geographic, climatic, and geologic features of study areas are given to serve as a background for interpretation of records. The practical sustained yield is defined as the maximum amount of ground water that can be continuously pumped without eventually lowering water levels below tops of screens in production wells or tops of laterals in a collector.

Complex aquifer conditions are simulated with simplified model aquifers. Geohydrologic boundaries are assumed to be straight line demarcations and are given mathematical expression by means of the image-well theory. The hydraulic properties of the aquifer and overlying confining beds are considered mathematically by using ground-water formulas. Records of past pumpage and water levels are used to establish the validity of this mechanism to describe the response of aquifers to pumping, to predict the effects of future ground-water development, and to estimate the practical sustained yield of aquifers and existing well fields.

Acknowledgments

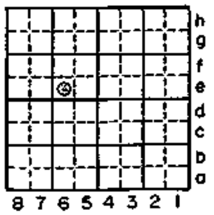
The geologic sections of this report were prepared by R. E. Bergstrom, J. E. Hackett, and J. P. Kempton of the Illinois State Geological Survey. Data on ground-water conditions were furnished by officials of the city of Taylorville; Hopper Paper Company; Allied Mills, Inc.; Warren & Van Praag, Inc., Consulting Engineers; officials of the city of Arcola; Wilson and Anderson, Consulting Engineers; Crenshaw and Jost, Engineers & Architects; G. E. DeJong, Consulting Engineer; and officials of the village of Tallula. Well drilling firms including Layne Western Co., L. R. Burt, M. S. Burt & Son, Hayes & Sims, Woollen Bros., E. C. Baker & Sons, and C. M. Hayes provided logs of wells and other subsurface information. Special acknowledgment for collection of data is due Jason Daykin, Water Superintendent of the city of Taylorville; P. G. Gottschalk, Plant Superintendent of Allied Mills, Inc.; and John Sinclair, Water Superintendent of the village of Tallula.

Many former and present members of the State Water Survey assisted in the collection of data in study areas, wrote earlier special reports which have been used as reference materials, or aided the writers indirectly in preparing this report. Grateful acknowledgment is made, therefore, to the following engineers: H. F. Smith, W. J. Roberts, R. A. Hanson, R. T. Sasman, R. R. Russell, J. P. Dorr, J. B. Stall, H. G. Rose, R. J. Schicht, Jack Bruin, R. E. Aten, T. A. Prickett, and O. D. Michels. J. W. Brother prepared the illustrations of this report.

The coauthors of this report participated in the following manner: W. H. Walker processed the data, made most of the computations, and prepared parts of the manuscript; W. C. Walton supervised computations, prepared much of the text, and brought the manuscript to final form.

Well-Numbering System

The well-numbering system used in this report is based on the location of the well, and uses the township, range, and section for identification. The well number consists of five parts: county abbreviation, township, range, section, and coordinate within the section. Sections are divided into rows of 1/8-mile squares. Each 1/8-mile square contains 10 acres and corresponds to a quarter of a quarter section. A normal section of 1 square mile contains 8 rows of 1/8-mile squares; an odd-size section contains more or fewer rows. Rows are numbered from east to west and lettered from south to north as shown below:



Douglas County
T. 14N., R. 8E.
sec. 4

The number of the well shown in section 4 above is as follows:

DGL 14N8E-4.6e

Where there is more than one well in a 10-acre square they are identified by arabic numbers after the lower case letter in the well number.

The abbreviations for counties discussed in this report are listed below:

Christian	CHR	Douglas	DGL	Menard	MEN

TAYLORVILLE

Water for municipal and industrial use at Taylorville is obtained from wells in a sand and gravel aquifer approximately 3/4-mile wide and 50 feet thick that receives recharge directly from precipitation. Since 1888, when the aquifer was first tapped for the municipal water supply, the average daily withdrawal increased from about 27,000 gallons to over 3 million gallons in 1953. Exploitation of ground-water resources caused a general water-level decline in the Taylorville area and the water table receded to near critical levels in some of the major pumping centers.

Geography

Location and Extent of Study Area

The city of Taylorville, the county seat of Christian County, is located 27 miles southwest of Decatur as shown in figure 1. State Highways 29, 48, and 104 pass through the city as do the Wabash, Chicago and Illinois Midland, and the Baltimore and Ohio railroads.

Detailed study was confined to a rectangular area, hereafter referred to as "the area," of about

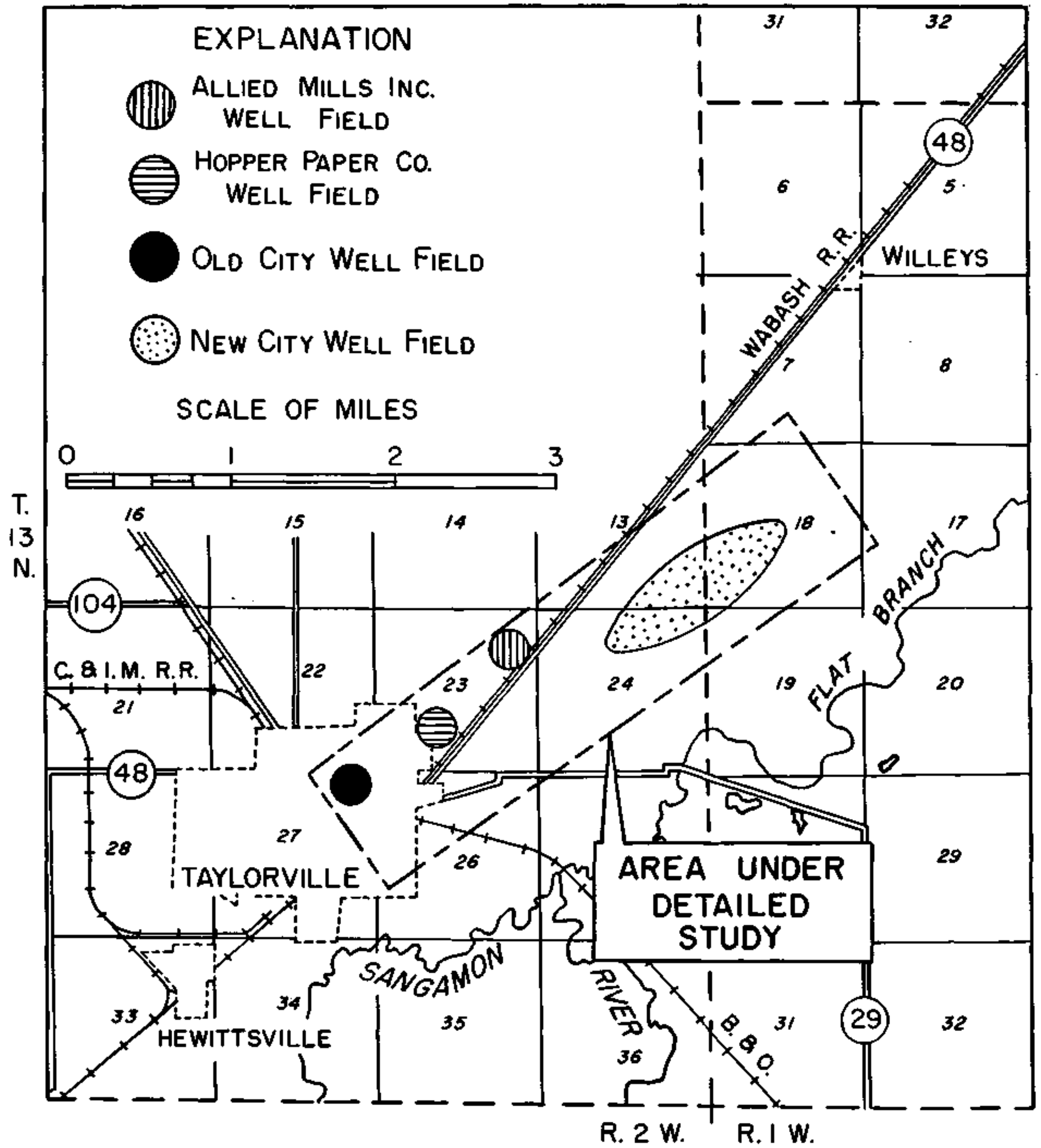


Figure 2. Map showing location of study area and pumping centers at Taylorville

4 square miles in and northeast of Taylorville in T. 13 N., R. 1 W., R. 2 W. as shown in figure 2. The area is between 89°10' and 89°20' west longitude and between 39°30' and 39°40' north latitude.

Topography and Drainage

Except for a low narrow ridge extending southwest to northeast through the center of the area, the land surface is a level to gently undulatory plain. The elevation of the land surface declines from about 636 feet on the ridge 1-1/2 miles northeast of Taylorville to about 600 feet 1/2 mile northeast of Taylorville in the valley of a short tributary to Flat Branch. Southeast of the area the flood plain of Flat Branch has an average elevation of 575 feet, and the flood plain of South Fork Sangamon River southwest of Taylorville has an average elevation of 565 feet.

Drainage is largely southeastward to Flat Branch and to South Fork Sangamon River which flow in courses about 1/2 mile southeast of the area as shown in figure 2. Ditches drain the northern third of the area towards tributaries of the Sangamon River northwest of Taylorville.

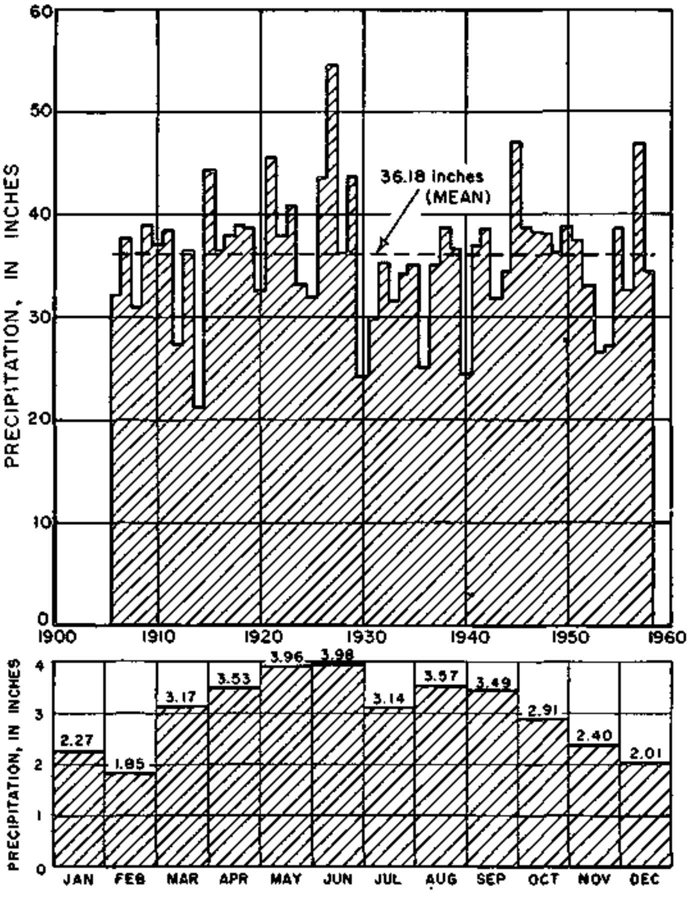


Figure 3. Annual and mean monthly precipitation at Taylorville

Climate

Graphs of annual and mean monthly precipitation at Taylorville given in figure 3 were compiled from precipitation data collected by the U. S. Weather Bureau at Morrisonville (1906-1940) and at Taylorville (1941-1958). According to these records the mean annual precipitation is 36.18 inches. The months of greatest precipitation are April, May, June, and August, each having more than 3.5 inches; February is the month of least precipitation having less than 2 inches.

A large part of central and southern Illinois including the Taylorville area experienced a severe drought beginning in the latter half of 1952 (Hudson and Roberts, 1955). For the period 1952 through 1956, cumulative deficiency of precipitation at Taylorville was about 23 inches. Recharge from precipitation was much below normal during the dry years and large quantities of water were taken from storage within the aquifer to balance pumpage.

The occurrence of annual maximum and minimum precipitation amounts expected on an average of once in 5 and once in 50 years, based on data in the Atlas of Illinois Resources, Section 1, is given below:

	Lowest annual precipitation expected (inches)	Highest annual precipitation expected (inches)
Once in 5 years	30	41
Once in 50 years	24	54

The mean annual snowfall is 19 inches. On the average about 24 days a year have 1 inch or more of ground snow cover. About 2 days a year have 3 inches or more of ground snow cover.

Based on records collected by the U. S. Weather Bureau at Morrisonville and at Taylorville, the mean annual temperature is 53.9 F. June, July, and August are the hottest months with mean temperatures of 73.2°F, 77.2°F, and 75.2°F, respectively; January is the coldest month with a mean temperature of 30.7°F. The mean length of the growing season is about 185 days.

Geology

The unconsolidated glacial deposits in the Taylorville area are chiefly Illinoian in age and range in thickness from about 50 feet to 180 feet. These deposits vary in thickness in part because of a buried valley cut into the underlying bedrock of Pennsylvanian age and in part because of the uneven topography of the land surface.

The glacial deposits are a complex of ice-laid till, water-laid silt, sand and gravel outwash, and wind-deposited silt and fine sand called loess. The sand and gravel outwash is permeable and yields water in large quantities to wells. Both the glacial till, which contains considerable silt and clay, and the underlying shale bedrock of Pennsylvanian age are relatively impermeable. The loess is of Wisconsinan age and has been deposited as a blanket, 5 to 10 feet thick, on the older tills and outwash deposits.

Logs of wells, test holes, and coal test borings indicate that the bedrock valley in the Taylorville area (see Horberg, 1957) was at one time in the past largely filled with glacial till containing only a few thin, probably discontinuous beds or lenses of glacial outwash. As shown by cross section A-A' in figure 4, the aquifer occurs as a fill of outwash sand and gravel in a relatively narrow valley cut into the upper part of the till deposits. The map in figure 4 shows that the outwash deposits range in width from about 1/2 to 1 mile

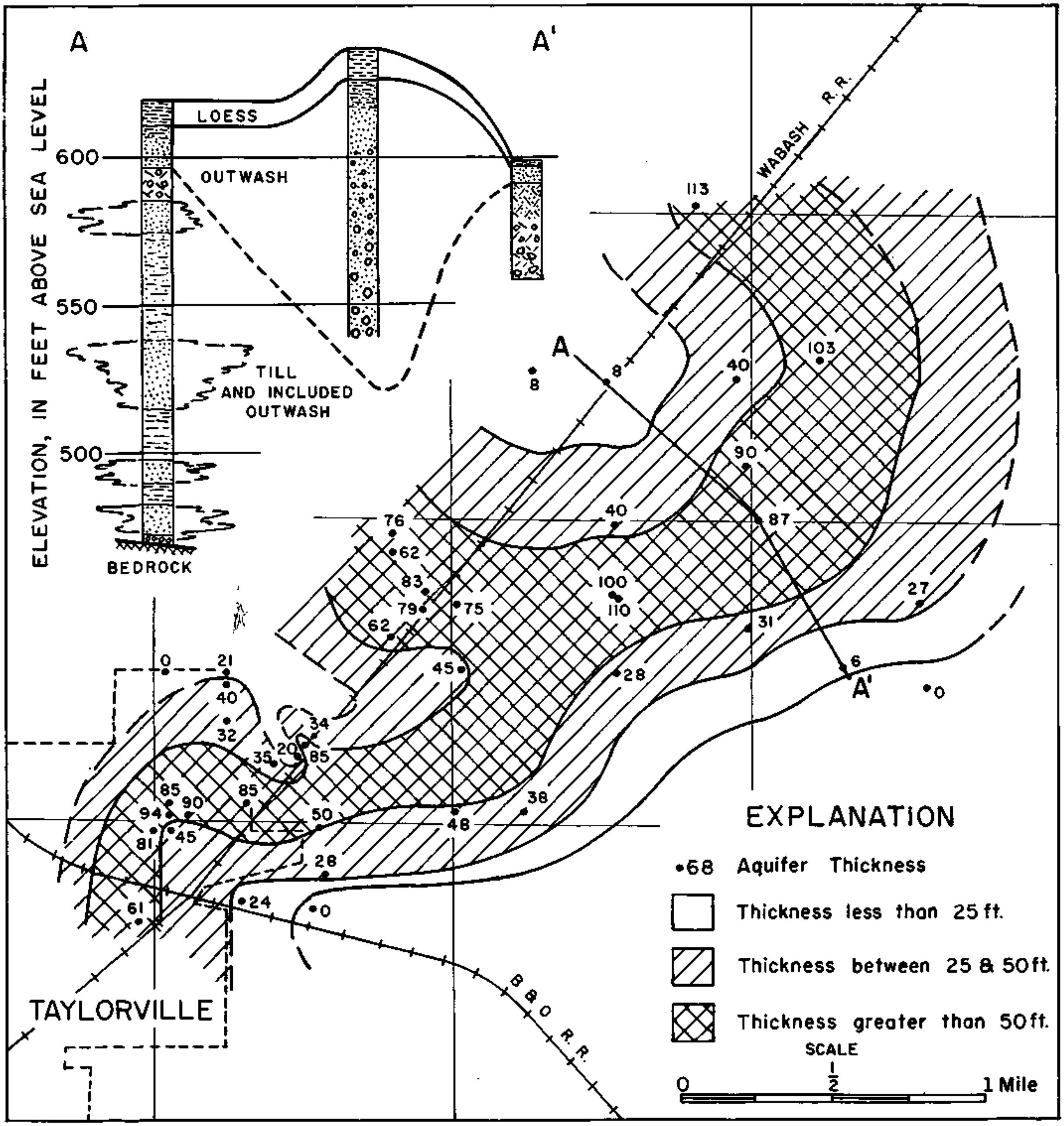


Figure 4. Map and geologic cross section showing thickness and areal extent of aquifer at Taylorville

and trend northeast to southwest. Lack of subsurface information does not allow for definition and extension of the outwash south and north of Taylorville in section 12, T. 13 N., R. 2 W., and sections 7 and 18, T. 13 N., R. 1 W. Additional information is also needed to determine the possible continuation of the outwash in the north half of section 23 and in section 14, T. 13 N., R. 2 W.

The permeable outwash forming the aquifer ranges in thickness from 0 to 113 feet and consists of stratified beds of sand, gravel, and silt in various mixtures. Generally, the upper part of the aquifer contains finer-grained material than the lower part.

Logs of wells and test holes are given in table 1; the location of wells and test holes for which geologic data are available is shown in figure 5. Records of wells and test holes appear in table 2.

Table 1. Logs of Wells and Test Holes at Taylorville

Well Number	Type of Record°	Formation	Thickness (feet)	Depth (feet)
CHR 13N2W-				
27.2h1	driller's log	clay	17	17
		sand, fine	43	60
		sand, coarse	5	65
		sand and gravel	34	99
		clay	--	100
27.2h2	driller's log	top soil and clay	18	18
		sand, fine	12	40
		sand, coarse	26	66
		gravel, coarse	31	97
		clay	--	97
27.2h6	correlated driller's log	Pleistocene Series		
		soil and clay	15	15
		sand, some clay	25	40
		sand and gravel	74	114
24.4g	driller's log	soil	2	2
		clay	14	16
		sand, fine	14	30
		sand, medium coarse	20	50
		sand, coarse	40	90
		sand, coarse and boulders	15	105
		sand and gravel, coarse	15	120
23.2f2	driller's log	top soil	5	5
		clay	10	15
		clay, sandy	25	40
		sand	10	50
		sand, some gravel	20	70
		sand and gravel	20	90
		clay	--	92
26.5h	S.S. 832	Pleistocene Series		
		loess, top soil	10	10
		sand, fine to coarse with some clayey streaks	50	60
		till, pebbly, sandy	25	85
		clay, silty	5	90
		silt, sandy	5	95
23.3c	S.S. 840	Pleistocene Series		
		loess	5	5
		clay, reddish brown, very sandy	5	10
		sand, clayey	5	15
		gravel, clayey	5	20
		sand, medium, gravelly	30	50
		gravel coarse and sand fine	5	55
		sand, medium to coarse	5	60
		sand, very coarse	10	70
		gravel	25	95
		till	15	110
		till, gravelly	5	115
24.8d	S.S. 951	Pleistocene Series		
		soil and loess	7	7
		sand, clayey, reddish brown	8	15
		sand, fine to coarse	35	50
		sand with few pebbles	5	55
		gravel and sand	3	58
		till, sandy and pebbly	42	100
		clay and silt	20	120
		till	5	125
		sandstone	--	130
24.4f	driller's log	top soil and clay	19	19
		sand, some gravel	10	29
		sand and gravel, coarse	90	119
		clay, gravelly	--	124
23.5b	S.S. 963	Pleistocene Series		
		loess	5	5
		gumbo sand	5	10
		sand, clayey	6	16
		sand, medium to coarse	20	36
		silt, sandy	9	45
		till, sandy	15	60
		clay	5	65
		till	20	85
		silt	5	90
		gravel, fine	10	100
		Pennsylvanian System		
		shale	10	110
		sandstone	--	120
23.6a	S.S. 964	Pleistocene Series		
		soil and loess	5	5
		sand, clayey	5	10
		sand, gravelly	45	55
		gravel, fine to coarse, mostly medium	40	95
		silt, sandy	--	96
23.8d	driller's log	top soil and clay	13	13
		sand, fine	8	21
		clay, gravelly	30	51
		sand, dirty	3	54
		clay	1	55
		clay, gravelly with sand streaks	37	92
		shale	--	94
23.7d1	driller's log	top soil and clay	14	14
		sand, yellow	14	28
		clay and sand	2	30
		sand, gray	5	35
		clay, gravelly with sand streaks	61	96
		shale	--	97

° S.S. refers to sample set No. of State Geological Survey

Table 1. Logs of Wells and Test Holes at Taylorville (continued)

Well Number	Type of Record*	Formation	Thickness (feet)	Depth (feet)
CHR 13N2W-				
26.6h	S.S. 17721	Pleistocene Series		
		till, silty	9	9
		sand, fine	21	30
		sand, fine to coarse	30	60
		gravel, partly dirty	4	64
		"shale"	--	65
26.8h	S.S. 17722	Pleistocene Series		
		till	9	9
		sand, very fine to fine	21	30
		sand, medium to very coarse	25	55
		till, gravelly & silty	55	110
		till, silty	7	117
		Pennsylvanian System		
		"shale"	--	118
23.8a3	driller's log	clay, yellow	14	14
		sand, yellow with some clay	31	45
		sand and gravel	54	99
		shale	--	100
23.8a4	driller's log	clay, yellow	4	4
		sand, fine	46	50
		sand, coarse	8	58
		clay, sandy	31	89
		sand, dirty	5	94
		clay	31	125
		shale	--	128
23.8a5	driller's log	clay, yellow	5	5
		clay, sandy	13	18
		sand	4	22
		sand and gravel, dirty and clayey	55	77
		sand and gravel	32	109
		clay, blue	--	130
23.8a6	driller's log	clay, yellow	16	16
		sand and clay	34	50
		sand with clay showing	17	67
		sand and gravel becoming fine at base	43	110
		siltstone	--	111
27.1h	driller's log	top soil and clay	14	14
		sand, fine	36	50
		sand, coarse	45	95
		gravel	1	96
		"shale" (?)	--	96
23.6b11	driller's log	clay	27	27
		gravel, coarse	25	52
		sand, fine	20	72
		sand, water-bearing	8	80
		hard pan	2	82
		sand	--	90
23.6b12	coal test	clay, coarse gravel	80	80
		sand, water-bearing	--	100
26.4f1	driller's log	clay	12	12
		sand, fine	13	25
		sand and gravel	1	26
		clay and sand	14	40
		clay	7	47
		sand and gravel	2	49
		sand	2	51
		clay, sandy	9	60
		sand, gray	2	62
		clay, soft	38	100
26.4f2	driller's log	clay	5	5
		clay, sandy	5	10
		sand	5	15
		clay	--	60
23.4c	driller's log	clay	15	15
		sand	23	38
		sand, some gravel	11	49
		clay	21	70
		clay, sandy	30	100
24.8g	driller's log	loam, sandy	5	5
		clay, sandy	10	15
		sand	5	20
		clay, sandy	25	45
		clay and gravel	15	60
		clay	--	65
24.8h	driller's log	clay	7	7
		clay, sandy	7	14
		sand, fine	11	25
		sand, coarse	--	40
23.1g1	driller's log	clay	7	7
		clay, sandy	7	14
		sand	46	60
		sand and gravel	35	95
		clay	--	96
23.2f1	driller's log	top soil and clay	14	14
		sand, some gravel	6	20
		sand	40	60
		sand and gravel	16	76
		clay	--	85
23.1f1	driller's log	top soil and clay	15	15
		sand	15	30
		sand, some gravel	10	40
		sand and gravel	10	50
		sand	5	55
		sand and gravel	39	94
		clay	--	110
23.1g2	driller's log	top soil and clay	15	15
		clay, sandy	5	20
		sand	35	55
		sand and gravel	35	90
		gravel	8	98
		clay	--	102
24.1e1	driller's log	top soil and clay	12	12
		clay, sandy	18	30
		sand	13	43
		clay	26	69
		sand, some gravel	2	71
		clay	--	71

* S.S. refers to sample set No. of State Geological Survey

Table 1. Logs of Wells and Test Holes at Taylorville (continued)

Well Number	Type of Record°	Formation	Thickness (feet)	Depth (feet)
CHR 13N2W-				
24.1e2	driller's log	top soil	2	2
		sand and clay	24	26
		sand	6	32
		clay	29	61
		sand, fine silty	7	68
		clay	--	136
26.6f	driller's log	soil	13	13
		gravel, cemented	24	37
		clay, white	7	44
		gravel and clay	17	61
		sand and gravel	17	78
		sand	15	93
		clay, green	12	105
		sand and gravel	11	116
		clay and gravel	7.5	123.5
		shale	1.5	125
13.7e	driller's log	clay	14	14
		sand	8	22
		clay, gravelly	11	33
		sand, fine to coarse	11	44
		sand and clay	37	81
		sand	23	104
		clay	17	121
		sand	8	129
		clay	7	136
		sand	11	147
		gravel	2	149
		sandy clay	2	151
		loose boulders	1.5	152.5
		sandstone	--	152.5
24.4c	driller's log	top soil and clay	18	18
		sand	15	33
		sand and gravel, clayey	25	40
		clay, gravelly	62	120
24.1h	S.S. 18588	soil and silt	10	10
		silt, sandy, clayey	10	20
		sand and gravel, silty	--	97
24.4d	S.S. 18590	soil and silt	8	8
		silt, sandy, some clay	12	20
		sand, medium to coarse, silty	10	30
		till	--	120
23.1f1	S.S. 18591	soil	5	5
		silt, sandy	10	15
		sand, medium to coarse, silty	30	45
		gravel and sand, silty	40	85
		till	--	90
13.1c	S.S. 18592	soil and silt	12	12
		silt, sandy	8	20
		sand, medium to coarse, silty	5	25
		gravel and sand, silty	70	95
		till	--	98
24.3d	S.S. 18594	soil and silt	7	7
		silt, sandy	8	15
		sand, medium to coarse, silty	35	50
		gravel, slightly silty	35	85
		gravel and sand, silty	--	120
27.4b	driller's log	clay	5	5
		sand and clay	4	9
		sand	3	12
		sand, fine	7	19
		sand, very fine	6	25
		sand	5	30
		sand, fine	19	49
		sand, coarse	6	55
		sand, coarse and gravel fine	11	66
34.8h	driller's log	top soil, clay and sandy clay	45	45
		sand, fine	20	65
		sand, fine to coarse	5	70
		sand, coarse	12	82
		mud	--	82
24.4h	S.S. 18586	soil and silt	5	5
		silt, sandy	15	20
		sand, silty	5	25
		gravel, sandy, silty	5	30
		soil, dark brown	5	35
		sand, silty, some gravel	10	45
		till	55	100
23.2g1	driller's log	top soil and clay	15	15
		sand	25	40
		sand and gravel	37	77
		clay, blue	--	85
23.8a5	driller's log	top soil	5	5
		clay, sandy	10	15
		sand, fine, some clay	25	40
		sand and gravel	74+	114
23.7d2	S.S. 836	clay	5	5
		clay, sandy	8	13
		sand	13	26
		sand and gravel	13	39
		clay	3	42
		sand and gravel	3	45
		clay, sandy with some gravel	60+	105
22.8a6	S.S. 840	loess	5	5
		clay, reddish brown, sandy	5	10
		gravel, clayey	5	15
		sand and gravel, clayey	8	23
		sand with some gravel	37	60
		gravel	40	100
		shale, sandy	--	104
13.4d	driller's log	clay	14	14
		sand	8	22
		clay and rocks	11	33
		sand coarse	7	40
		sand, fine	4	44
		clay and sand	37	81
		sand	23	104
		clay	17	121
		sand	8	129
		clay	7	136
		sand	11	147
		gravel	2	149
		clay, sandy	2	151
		boulders, loose	2	153
		sandstone	10	163

° S.S. refers to sample set No. of State Geological Survey

Table 1. Logs of Wells and Test Holes at Taylorville (continued)

Well Number	Type of Record*	Formation	Thickness (feet)	Depth (feet)
CHR 13N2W-				
23.2g2	driller's log	top soil and clay	15	15
		clay, sandy	25	40
		sand	10	50
		sand and gravel	40	90
		clay blue	--	92
23.2h	driller's log	top soil and clay	15	15
		sand, yellow, gray	35	50
		sand and gravel	41	91
		clay, gray	--	96
CHR 13N1W-				
18.8e	S.S. 18589	top soil and silt	12	12
		sand, silty	33	45
		till	70	115
		sand, silty	25	140
		till	--	150
18.6e	S.S 18593	soil and silt	5	5
		sand, fine to very coarse	25	30
		till	10	40
		gravel and sand	10	50
18.6e (continued)		sand, coarse, silty	15	65
		sand and gravel, silty	15	80
		gravel, silty	28	108
		till	--	110
19.6e	sample set description	sand, gray	2	2
		sand, yellow	6	8
		till, silty	12	20
		sandy loam, yellow, gravelly	8	28
		silt, pebbly, clayey, sandy	12	40
30.5g	driller's log	clay	12	12
		sand	3	15
		hard pan	13	28
		clay	23	51
		sandy clay	36	87
		clay, blue	28	115
		shale, blue	5	120
		lime shale	25	145
		limestone	11	156

*S.S. refers to sample set No. of State Geological Survey

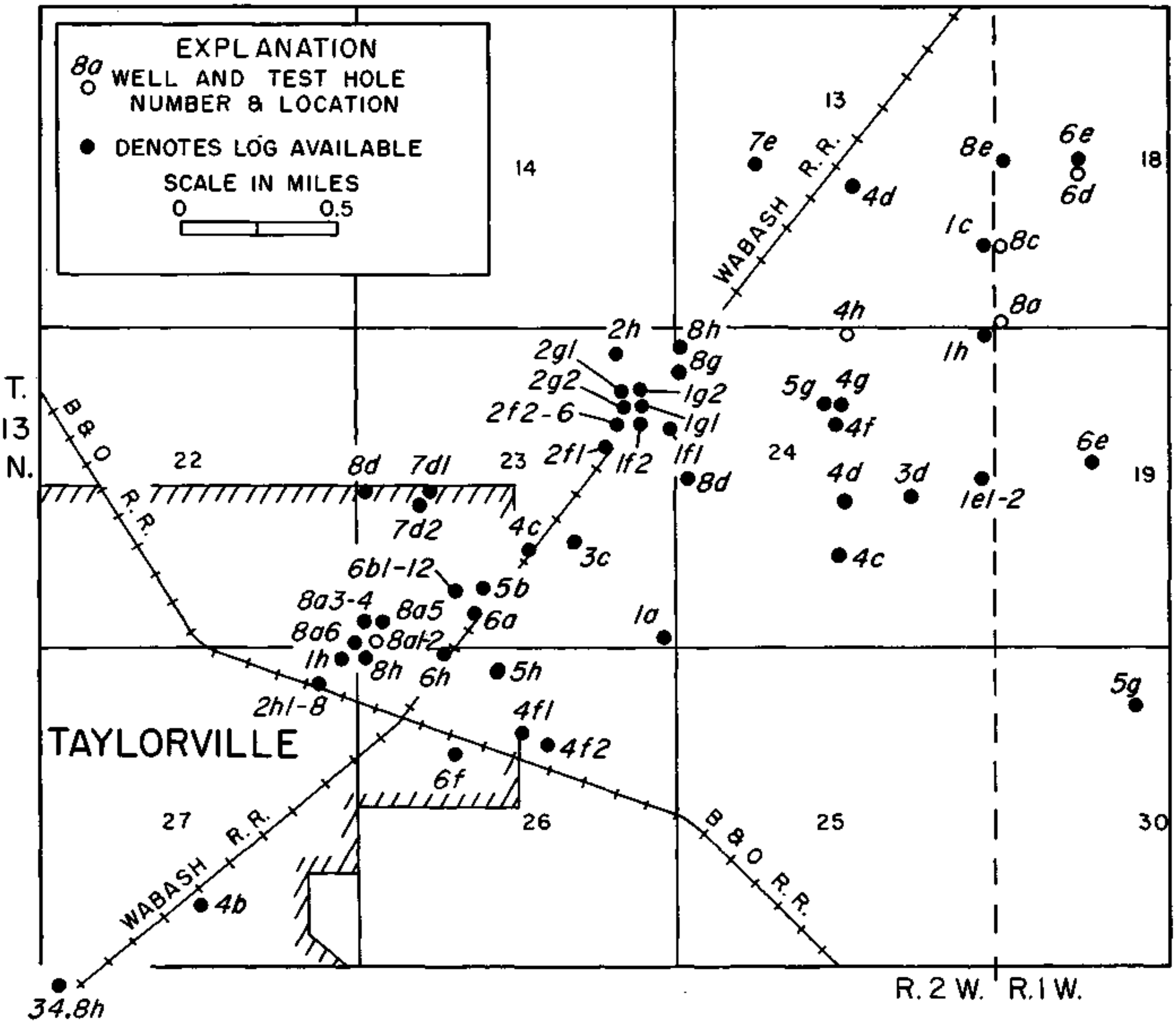


Figure 5. Map showing location of wells and test holes at Taylorville

Table 2. Records of Wells and Test Holes at Taylorville
(Elevations in feet above sea level)

Well Number	Owner	Driller	Date drilled	Land surface elevation	Remarks
CHR 13N2W-					
27.2h1	City	Sickel Water Production Co.	1923	625	At pumping station, Cherokee & Vine Sts.,
27.2h2	City	Sickel Water Production Co.	1923	624	At pumping station, Cherokee & Vine Sts., 100' from Well No. 1
27.2h6	City	L. R. Burt	1940	625.6	
24.4g	City	Layne Western	1951	629.7	
23.2f2	Allied Mills, Inc.	L. R. Burt	1944	626.6	
26.5h	City	M. S. Burt & Son	1929	620	Test hole 1-29
23.3c	City	M. S. Burt & Son	1929	635.5	Test hole 4-29
24.8d	City	M. S. Burt & Son	1929	624.8	Test hole 5-29
24.4f	City	M. S. Burt & Son	1929	629.0	Test hole 6-29
23.5b	City	M. S. Burt & Son	1929	621.6	
23.6a	City	M. S. Burt & Son	1929	627.7	Test hole 8-29
23.8d	City	Hayes & Sims	1948	618	Test hole 1-48
23.7d1	City	Hayes & Sims	1948	620	Test hole 2-48
26.6h	City	Hayes & Sims	1948	620	Test hole 3-48
26.8h	City	Hayes & Sims	1948	620	Test hole 4-48
23.8a3	City	Hayes & Sims	1948	617	North of Well No. 9; Test hole 5-48
23.8a4	City	Hayes & Sims	1948	616	Test hole 6-48
23.8a5	City	Hayes & Sims	1948	628	Near Well No. 11; Test hole 7-48
23.8a6	City	Hayes & Sims	1948	620	Test hole 8-48
27.1h	City	Peabody Coal Co.	1948	620	Test hole 9-48
23.6b11	Hopper Paper Co.	-------	----	628	
23.6b12	Hopper Paper Co.	Cook Well Co.	1891	---	
26.4f1	Allied Mills, Inc.	L. R. Burt	1944	---	Test hole 2-44
26.4f2	Allied Mills, Inc.	L. R. Burt	1944	610	Test hole 3-44
23.4c	Allied Mills, Inc.	L. R. Burt	1944	---	Test hole 4-44
24.8g	Allied Mills, Inc.	L. R. Burt	1944	---	Test hole 5-44
24.8h	Allied Mills, Inc.	L. R. Burt	1944	---	Test hole 6-44
23.1g1	Allied Mills, Inc.	L. R. Burt	1944	---	Test hole 7-44
23.2f1	Allied Mills, Inc.	L. R. Burt	1944	---	Test hole 8-44
23.1f1	Allied Mills, Inc.	L. R. Burt	1944	---	Test hole 9-44
23.1g2	Allied Mills, Inc.	Jessie Michael	1953	---	Test hole 1-53
24.1e1	Bart Hall	Woollen Bros.	1946	---	Test hole 1-46
24.1e2	Bart Hall	Woollen Bros.	1946	---	Test hole 2-46
26.6f	Taylorville Coal Co.	Unknown	1926	592	
13.7e	Byrd-Willey	Unknown	1926	618.6	Test hole 2-26
24.4c	City	Hayes & Sims	1948	625	Test hole 11-48
24.1h	City	Hayes & Sims	1948	637	Near Well No. 12; Test hole 12-48
24.3d	City	Hayes & Sims	1948	634	Test hole 18-48
27.4b	Central Illinois Public Service Co. at gas plant	D. W. Johnson	1925		
34.8h	Chicago & Illinois Midland Railroad	D. W. Johnson	1932		At C. & I.M. Shops
24.4h	City	Hayes & Sims	1948	630	Test hole 10-48
23.2g1	Allied Mills, Inc.	L. R. Burt	1944	615	Test hole 11-44
23.8a5	City	L. R. Burt	1940	620	Test hole 6-40
23.7d2	City	L. R. Burt	1929	620	Test hole 2-29
22.8a6	City	L. R. Burt	1929	620	Test hole 3-29
13.4d	Tolliver	Byrd-Willey	----	619	
23.2g2	Allied Mills, Inc.	L. R. Burt	1944	620	Test hole 1-44
23.2h	Allied Mills, Inc.	L. R. Burt	1944	615	Test hole 10-44
CHR 13N1W-					
18.8e	City	Hayes & Sims	1948	624	Test hole 13-48
24.4d	City	Hayes & Sims	1948	628	Test hole 14-48
23.1f1	City	Hayes & Sims	1948	632	Test hole 15-48
13.1c	City	Hayes & Sims	1948	636	Near Well No. 13; Test hole 16-48
18.6e	City	Hayes & Sims	1948	634	Near Well No. 14; Test hole 17-48
19.6e	"Taylorville Damsite"	U. S. Engineers	1945	599	Test hole 5-45
30.5g	"Coal Test"	W. J. Jenkins	1918	586	Test hole 2-18

Ground-Water Withdrawals

The first municipal wells at Taylorville were constructed in 1888 at the old city water plant near Cherokee and Vine Streets. In 1900 about 28,000 gallons per day (gpd) were pumped from 8 tubular wells to satisfy the commercial and domestic water needs of the city. As shown in figure 6 water use has steadily increased since 1888 as the city has grown in population from 4248 to 9750 people, and in 1958 approximately 950,000 gpd were required to fulfill industrial, commercial, and domestic water demands. This represents an increase in total per capita consumption from 6.6 gpd per person in 1900 to nearly 100 gpd per person in 1958. In 1951, wells in the old city well field were abandoned and the municipal water supply was obtained from wells in a new field northeast of the city limits (see figure 2). Quality of water and well deterioration problems were responsible for the change in pumping centers.

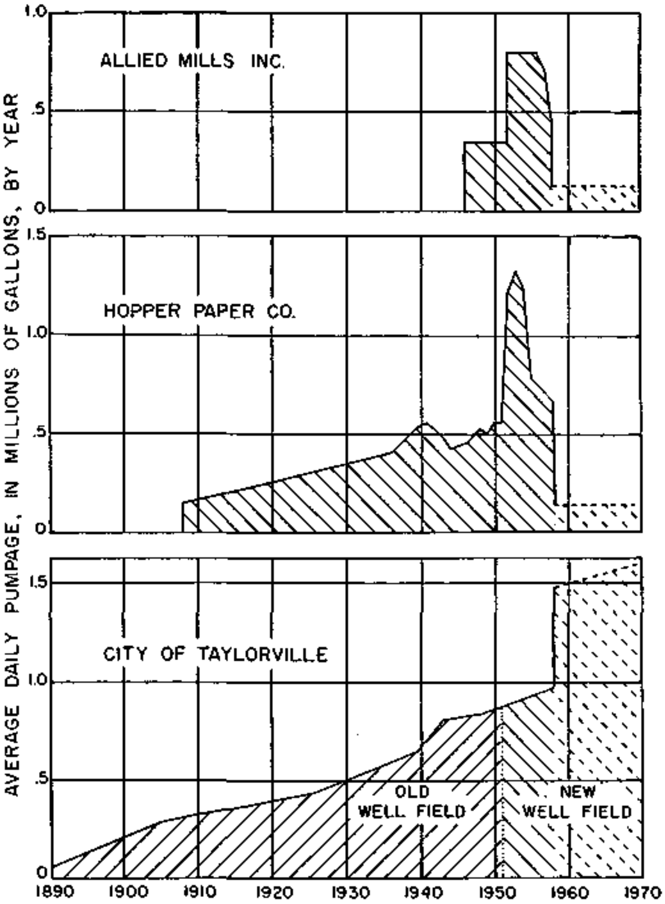


Figure 6. Distribution of pumpage, 1890-1959, and estimated pumpage to 1970 at Taylorville

Two industries, Hopper Paper Company and Allied Mills, Inc., also pump large quantities of ground water from the aquifer at Taylorville. The water demand at Hopper Paper Company increased as shown in figure 6 at a relatively uniform rate from 150,000 gpd in 1908 to 550,000 gpd in 1952. In 1953 the rate of ground-water withdrawal was increased to 1,320,000 gpd. This increase in pumpage caused such a rapid rate of water-level decline that the pumpage had to be reduced to 770,000 gpd in 1955, and to 650,000 gpd in 1958. A further reduction to 144,000 gpd was made in April 1958, and since that time Hopper Paper Company has purchased an average of 632,000 gpd from the city to supplement the amount pumped from their well field.

The soybean processing plant owned by Allied Mills, Inc. pumped about 350,000 gpd from 1946 until 1952. Plant expansion resulted in an increase of the water demand to 800,000 gpd in 1952. Ground-water levels declined rapidly to critical stages and in 1957 cooling towers were installed to conserve water. Conservation practices resulted in a reduction in ground-water withdrawal at the plant of about 675,000 gpd. Since 1958 about 125,000 gpd have been pumped from wells at Allied Mills, Inc.

The distribution of ground-water pumpage in May 1959 at Taylorville was 1,500,000 gpd from municipal wells 23.6b7 and 23.6b9; 144,000 gpd from the Hopper Paper Company well field; and 125,000 gpd from wells at Allied Mills, Inc. Total ground-water withdrawals increased progressively from about 28,000 gpd in 1890 to a maximum of about 3,000,000 gpd in 1953 as shown in figure 7. Pumpage decreased rapidly from 3,000,000 gpd in 1953 to about 1,750,000 gpd in 1957 owing to the great decline in the water table. In May 1959 total ground-water withdrawal was about 1,770,000 gpd.

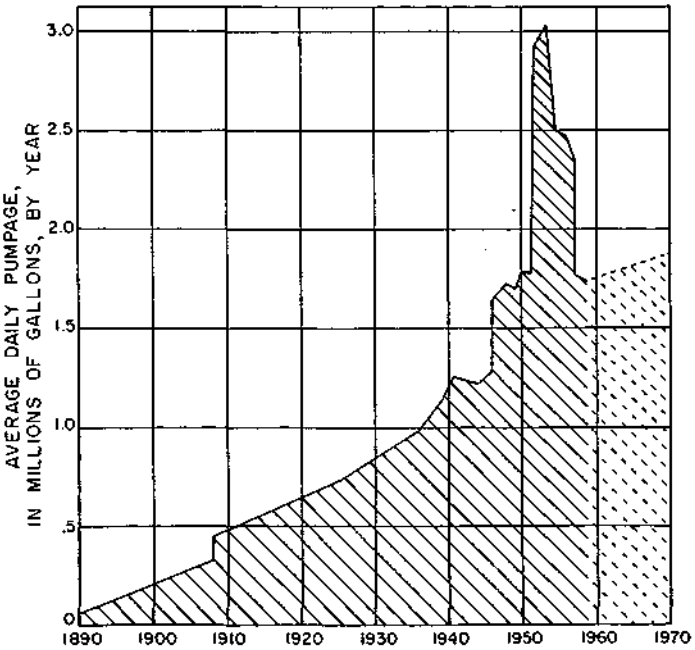


Figure 7. Ground-water pumpage, 1890-1959, and estimated pumpage to 1970 at Taylorville

Records of pumpage are fairly complete for the period 1935 to May 1959; very few records of pumpage are available for years prior to 1935. The portions of the graphs in figures 6 and 7 for the period prior to 1935 were constructed by piecing together fragments of information on pumpage found in the files of the State Water Survey; by making evaluations based on number of wells, their reported yields, and their time of construction; and by taking into consideration population growth and per capita consumption.

Fluctuations of Water Levels and Their Significance

Under natural conditions, the water table at Taylorville generally receded in late spring, summer, and early fall months when discharge by evapotranspiration and ground-water runoff were greater than recharge from precipitation. Water levels began to recover late in the fall when evapotranspiration losses were small, soil moisture was replenished, and conditions were favorable for the infiltration of rainfall to the water table. The annual cycle of water levels reflected the effects of seasonal variation in precipitation and other climatic factors. Although ground-water levels fluctuated from season to season and from year to year, the long-term picture was one of equilibrium between recharge and discharge.

Starting in 1888 water-level fluctuations caused by pumping were superimposed on the natural cycle. If pumpage had remained at a constant rate, water levels would have declined at a decreasing rate with time and eventually would have stabilized at a stage lower than that measured prior to pumping. However, pumpage rates did not remain constant but increased almost without interruption, as shown in figure 7; as a result water levels never stabilized but declined continuously throughout the period of development.

Water-level measurements were made infrequently in several wells at Taylorville between 1913 and 1958; periodic measurements were made near the centers of pumping starting in 1950. Water-level hydrographs forwells in the newcity well field, well 23.2f6 at Allied Mills, Inc., and well 23.6b6 at Hopper Paper Company are shown in figure 8. It should be emphasized that water levels in figure 8 are nonpumping levels. Water levels in wells with short or interrupted records are summarized in table 3. Records of wells for which water-level data are available are given in tables 2 and 4.

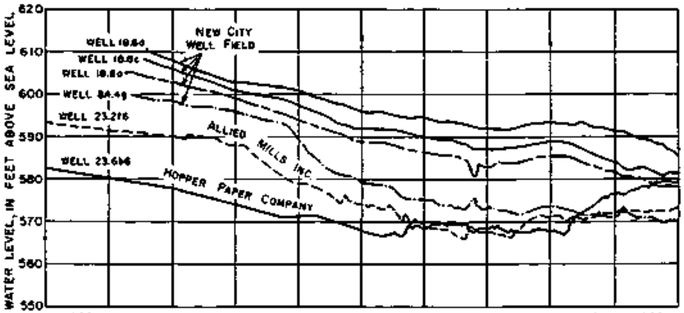


Figure 8. Wafer levels in wells at Taylorville, **1950-1959**

Table 3. Water Levels in Wells at Taylorville

Well Number	Date	Depth to water°
CHR 13N2W		
---	1913	25.0
---	1923	48.0
27.2h1	Dec. 1923	35.0
27.2h1	April 1925	32.3
24.8d	Jan. 1930	24.2
24.4f	Feb. 1930	23.7
23.6a	March 1930	32.2
27.2h4	June 1938	34.0
27.2h6	Aug. 1940	40.0
27.2h7	1943	49.0
27.2h4	Aug. 1944	40.0
27.2h5	Aug. 1944	40.0
27.2h6	Aug. 1944	40.0
27.2h4	July 1945	45.0
27.2h6	Aug. 1945	45.0
27.2h7	Aug. 1945	49.0
27.2h8	1945	44.0
27.2h5	April 1947	50.0
27.2h6	Feb. 1947	50.0
27.2h7	Nov. 1947	51.9
27.2h4	Jan. 1948	52.5
27.2h5	Jan. 1948	46.7
23.8a1	March 1948	37.2
27.2h5	May 1948	47.7
27.2h5	Aug. 1948	48.2
23.8a1	June 1949	38.8
27.2h5	April 1954	45.6
27.2h5	Oct. 1955	50.7
27.2h5	June 1956	50.85
23.8a1	June 1956	40.0
23.8a1	June 1957	35.0
23.6b3	1928	36.0
23.6b3	Nov. 1929	34.5
23.6b6	Feb. 1934	29.0
23.6b3	June 1935	36.0
23.6b3	1940	42.67
23.6b5	Dec. 1943	42.3
23.6b3	April 1945	44.6
23.6b1	1946	42.0
23.6b1	Dec. 1947	45.0
23.6b6	Aug. 1948	44.5
23.6b3	Feb. 1949	43.0
23.6b5	Oct. 1949	46.8
23.6b3	Feb. 1950	43.0
23.6b3	June 1950	46.0
23.6b1	Aug. 1953	53.0
23.6b5	Sept. 1953	58.5
23.6b5	March 1954	58.2
23.6b10	May 1951	43.5
23.6b10	Jan. 1954	58.9
23.2f6	Aug. 1944	31.25
23.2f6	1946	32.0
23.2f6	Aug. 1948	32.0

°Depth in feet below measuring point

Table 4. Records of Production Wells at Taylorville

Well		Date	Depth	Casing		Screen			Specific	
Number	Owner	drilled	(feet)	Depth (feet)	Dia. (inches)	Length (feet)	Dia. (inches)	Yield (gpm)	capacity (gpm/ft)	Remarks
CHR 13N2W-										
27.2h1	City	1923	100	80	18	20	15	775	22	Old No. 1 well; log available; abandoned and filled 1943
27.2h2	City	1923	100	78	18	22	15	300	--	Old No. 2 well; measuring point (MP) elevation 623.9; log available; abandoned and capped 1938
27.2h3	City	1929	100	80	18	20	15	800	23	Old No. 3 well (south); abandoned 1940
27.2h4	City	1936	115	89.5	18	25.5	15	600	20	Old No. 4 well; MP elev. 625.6; abandoned 1951
27.2h5	City	1937	119	100	18	19	15	870	22	Old No. 5 well; MP elev. 626.96; abandoned 1951
27.2h6	City	1940	110	85	12	25	12	600	30	Old No. 6 well; log available; MP elev. 623.9; abandoned 1951
27.2h7	City	1943	128	108	12	20	12	264	22	Old No. 7 well; MP elev. 629.61; abandoned and pulled 1947
27.2h8	City	1945	130	102	18	28	15	600	55	Old No. 8 well; abandoned 1951
23.8a1	City	1948	100	80	16	20	16	414	18	Old No. 9 well; MP elev. 620.0; abandoned 1951
23.8a2	City	1934	97	77	30	20	18	310	17	Wabash well; MP elev. 623.9; abandoned 1951
24.4g	City	1951	118	88	26	30	26	1100	67	New No. 1 well; MP elev. 629.70; log available
23.6b1	Hopper Paper Co.	1926	92	72	8	20	8	---	--	Old No. 1 well
23.6b2	Hopper Paper Co.	1926	87	68	8	19	8	250	--	Old No. 2 well
23.6b3	Hopper Paper Co.	1926	93.5	72.5	8	21	8	---	--	Old No. 3 well
23.6b4	Hopper Paper Co.	1926	93.5	73.5	8	20	8	250	--	Old No. 4 well
23.6b5	Hopper Paper Co.	1942	95	75	8	20	8	280	28	Old No. 5 well; MP elev. 629.48
23.6b6	Hopper Paper Co.	1942	92	72	8	20	8	280	28	Old No. 6 well
23.6b7	Hopper Paper Co.	1951	96.5	76.5	8	20	8	---	--	New No. 1 well; MP elev. 627.72
23.6b8	Hopper Paper Co.	1951	94.5	74.5	8	20	8	---	--	New No. 2 well; MP elev. 628.70
23.6b9	Hopper Paper Co.	1951	93.4	73.5	8	20	8	---	--	New No. 3 well; MP elev. 626.40
23.6b10	Hopper Paper Co.	1951	96	76	8	20	8	---	--	New No. 4 well; MP elev. 628.20
23.2f2	Allied Mills, Inc.	1944	92	71	12	21	12	270	16.8	Well No. 1 (11); log available; land surface elev. 626.57
23.2f3	Allied Mills, Inc.	1945	90	75	18	15	15	250	--	Well No. 2 (11-A); land surface elev. 627.6
23.2f4	Allied Mills, Inc.	1952	90	65	12	25	12	---	--	Well No. 3 (11-B)
23.2f5	Allied Mills, Inc.	1952	90	65	12	25	12	---	--	Well No. 4 (11-C)
23.2f6	Allied Mills, Inc.	1952	90	--	6	--	--	---	--	Observation well
CHR 13N1W-										
18.8a	City	1951	88	68	26	20	26	800	35.5	New No. 2 well; MP elev. 635.86
18.8c	City	1951	88	68	26	20	26	900	117	New No. 3 well; MP elev. 635.51; used as stand-by well
18.6d	City	1951	96	78	26	20	26	900	84	New No. 4 well; MP elev. 634.59; used as stand-by well

The average elevation of the water table at Taylorville in 1888 was probably about 615 feet. By 1951 the water table had declined in response to continual withdrawals of water to an average elevation of 595 feet. Thus, in a period of 63 years, water levels declined 20 feet or at a rate of about 0. 3 foot per year. As the result of progressive increases in pumpage and drought conditions, water levels declined from an average elevation of 595 feet in 1951 to an average elevation of 575 feet in 1956. The average rate and total decline of water levels, 1951 through 1956, were about 3.3 feet per year and 20 feet, respectively. Between 1956 and 1958 water levels recovered slightly due to reduced rates of pumping and above normal precipitation. Recovery terminated in wells in the new city well field early in 1958 and since that time water levels in those wells have declined continuously.

A combination of several effects is reflected in the hydrographs presented in figure 8. The graphs of water-level fluctuations in wells 24.4g, 18. 8a, 18. 8c, and 18. 6d in the new city well field reflect alternate pumping from each of the four municipal wells until about October 1952 when pumping was shifted to wells 24.4g and 18.8a. Alternate pumping of these two wells continued until October 1953 when well 18.8a was placed on a stand-by basis and most of the municipal water supply for the city was pumped from well 24.4g. From about September 1 through October 15, 1956, well 18.8a was used exclusively and a distinct recovery of water levels in wells 24. 4g and 23. 2f6 occurred while the water levels in wells 18. 8a and 18. 8c declined as the water table adjusted to the shift in pumping centers. The recovery of water levels in all wells from May through December 1957 was the result of above average rainfall during this period and a reduction of pumpage at the Allied Mills, Inc. plant.

The hydrographs for well 23. 2f6, located between production wells at the Allied Mills, Inc. plant, and for well 23. 6b6, at the Hopper Paper Company plant, correlate in general with the hydrographs of wells in the new city well field given in figure 8. The hydrographs for wells 23.2f6 and 23. 6b6 are greatly affected by shifts in pumping centers and changes in pumping rates within the Allied Mills, Inc. and Hopper Paper Company well fields. From January 1952 to September 1956, for example, the withdrawal rate at Allied Mills, Inc. was increased to 800, 000 gpd, twice the original pumping rate. Water levels in the area declined 24 feet as a result of this increase in pumpage. Pumpage was reduced in 1956 and as a result the water table recovered 7 feet from 1956 to May 1959. The hydrograph of well 23. 6b6 at Hopper Paper Company indicates that the 632,000 gpd reduction in pumpage from the Hopper well field on April 1, 1958 caused the water table to rise 8 feet in less than a year.

Changes in Ground-Water Storage

As water levels decline the saturated thickness of the aquifer decreases and ground-water storage is reduced. The volumetric decrease in ground-water storage is the product of the volumetric decrease in saturated thickness and the gravity yield of the aquifer. The gravity yield was defined by Rasmussen and Andreasen (1959, p. 83) as the ratio of the volume of water that the aquifer will yield by gravity drainage to the total volume of the aquifer drained during a given period of ground-water decline. Pumping test data suggest that the long-term gravity yield of the aquifer at Taylorville is about 20 per cent, or 0. 20.

Profiles of the water table in 1888, 1951, and 1958 were prepared based on the topographic maps of the area and on water-level data for wells in the old city, Allied Mills, Inc., Hopper Paper Company, new city, and village of Stonington well fields. These profiles and cross sections showing the areal extent of the aquifer were used to estimate changes in saturated thickness. The decreases in ground-water storage from 1888 to 1958 and from 1951 to 1958 were computed by multiplying estimated changes in saturated thickness by a gravity yield of 0. 20. It is estimated that 7. 7 billion gallons of water were taken from storage within the aquifer during the period 1888 to 1958. The average volumetric rate of decrease of ground-water storage during that period was about 300, 000 gpd. Computations show that about 2. 7 billion gallons of water were taken from storage at an average rate of 1,100,000 gpd during the period 1951 to 1958.

The ground water in storage in the aquifer permits pumping at rates greater than recharge for limited periods. Eventually, however, discharge from wells must be balanced by recharge if pumping is to be continued without eventually dewatering the aquifer below tops of screens in production wells.

Recharge to Aquifer

The source of recharge to the aquifer is precipitation. Ground-water recharge is greatest in spring months of heavy rainfall and least in the summer, fall, and winter months. Most recharge occurs during spring months when evapotranspiration is small and soil moisture is maintained at or above field capacity by frequent rains. During summer and fall months evapotranspiration and soil moisture requirements have first priority on precipitation and are so great that little precipitation percolates to the water table except during periods of excessive rainfall. Recharge during the winter months when the ground is frozen is negligible.

Only a small fraction of the annual precipitation percolates downward to the water table. A large proportion of the precipitation runs overland to streams or is discharged by the process of evapotranspiration before it reaches the aquifer. The amount of precipitation that reaches the zone of saturation depends upon several factors. Among these are the character of the soil and other materials above the water table; the topography; vegetal cover; land use; soil moisture; the depth of the water table; the intensity, duration, and seasonal distribution of rainfall; the occurrence of precipitation as rain or snow; and the air temperature.

The balance between total ground-water withdrawals and the amount of water taken from storage within the aquifer is recharge. During the period 1951 to 1958, total pumpage at Taylorville averaged 2,500,000 gpd and water was taken from storage at an average rate of 1, 100,000 gpd. Thus, recharge from precipitation averaged 1, 400,000 gpd.

The recharge area of the aquifer was inferred from data on the water table, extent of the aquifer, and the topography of the area. In 1954 the water table was at elevations of 581 feet at the old city well field, 565 feet at the Hopper Paper Company well field, 576 feet at the Allied Mills, Inc. well field, 598 feet at the new city well field, and 576 feet at the village of Stonington well field which is located about 6 miles northeast of Taylorville. The average elevation of the flood plain of South Fork Sangamon River southwest of Taylorville is 565 feet. These data indicate that in 1954 ground-water divides existed about 5-1/4 miles northeast and 2-1/4 miles southwest of the Hopper Paper Company well field.

The aquifer and permeable surficial deposits extend as a strip about 3/4-mile wide in a general southwest to northeast direction as shown in figure 4. The major recharge area of the aquifer is bounded approximately by the ground-water divides and the boundaries of the aquifer. It is estimated that the recharge area is about 6. 3 square miles.

Based on a recharge rate of 1,400,000 gpd and a recharge area of 6. 3 square miles, an average of about 6 inches of precipitation reaches the water table annually. This is about 17 per cent of the mean annual precipitation. Houk (1921), Meinzer and Stearns (1929), and Rasmussen and Andreasen (1959) evaluated recharge from precipitation on areas in Ohio, Connecticut, and Maryland. In light of the results of these studies, taking into consideration differences in ground-water conditions, the computed annual rate of recharge at Taylorville seems reasonable.

The hydrograph of well 18. 6d in figure 9 illustrates the effects of recharge from precipitation. Considering the downward trend prior to April, the water level in well 18. 6d rose 3 feet from March to December, 1957. Part of the rise was caused by a 550,000 gpd decrease in pumpage at Allied Mills, Inc. However, prior to the first week in June, when pumpage at Allied Mills, Inc. was reduced, the water table rose 0.8 foot in response to recharge from precipitation.

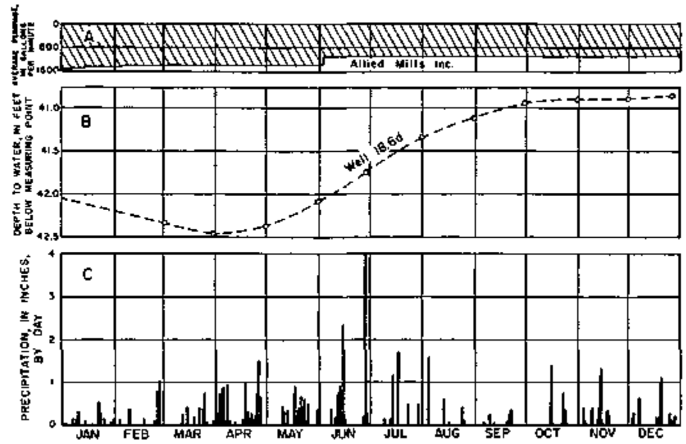


Figure 9. Ground-water pumpage (A), water levels in well 18.6d (B), and precipitation (C) during 1957 at Taylorville

Hydraulic Properties of Aquifer

The principal hydraulic properties of an aquifer influencing water-level decline and the yields of wells are the coefficients of transmissibility, T, or permeability, P, and storage, S. The capacity of a formation to transmit ground water is expressed by the coefficient of transmissibility, which is defined as the rate of flow of water in gallons per day, through a vertical strip of the aquifer 1 foot wide and extending the full saturated thickness under a hydraulic gradient of 100 per cent (1 foot per foot) at the prevailing temperature of the water. The coefficient of transmissibility is the product of the saturated thickness of the aquifer, m, and the coefficient of permeability, which is defined as the rate of flow of water in gallons per day, through a cross sectional area of 1 square foot of the aquifer under a hydraulic gradient of 100 per cent at the prevailing temperature of the water. The storage properties of an aquifer are expressed by the coefficient of storage, which is defined as the volume of water released from storage per unit surface area of the aquifer per unit change in the water level. Under water-table conditions, ground water is derived from storage mainly by the gravity drainage of a portion of the aquifer.

Cone of Depression

The manner in which T and S are related to water-level decline and the yields of wells can best be illustrated by a discussion of the cone of depression. When a well is pumped, water levels decline and a funnel-shaped hole called a cone of depression is formed with the lowest point at the pumped well. Water moves from surrounding areas down the gradient of the cone toward the pumped well. The shape of the cone is controlled in part by the coefficient of transmissibility. With other factors remaining constant, the lower the coefficient of transmissibility, the steeper will be the gradient of the cone of depression and the greater will be the drawdown in a well.

During the initial period of pumping, discharge is balanced by water taken from storage within the aquifer close to the well. As pumping continues a larger percentage of water is taken from storage at greater distances from the well as the area of influence of pumping becomes greater and the rate of lowering of water levels decreases. The greater the coefficient of storage, the less water-level decline is required to obtain from storage the amount of water being pumped.

With continuous pumping the cone of depression grows in size and depth at a diminishing rate until (1) the lowering of water levels results in increased recharge to, and/or decreased natural discharge from, the aquifer and (2) hydraulic gradients are established sufficient to bring from recharge or natural discharge areas the amounts of water pumped. Provided the aquifer is infinite in areal extent, the dimensions of the cone of depression depend upon the hydraulic properties of an aquifer, the pumping rate, and the time after pumping started. Water-level decline is directly proportional to the pumping rate and diminishes in a logarithmic manner outward from the well.

Under natural conditions, precipitation reaching the water table percolates towards streams to become ground-water runoff or is discharged into the atmosphere by the process of evapotranspiration. The cone of depression intercepts part of the water which otherwise would become ground-water runoff or ground-water evapotranspiration and diverts it into wells.

Thus far the cone of depression created by pumping a single well has been considered. In a multiple-well system the cones of individual wells overlap and water levels lower more rapidly and to greater depths as the result of mutual interference between wells. The amount of interference is directly proportional to pumping rates and inversely proportional to the logarithm of the distances between wells. Under a given spacing of wells and pumping regimen, a quantitative evaluation of interference is largely dependent on the determination of the hydraulic properties of the aquifer.

Pumping Tests

The hydraulic properties of an aquifer may be determined by means of pumping tests, wherein the effect of pumping a well at a known constant rate is measured in the pumped well and at observation wells penetrating the aquifer. Graphs of drawdown versus time after pumping started, and/or of drawdown versus distance from the pumped well, are used to solve equations which express the relation between the coefficients of transmissibility and storage of an aquifer and the lowering of water levels in the vicinity of a pumped well.

During the period 1930 to 1951, seven pumping tests were made at Taylorville to determine the hydraulic properties of the outwash deposits. Some of the data collected during the pumping tests were analyzed by methods described by Cooper and Jacob (1946) and Ferris (1959). The equations and methods used to analyze data for two pumping tests are given in figure 10.

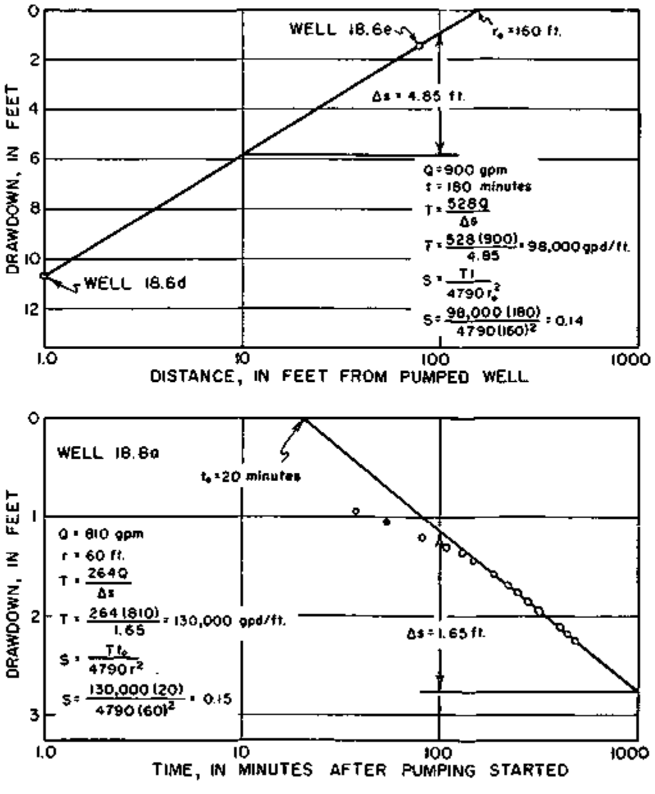


Figure 10. Graphs of results obtained from pumping toots at Taylorville

Estimates of the coefficient of transmissibility were also made by substituting in the nonequilibrium formula (Theis, 1935, pp. 519-524) specific-capacity data, a water-table coefficient of storage, and well-construction data. Specific capacity is expressed as the yield of the well in gallons per minute per foot of drawdown (gpm/ft) for a given pumping rate and period. Specific-capacity data were adjusted for the effects of partial penetration (see Muskat, 1946, p. 274) and well loss (see Jacob, 1946, pp. 629-646) before they were used to estimate the coefficient of transmissibility.

A summary of the coefficients of transmissibility and storage obtained from the pumping tests is given in table 5. These data indicate that the coefficient of transmissibility ranges from 34,000 to 130,000 gallons per day per foot (gpd/ft)and the coefficient of permeability ranges from 600 to 2200 gallons per day per square foot (gpd/sq ft). The smaller values of transmissibility and permeability reflect thinner or less permeable deposits near valley walls, whereas the larger values reflect much thicker or more permeable deposits near the center of the valley. Based on the results of the tests and the method of proportional parts, the average coefficient of transmissibility of the outwash deposits is estimated to be 70,000 gpd/ft.

The coefficients of storage in table 5 are characteristic of water-table conditions and average 0.15. The coefficients of storage were computed from the results of relatively short-term tests. Gravity drainage was not complete at the end of the tests and longer pumping tests would give larger coefficients of storage. Therefore, for periods of pumping involving several years or more, a coefficient of storage of 0.20 is more realistic than the determined value of 0.15 and is used in this report.

Theoretical Effects of Pumping

Pumping from wells in the outwash deposits has a widespread effect on water levels. The nonequilibrium formula and the hydraulic properties determined from the results of pumping tests were used to evaluate the magnitude of interference between wells and well fields and to compute the theoretical decline in the water table at any distance from a pumped well and within any length of time after pumping started.

Figure 11A shows the amount of interference that will occur at distances of 100 feet to about 19 miles from a well pumping continuously at 347 gpm for periods of 30 days, 1 year, 30 years, and 80 years. The drawdowns given occur at equal distances from the pumped well in all directions. The graphs assume that all the water pumped is withdrawn from storage and that the aquifer is infinite in areal extent.

The drawdown is appreciable several miles from the pumped well indicating that even widely spaced wells in the outwash deposits will interfere with one another. For example, the drawdown at a distance of 1/2 mile is about 1-1/2 feet for a pumping period of 1 year. The theoretical drawdown is directly proportional to the pumping rate. If the pumping rate is 694 gpm instead of 347 gpm the drawdown would be double that shown in figure 11A.

Table 5. Coefficients of Transmissibility, Permeability, and Storage for Aquifer at Taylorville

Well Number	Date of test	Length of test (hours)	Pumping rate (gpm)	Method of Analysis	Adjusted specific capacity (gpm/ft)	Coefficient of transmissibility (gpd/ft)	Saturated thickness (feet)	Coefficient of permeability (gpd/sq ft)	Coefficient of storage
CHR 13N2W-									
24.4f	2/18/30	5	189	Specific capacity	58	100,000	90	1,100	
23.2f2	8/24/44	21.5	265	Distance-drawdown	--	34,000	57	600	0.16
23.2f2	8/24/44	0.2	265	Specific capacity	25	40,000	57	700	
27.2h4	1/29/48	0.5	383	Specific capacity	25	40,000	60	670	
23.8a1	3/12/48	0.5	290	Specific capacity	46	80,000	65	1,200	
24.4g	1/26/51	0.2	1,000	Specific capacity	67	110,000	90	1,200	
CHR 13N1W-									
18.8a	1/12/51	0.7	820	Specific capacity	39	66,000	60	1,100	
18.8a	1/12/51	7.5	851	Distance-drawdown	--	98,000	60	1,600	0.14
18.8a	1/12/51	7.5	810	Time-drawdown	--	130,000	60	2,200	0.15
18.6d	7/14/51	3	900	Specific capacity	77	130,000	80	1,600	
18.6d	7/14/51	3	900	Distance-drawdown	58	98,000	80	1,200	0.14

Figure 11B shows the amount of interference that will occur at any time from 36 days to 100 years at distances of 0. 1, 0.5, 1, and 5 miles from a well being pumped continuously at 347 gpm. Again an aquifer infinite in areal extent is assumed.

Geohydrologic Boundaries of Aquifer

The graphs in figures 11A and 11B were constructed assuming an aquifer of infinite extent. However, geologic conditions limit the extent of the outwash deposits. As shown in figure 4 the outwash deposits are bounded on the southeast and northwest by relatively impervious deposits of till which delimit the aquifer and act as barrier boundaries. The barrier boundaries distort cones of depression and increase drawdown in wells. By treating the boundaries as straight-line demarcations, the image-well theory described by Ferris (1959) can be used to evaluate the influence of the barrier boundaries on the regional effects of pumping.

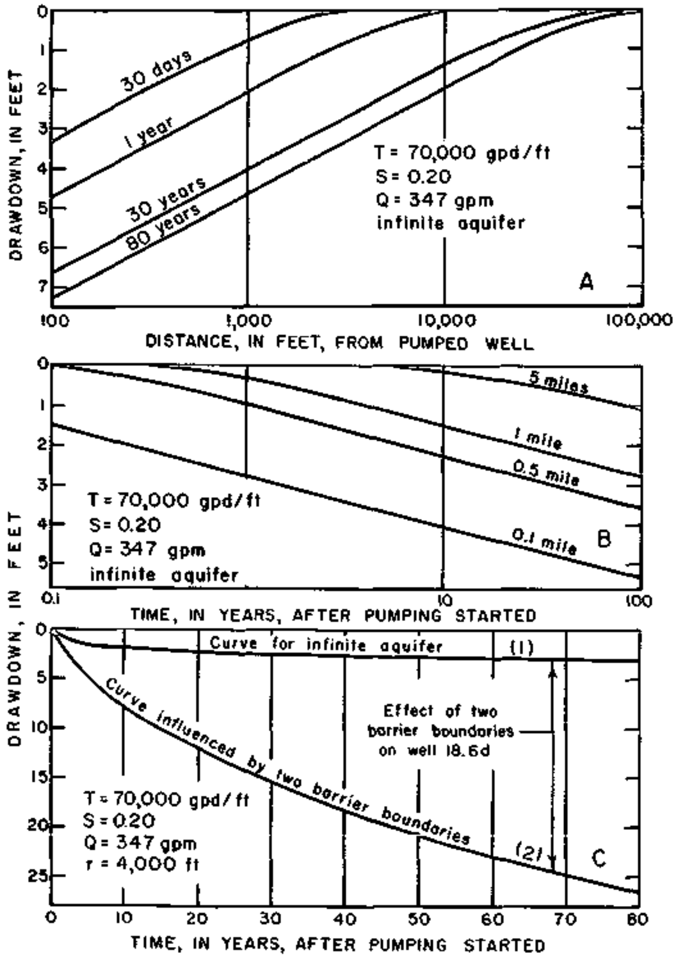


Figure 11. Graphs of theoretical distance-drawdown (A), time-drawdown (B), and time-drawdown considering boundaries (C) for the aquifer at Taylorville

The image-well theory as applied to barrier boundaries may be stated as follows (Walton, 1955, p. 18): the effect of a barrier boundary on the drawdown in a well as a result of pumping from another well, is the same as though the aquifer were infinite and a like discharging well were located across the real boundary, on a line at right angles thereto, and at the same distance from the boundary as the real pumping well. Thus, an imaginary hydraulic system of a well and its image counterpart in an infinite aquifer satisfies the actual barrier boundary conditions.

The two barrier boundaries are for practical purposes parallel. The arrangement of the boundaries is such that analysis by the image-well theory requires the use of a multiple image-well system extending to infinity (see Knowles, 1955).

Figure 11C shows the effects of the barrier boundaries on the drawdown in well 18. 6d. Distances from a pumped well to well 18. 6d of 4000 feet, to the barrier boundary of Z500 feet northwest of well 18. 6d, and to the barrier boundary of 2000 feet southeast of well 18. 6d were assumed in constructing the graph.

As explained earlier, water occurs under water-table conditions in the outwash deposits and part of the precipitation on the area of influence of pumping percolates to the water table and recharges the aquifer. Recharge distorts the cone of depression and reduces the drawdown in well 18. 6d. The effects of recharge can be simulated by assuming that some of the drawdown due to the barrier boundaries is balanced by recharge and by using only a limited number of discharging image wells associated with the barrier boundaries.

Model Aquifer

The results of geologic and hydrologic studies indicate that it is possible to simulate complex aquifer conditions at Taylorville with an idealized model aquifer. The model aquifer is a rectilinear strip of sand and gravel 3/4 mile wide, 50 feet thick, and bounded on the sides and bottom by impermeable material. Based on pumping test data the average coefficients of transmissibility and storage of the model aquifer are 70, 000 gpd/ft and 0. 20, respectively. The orientation of the model aquifer in relation to Taylorville and the location of major pumping centers within it are shown in figure 12. The geohydrologic boundaries of the model aquifer can be given mathematical expression by means of the image-well theory and the hydraulic properties of the model aquifer are considered mathematically by using the nonequilibrium formula (Walton and Neill, 1961).

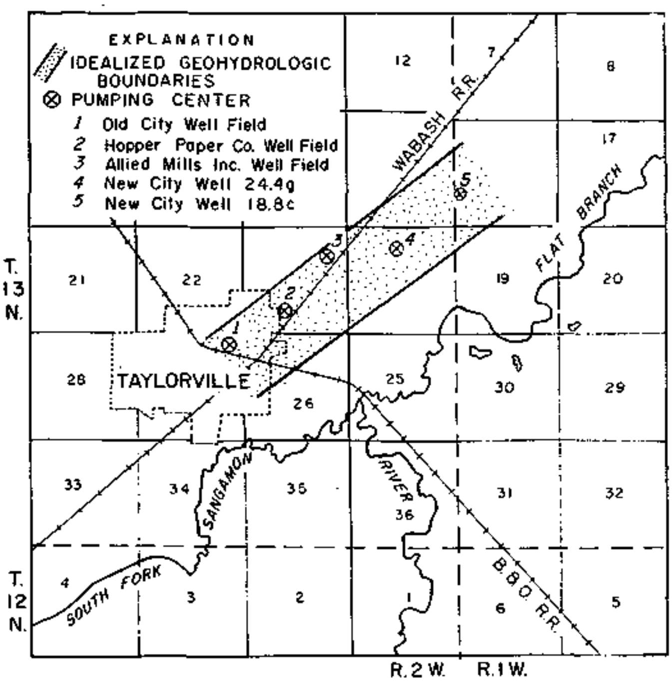


Figure 12. Location of major pumping centers and idealized geohydrologic boundaries of the aquifer at Taylorville

Records of past pumpage and water levels were used to determine the effects of recharge on the response of the aquifer to development by wells. The water-level decline at well 18. 6d from 1888 to 1956 was computed using the model aquifer discussed earlier, calculated hydraulic properties, the image-well theory, the nonequilibrium formula, and estimated pumpage data. The computed decline was then compared with the actual decline and the difference between computed and actual decline was attributed to the effects of recharge.

Ground-water withdrawals were grouped into five centers of pumping. Figure 12 shows the location of these centers. Pumpage from 1888 to 1956 was distributed among the five centers and further divided into step increments. The five centers of pumping and the barrier boundaries were drawn to scale on a map and the image wells associated with the barrier boundaries were located. The distances between well 18. 6d, the five pumping centers, and the image wells were scaled from the map.

The water-level decline at well 18.6d resulting from each increment of pumpage at each of the five pumping centers was determined, using the nonequilibrium formula and a digital computer (see Walton and Neill, 1961) to compute the effects of the real and image wells. In all, 357 drawdown computations were made.

The computed total water-level decline at well 18.6d from 1888 to 1956 is 43 feet. The actual decline from an estimated original nonpumping water-level elevation of 617 feet is 24 feet and much less than the computed decline. The difference between computed and actual decline, 19 feet, is attributed to the effects of recharge from precipitation. In order to obtain a computed decline comparable to the actual observed decline, all image wells beyond a radius of 20,000 feet from well 18. 6d were eliminated and a new series of drawdown computations was made using procedures described earlier. A computed decline equal to the observed decline of 24 feet was obtained. Thus, the effects of two barrier boundaries and recharge from precipitation on the response of the outwash deposits to development of wells can be simulated by computing the effects of image wells associated with the model aquifer discussed earlier and located within a radius of 20, 000 feet of well 18. 6d.

To test the modified model aquifer, the drawdown in well 18. 6d from 1888 to 1953 was computed and compared with the actual drawdown. The computed decline, 17.2 feet, is within 3 per cent of the actual decline, 16. 6 feet. The close agreement between computed and actual decline indicates that the modified model aquifer closely describes the geohydrologic conditions of the outwash deposits. It is believed that the modified model aquifer may be used to predict with reasonable accuracy the effects of future ground-water development and the practical sustained yield of the aquifer.

Potential Ground-Water Development and Its Effects

Pumpage between the present time and any future date must be estimated before future decline in water levels in wells at Taylorville can be calculated. It is understood that future ground-water withdrawals at Hopper Paper Company plant and Allied Mills, Inc. plant will not exceed present withdrawal rates. In May 1959 pumpage at Hopper Paper Company plant averaged 100 gpm and pumpage at Allied Mills, Inc. plant averaged 90 gpm. Taking into consideration past rates of growth of pumpage it is estimated that municipal pumpage will increase at a uniform rate from 1040 gpm in May 1959 to 1110 gpm in 1970. The total daily withdrawal from the outwash deposits will probably increase from 1230 gpm in May 1959 to 1300 gpm in 1970 as shown in figure 7. Estimated future withdrawal rates for the three major pumping centers between 1959 and 1970 are shown in figure 6.

Water-level declines in wells 24.4g, 18.8c, 23. 6b9, and 23. 2f4 were calculated using the modified model aquifer. Computed declines from 1959 to 1965, which are shown graphically in figure 13, are based on the assumption that the distribution of pumping remains the same as in May 1959 and that pumpage increases at rates given in figure 6. It should be emphasized that the water-level declines shown in figure 13 are nonpumping declines. Pumping levels will decline at about the same rate as the nonpumping water levels if the May 1959 rates of pumping from individual wells are maintained.

It is probable that in 1961 the pumping level in well 23. 2f4 will be below the top of the screen and the pumping level in well 18. 8c will be only 2 feet above the top of the screen. It is further estimated that by 1963 the pumping level in well 18.8c will decline below the top of the screen and by 1965 the pumping levels in wells 18.8c, 23.6b9, and 23. 2f4 will decline to critical stages several feet below tops of screens.

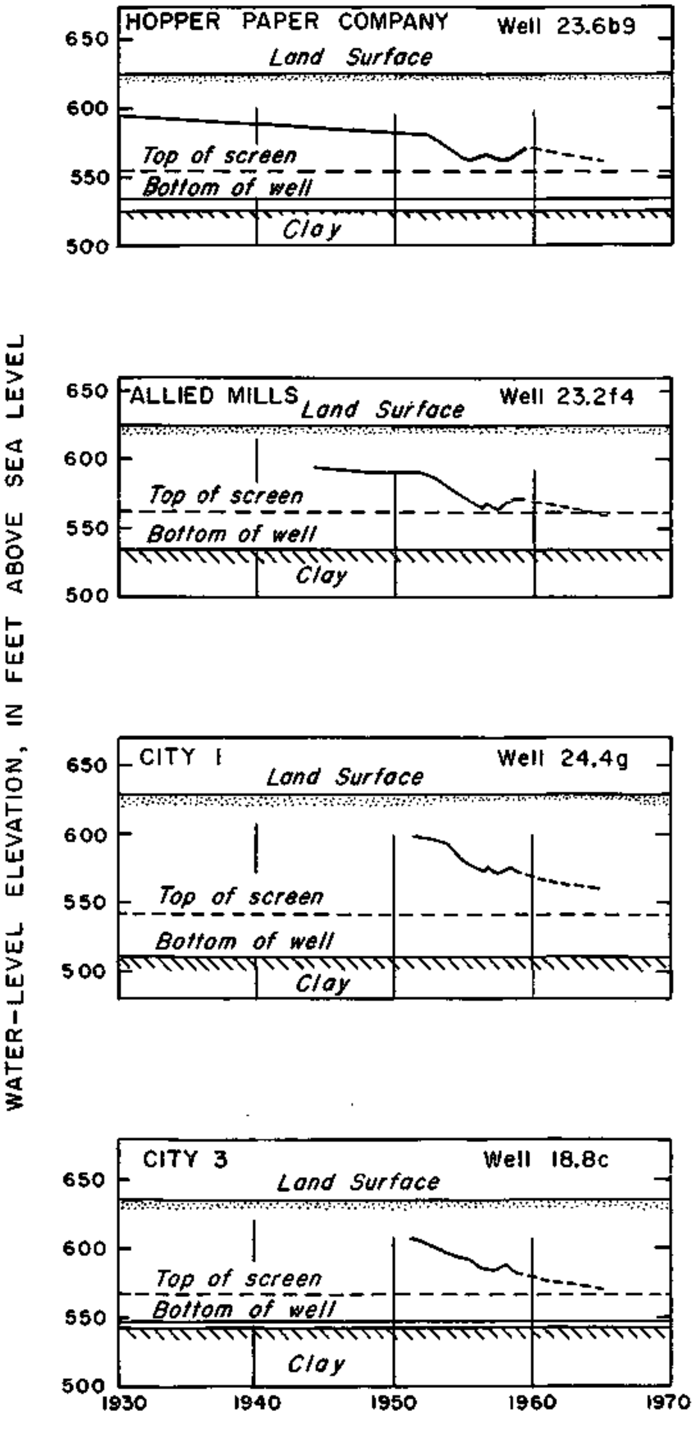


Figure 13. Estimated future nonpumping water levels in wells at Taylorville, 1959-1965

Practical Sustained Yield of Aquifer

The practical sustained yield of the aquifer at Taylorville is largely dependent on the rate of recharge, the hydraulic properties of the aquifer, the geohydrologic boundaries of the aquifer, the thickness of the aquifer, and the spacing of wells and well fields. It has been estimated that the area of influence of pumping with production wells distributed within a 3-mile radius of Taylorville is about 6. 3 square miles and that 17 per cent of the mean annual precipitation percolates to the water table. Total recharge is therefore about 1,400,000 gpd or 970 gpm. However, computations made with the modified model aquifer using the present pumping distribution indicate that if pumpage exceeds 745 gpm water levels will eventually decline below tops of screens. Thus, the practical sustained yield, 745 gpm, of the aquifer at Taylorville with the present distribution of pumpage is less than available recharge, 970 gpm, largely because of the following reasons:

(1) The average coefficient of permeability of the outwash deposits, 1400 gpd/sq ft, is not great and the aquifer is limited in areal extent by the walls of the buried valley.

(2) The available drawdown is small because the saturated thickness of the aquifer was greatly reduced as the result of heavy pumping in excess of recharge during the period 1951-1958.

(3) Most existing production wells are located in the thinner and less permeable parts of the aquifer.

(4) The distribution of pumpage is not uniform.

Computations made with the modified model aquifer show that 970 gpm (1,400,000 gpd) can be obtained without excessive drawdown from four wells screened in the thicker and more permeable section of the aquifer. In these computations it was assumed that pumpage was uniformly distributed to well 24.4g and to three hypothetical wells approximately located opposite Allied Mills, Inc. and Hopper Paper Company, and near well 18. 8c in the new city well field.

ARCOLA

The city of Arcola municipal water supply is obtained from wells in a narrow and thin deposit of sand and gravel approximately 400 feet wide and 20 feet thick that trends northeast to southwest through the city. The aquifer is encountered 100 to 125 feet below the land surface and is recharged by the vertical leakage of water through 70 feet of overlying clayey materials. Much test drilling has been done in the vicinity of Arcola to define the limits of the aquifer, and a total of 8 production wells have been drilled for the city since 1915 to satisfy ever increasing water demands. Only 3 of these wells are presently being used; the others were abandoned as well yields declined.

Between 1891 and 1959 the average daily pumpage from the aquifer increased from about 18, 000 to 146,000 gallons. Continual increases in pumpage caused a general water-level decline and in 1955 water levels receded to near critical stages. As a result a new well field was developed northeast of town.

Geography

Location and Extent of Study Area

Areola is located in the southern part of Douglas County in east-central Illinois, 23 miles south of Champaign and 45 miles east-southeast of Decatur as shown in figure 1. U. S. Highway 45 and State Highway 133 pass through the city as do the Pennsylvania and the Illinois Central railroads.

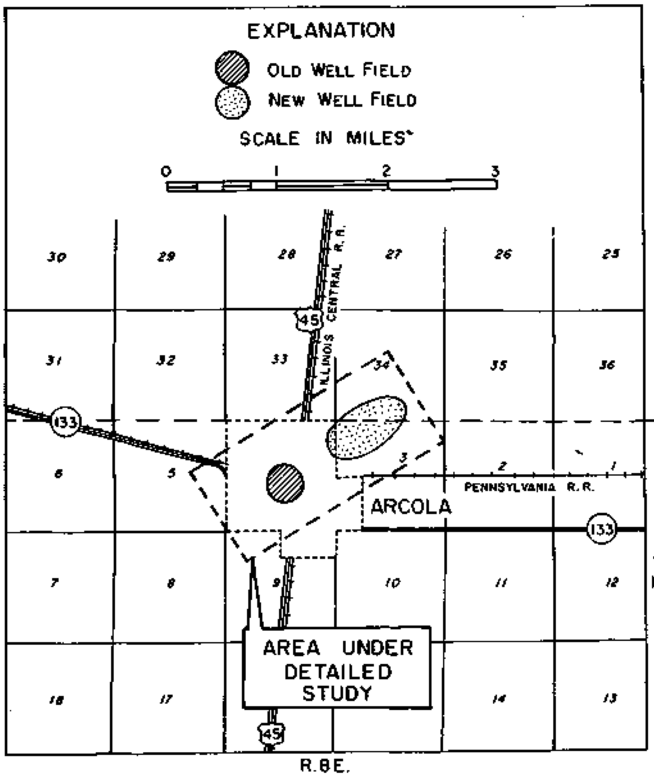


Figure 14. Map showing location of study area and pumping centers at Areola

Detailed study was confined to a rectangular area, hereafter referred to as "the area, " of about 2 square miles in and northeast of Areola in T. 14 N., T. 15 N., R. 8 E. as shown in figure 14. The area is between 88°15' and 88°20' west longitude and between 39°40' and 39°45' north latitude.

Topography and Drainage

The land surface of the area is a gentle sloping plain and has elevations of about 675 feet within the corporate limits of Areola and 640 feet about 4 miles southwest and northeast of the city. Drainage is to the southwest and northeast to short tributaries of the Kaskaskia and Embarrass rivers which flow in courses about 5 miles west and east of the area.

Climate

Graphs of annual (1893-1959) and mean monthly precipitation in figure 15 were compiled from precipitation data collected by the U. S. Weather Bureau at Tuscola, 8 miles north of Areola. According to these records, the mean annual precipitation at Tuscola is 37. 73 inches.

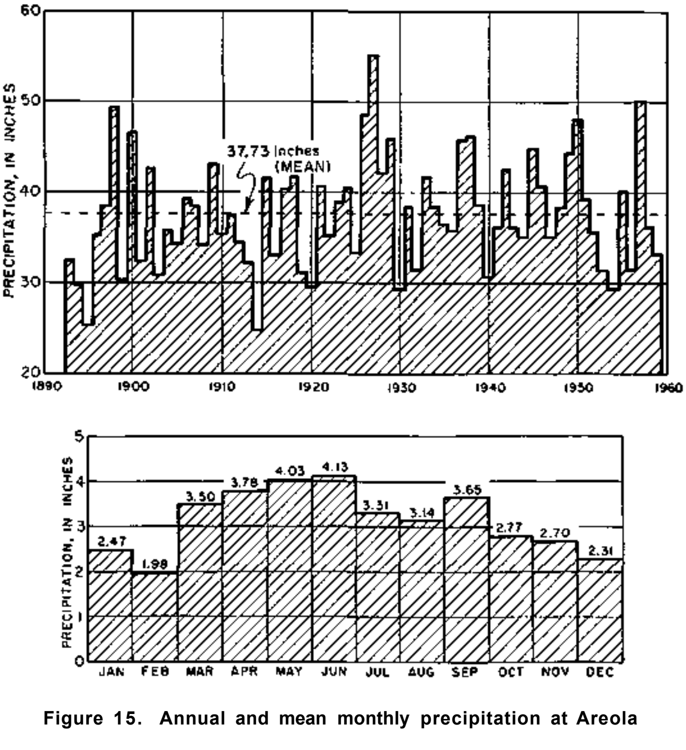


Figure 15. Annual and mean monthly precipitation at Areola

The months of greatest precipitation are March, April, May, June, and September, each having more than 3.5 inches; February is the month of least precipitation having less than 2 inches.

The Arcola area had a cumulative deficiency in precipitation of about 14 inches from 1952 to 1956. Recharge from precipitation was below normal during these dry years and the water table declined to record low levels. However, the available water in storage in the clayey materials above the aquifer and the small amount of recharge from precipitation were great enough to prevent the drought from noticeably affecting the yield of wells at Arcola.

The occurrence of the annual maximum and minimum precipitation amounts expected on an average of once in 5 and once in 50 years, based on data in the Atlas of Illinois Resources, Section 1, is given in the next column.

	Lowest annual precipitation expected (inches)	Highest annual precipitation expected (inches)
Once in 5 years	33	45
Once in 50 years	27	56

The mean annual snowfall is 17 inches. On the average about 25 days a year have 1 inch or more of ground snow cover; about 12 days a year have 3 inches or more of ground snow cover.

According to the Atlas of Illinois Resources, Section 1, the mean January temperature at Areola is 31 F and the mean July temperature is 77 F. The mean length of the growing season is about 176 days.

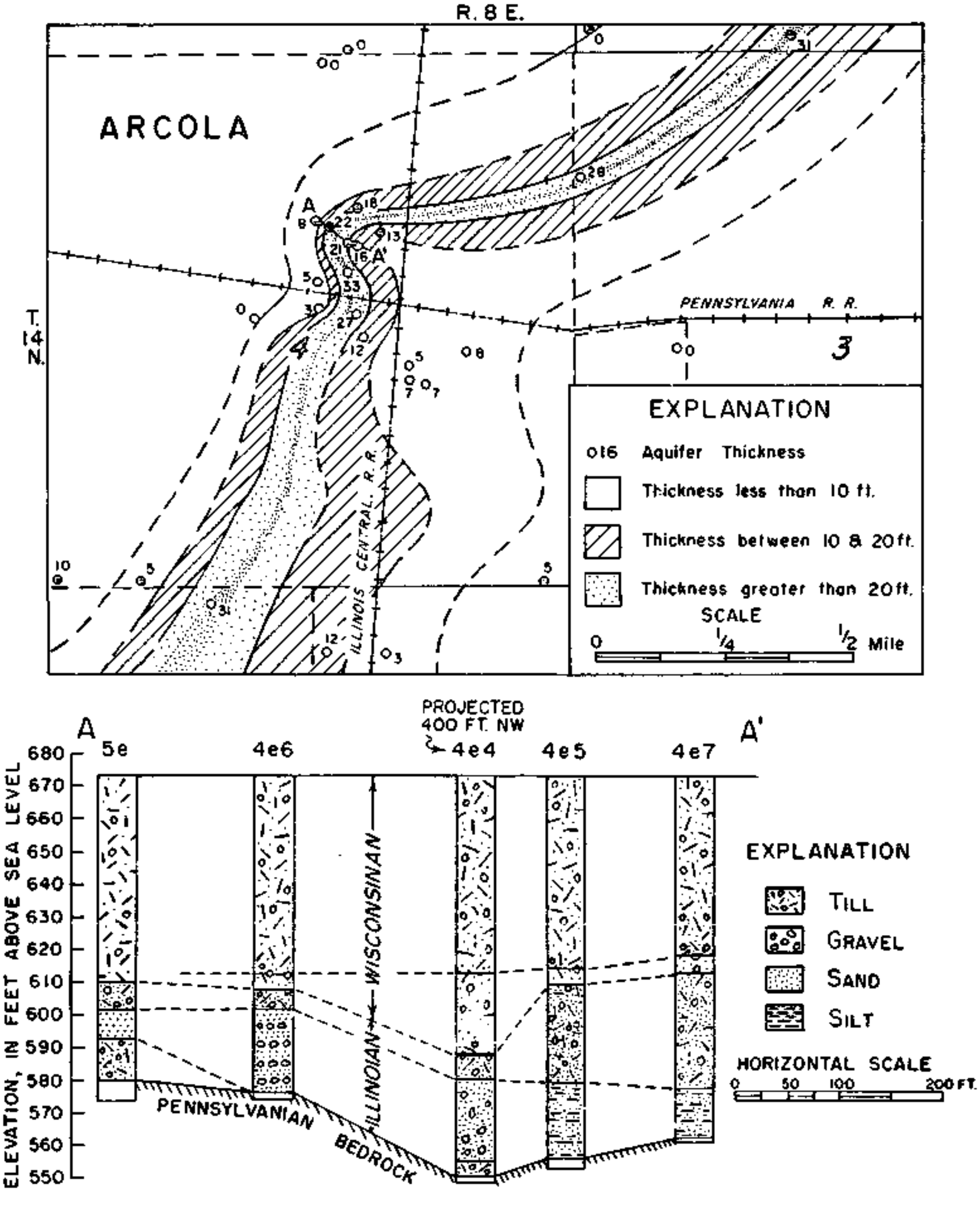


Figure 16. Map and geologic cross section showing thickness and areal extent of aquifer at Areola

Geology

The unconsolidated glacial deposits in the Arcola area are mainly Wisconsinan and Illinoian in age and range in thickness from 80 to 125 feet. As shown in figure 16 these deposits consist primarily of ice-laid till with some permeable water-laid silt, and sand and gravel outwash. The thicker sections of glacial material are contained in a narrow bedrock valley cut into Pennsylvanian bedrock, which consists mainly of shale. The outwash materials are generally found in the lower part of the drift between depths of 80 and 125 feet below land surface. The thicker and more permeable sections of the outwash deposits, hereafter referred to as "the aquifer, " are Illinoian in age.

The thick upper unit of the Wisconsinan glacial till which occurs from the surface to an average depth of 60 feet contains a high percentage of silt and clay. The lower Wisconsinan unit and the Illinoian deposits immediately overlying the aquifer contain sand lenses within sandy till. The aquifer contains a large amount of fine sand and silt and its permeability is not great.

The aquifer can be traced by logs of water wells and test holes from the south center of section 4 through the northwest part of section 3, T. 14 N., R. 8 E., and into the south center of section 34, T. 15 N., R. 8 E. Available geologic data suggest that the aquifer thins and is finer-grained to the southwest. However, additional subsurface information is needed to determine the lateral extent and thickness of the aquifer outside the study area.

The geologic cross section and the aquifer thickness map shown in figure 16 were drawn from available driller's logs of wells and test holes. The map shows a relatively thin and narrow strip of permeable material exceeding 20 feet in thickness trending from northeast to southwest through the study area. The more permeable part of the aquifer suitable for development by wells ranges in width from about 800 to less than 200 feet. This section of the permeable deposits is contained between the 20-foot thickness lines in figure 16.

The location of wells and test holes for which geologic and hydrologic data are available is shown in figure 17. Logs of wells and test holes are given in table 6; records of wells are summarized in table 7.

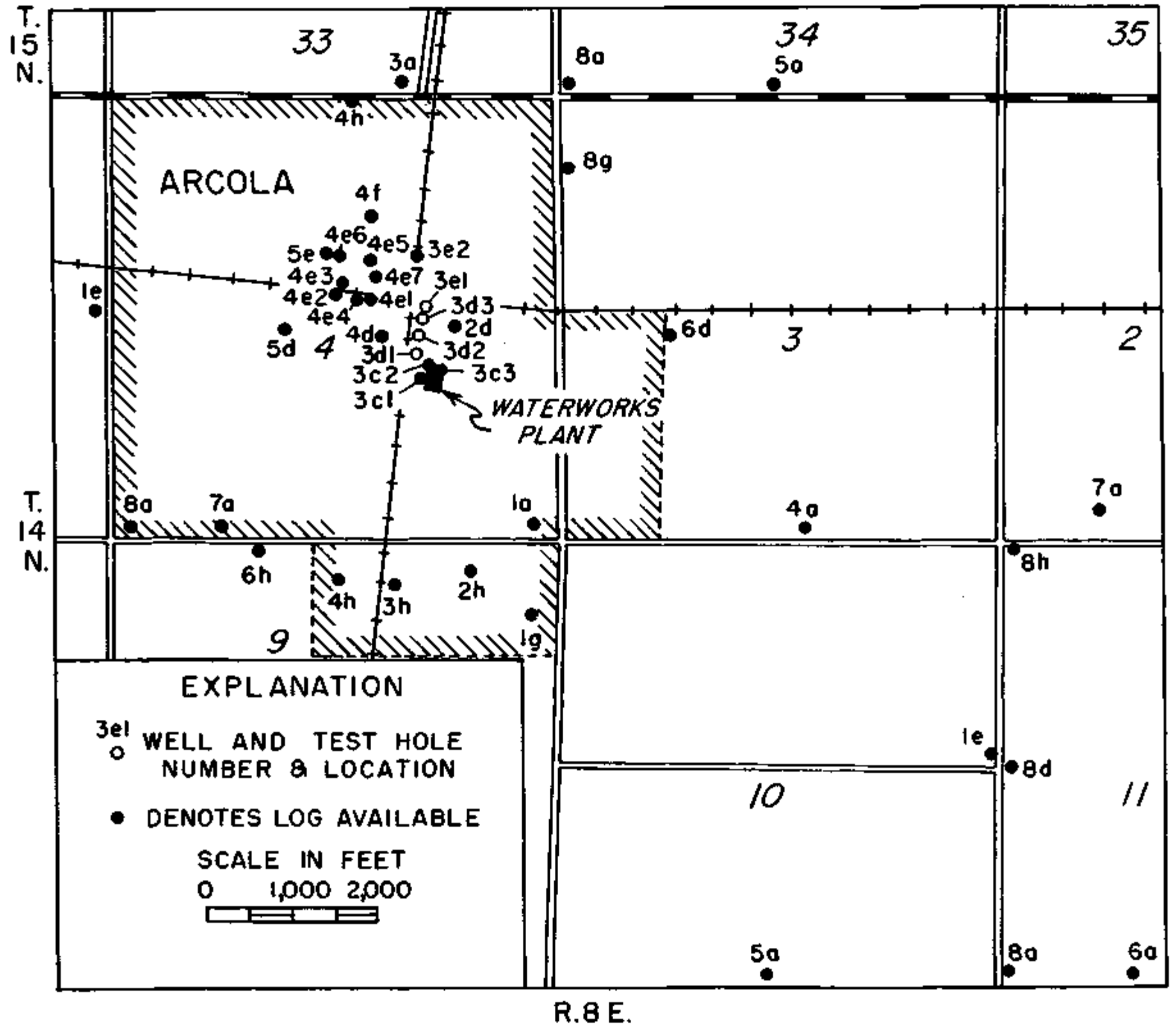


Figure 17. Map showing location of wells and test holes at Arcola

Table 6. Logs of Wells and Test Holes at Arcola

Well Number	Type of Record°	Formation	Thickness (feet)	Depth (feet)
DGL 14N8E-				
4.3c1	Composite driller's log	Top soil, with some water-bearing sand	20	20
		clay, hard, blue	74	94
		sand, hard	1	95
		sand, fine, water	6	101
		clay, blue and rock	--	101
4.3c2	driller's log	soil and clay	25	25
		blue clay	35	60
		packed sand	5	65
		blue clay	30	95
		sand and water	7.8	102.8
		peat	2.8	104.8
4.3c3	driller's log	drift	119	119
		lime with sand breaks	182	301
9.2h	driller's log	soil and clay	10	10
		blue clay	65	75
		sand	5	80
		blue clay	2	82
		gravel, coarse	3	85
		yellow hardpan and packed gravel	14	99
		shale	1	100
4.4e1	driller's log	soil and clay	67	67
		sand and gravel	5	72
		hard blue clay	23	95
		sand	10	105
		sand and gravel	17	122
		shale	6	128
4.4e2	driller's log	soil and clay	65	65
		hardpan	30	95
		sand	3	98
		hardpan	3	101
		shale	4	105
4.4d	driller's log	soil	2.5	2.5
		clay, yellow	9.5	12
		clay, blue	54	66
		sand, mud	4	70
		clay, blue	6	76
		clay and peat	14	90
		sand and gravel	12	102
		clay, blue	3	105
		clay, peat	6	111
		clay, sandy	3	114
4.5d	S.S. 20018	soil, black	5	5
		till	35	40
		sand, silty	5	45
		till	50.5	95.5
		shale, gray	--	98
4.4e3	S.S. 20019	soil	1	1
		till	84	85
		sand and gravel, silty	5	90
		till	6.5	96.5
		shale, gray	--	96.5
4.5e	S.S. 20020	till	75	75
		sand, fine	8	83
		till	12	95
		shale, gray	--	95
4.4e4		top soil and clay	10	10
		clay, sandy	5	15
		clay, gray	68	83
		sand, dirty	2	85
		clay, sandy	8	93
		sand, fine, dirty	31	124
		sand, gravel, boulders, muddy and dirty	2	126
		shale, blue	--	127
4.4h		soil	1	1
		clay, yellow	9	10
		clay, blue	39	49
		hardpan, gray	6	55
		clay, brown	9	64
		hardpan, yellow	3	67
		hardpan, gray	20	87
		hardpan, brown	6	93
		hardpan, yellow	--	96.5
3.6d		soil	1	1
		clay, yellow, blue	60	61
		hardpan	5	66
		sand, fine	7	73
		sand and gravel	2	75
		hardpan, yellow	2	77
		sand, yellow	2	79
		hardpan, yellow	4	83
		dark shale	7	90
		lime	2	92
11.8h	driller's log	soil	1	1
		clay	47	48
		peat	1	49
		clay, sandy	9	58
		hardpan	18	76
		shale	--	80
3.4a	driller's log	soil	3	3
		clay	11	14
		clay, sandy	45	59
		sand and gravel pack	6	65
		gravel pack	7	72
		hardpan, yellow	14	86
		shale, red	--	90
9.3h	driller's log	soil	2	2
		clay, yellow, blue, green	78	80
		sand and gravel	3	83
		clay, sandy	13	96
		shale	--	103
9.4h	driller's log	soil	3	3
		clay	69	72
		sand, fine	9	81
		sand and gravel	3	84
		hardpan	10	94
		shale	3	97
4.8a	driller's log	soil	4	4
		clay	43	47
		hardpan	11	58
		clay, sandy	22	80
		gravel pack	4	84
		sand, mud	6	90
		shale	--	93

° S.S. refers to sample set No. of State Geological Survey

Table 6. Logs of Wells and Test Holes at Arcola (continued)

Well Number	Type of Record*	Formation	Thickness (feet)	Depth (feet)
DGL 14N8E-				
9.6h	driller's log	soil	1	1
		clay	52	53
		clay, sandy	32	85
		sand and gravel	9	94
		sand, mud	16	110
		sand and gravel	2	112
		gravel pack	4	116
		lime	--	117
11.8d	driller's log	soil	2	2
		clay	53	55
		hardpan	6	61
		sand, fine	11	72
		sand and gravel	1	73
		clay	4	77
		sand and gravel	3	80
		gravel pack	3.5	83.5
		shale	5	88
11.8a	driller's log	soil	1	1
		clay	58	59
		hardpan	21	80
		shale, red	--	83
11.6a	driller's log	soil	4	4
		clay	50	54
		hardpan	8	62
		sand, fine	13	75
		sand, coarse	1	76
		clay	1	77
		sand and gravel	9.5	86.5
		shale, light	--	87.5
4.4f	driller's log	soil	2	2
		clay	67	69
		clay, sandy	16	85
		sand and gravel, dirty	13	98
		gravel	3	101
		sand and gravel, dirty	2	103
		shale	1	104
		slate	2	106
		lime	--	107
4.4e5	driller's log	soil	2	2
		clay	56	58
		clay, sandy	41	99
		sand, mud	21	120
		shale, light	--	122
4.3e2	driller's log	soil	2	2
		clay	55	57
		hardpan	23	80
		clay, silty	19	99
		gravel, dirty	1	100
		sand, mud	12	112
		shale, lime	--	115
4.4e6	driller's log	soil	2	2
		clay, sandy	8	10
		clay	49	59
		hardpan	6	65
		sand and gravel, mud	2	67
		clay sand	9	76
		sand and gravel	6	82
		sand and gravel pack	16	98
		shale	--	100
4.4e7	driller's log	soil	2	2
		clay	52	54
		clay, sandy	6	60
		clay	38	98
		sand, mud	16	114
		shale, lime	--	115
33.3a	driller's log	soil	2	2
		clay	23	25
		sand, loose	3	28
		clay, sandy	17	45
		clay, sand and gravel laminated	5	50
		clay, gravelly	5	55
		sand and clay, cemented	44	99
		shale, black	--	101
4.7a	driller's log	soil	2	2
		clay	53	55
		clay, gravelly	3	58
		sand	2	60
		clay, gravelly	41	101
		sand dirty with clay streaks	5	106
		bedrock	--	107
9.1g	driller's log	soil	2	2
		clay	57	59
		clay, gravelly	17	76
		sand, fine, dirty	4	80
		clay, gravelly	16	96
		bedrock	--	96
10.5a	driller's log	clay	58	58
		sand streak	2	60
		clay, gravelly	29	89
		shale	--	91
10.1e	driller's log	soil	2	2
		clay	53	55
		clay, gravelly	29	84.5
		shale	--	88
3.8g	driller's log	soil	2	2
		clay	53	55
		clay, sand streak at 79.5'	35	90
		sand and gravel with streaks of fine sand	28	118
		bedrock	--	120
5.1e	driller's log	soil	2	2
		yellow clay	11	13
		blue clay	60	73
		green sandy clay	4	77
		blue sandy clay	21	98
		lime and shale	5.5	103.5
4.2d	driller's log	soil and yellow clay	15	15
		blue clay	45	60
		packed sand	5	65
		green hardpan	10	75
		brown clay	5	80
		packed sand and gravel	8	88
		green hardpan	10	98
		shale, dark lime	7	105

* S.S. refers to sample set No. of State Geological Survey

Table 6. Logs of Wells and Test Holes at Arcola (continued)

Well Number	Type of Record[°]	Formation	Thickness (feet)	Depth (feet)
DGL 15N8E-				
34.5a	driller's log	soil	2	2
		clay	8	10
		clay, gravelly	65	75
		sand, fine to medium, with some gravel	10	85
		sand, fine to medium, compact with some clay	15	100
		sand and gravel	6	106
		shale	--	106
34.8a	driller's log	soil	4	4
		brown clay	6	10
		yellow clay	8	18
		gray clay	35	53
		dark clay	6	59
		green clay	10	69
		soft gray sandy clay	6	75
		gray hardpan	10	85
4.1a	driller's log	soil and yellow clay	10	10
		blue clay	53	63
		yellow sand	2	65
		yellow hardpan	10	75
		mud, sand	5	80
		blue clay, sand and gravel	5	85
		yellow hardpan	3	88
2.7a	driller's log	yellow clay and soil	15	15
		blue clay	60	75
		sand, fine	5	80
		clay, blue	1	81
		sand, coarse (water)	6	87
		clay, gray	1	88

[°] S.S. refers to sample set No. of State Geological Survey

Table 7. Records of Wells and Test Holes at Arcola
(Elevations in feet above sea level, estimated from topographic maps)

Well Number	Owner	Driller	Date drilled	Elevation of land surface
DGL 14N8E-				
4.3c1	City	---	before 1913	675
4.3c2	City	E. C. Baker & Sons	1945	675
4.3c3	City	Meister Bros.	----	675
9.2h	City	E. C. Baker & Sons	1945	675
4.4e1	City	E. C. Baker & Sons	1945	675
4.4e2	City	E. C. Baker & Sons	1945	675
4.4d	City	E. C. Baker & Sons	1947	675
4.5d	City	Hayes & Sims	1/26/50	674
4.4e3	City	Hayes & Sims	1/28/50	675
4.5e	City	Hayes & Sims	1/28/50	676
4.4e4	City	Hayes & Sims	1/30/50	675
4.4h	City	E. C. Baker & Sons	1953	675
3.6d	City	E. C. Baker & Sons	1953	670
11.8h	City	E. C. Baker & Sons	1953	660
3.4a	City	E. C. Baker & Sons	1953	665
9.3h	City	E. C. Baker & Sons	1953	673
9.4h	City	E. C. Baker & Sons	1953	670
4.8a	City	E. C. Baker & Sons	1953	671
9.6h	City	E. C. Baker & Sons	1953	672
11.8d	City	E. C. Baker & Sons	1953	665
11.8a	City	E. C. Baker & Sons	1953	667
11.6a	City	E. C. Baker & Sons	1953	665
4.4f	City	E. C. Baker & Sons	1953	675
4.4e5	City	E. C. Baker & Sons	1953	675
4.3e2	City	E. C. Baker & Sons	1954	675
4.4e6	City	E. C. Baker & Sons	1954	675
4.4e7	City	E. C. Baker & Sons	1954	675
4.7a	City	C. M. Hayes	1954	671
9.1g	City	C. M. Hayes	1954	675
10.5a	City	C. M. Hayes	1954	675
10.1e	City	C. M. Hayes	1954	665
3.8g	City	C. M. Hayes	1954	668
5.1e	Blackwell	E. C. Baker & Sons	1948	675
4.2d	Iris	E. C. Baker & Sons	1945	672
DGL 15N8E-				
34.8a	Harry Keal	E. C. Baker & Sons	1941	668
4.1a	Land Garage	E. C. Baker & Sons	----	678
2.7a	S. T. Rugh	E. C. Baker & Sons	1946	659
33.3a	City	C. M. Hayes	1954	672
34.5a	City	C. M. Hayes	1954	659

Occurrence of Ground Water

The aquifer is overlain by deposits (confining bed) which impede or retard the vertical movement of ground water. Recharge is derived at an altitude higher than the base of the confining bed; the aquifer is completely saturated with the water exerting an upward pressure on the base of the confining bed; vertical leakage through the confining bed is possible; and water is said to occur under leaky artesian conditions.

The surface to which water will rise under leaky artesian conditions, as defined by water levels in a number of wells, is the piezometric surface. When the pressure head, and hence, the piezometric surface is lowered by the pumping of wells, the aquifer is not dewatered but is still completely **full.** The water discharged from the well is derived by the compaction of the aquifer and associated beds, by the expansion of the water itself, and by vertical leakage through the confining bed into the aquifer.

Ground-Water Withdrawals

When the first municipal well was installed in 1891 only 25 per cent of the total population of the city used water from this source. The remainder of the population obtained their water supply from dug or bored wells that tapped a thin permeable deposit of silt and fine sand 15 to 20 feet below land surface. Between 1891 and 1915 only about 20, 000 gallons per day were pumped from the city wells. As the water works facilities were improved by the installation of new wells and a water treatment plant the demand for city water increased and in 1959 nearly 90 per cent of the total population used water from city wells. Municipal pumpage averaged 146,000 gpd in 1959. Average daily ground-water withdrawals, 1891-1959, are shown in figure 18.

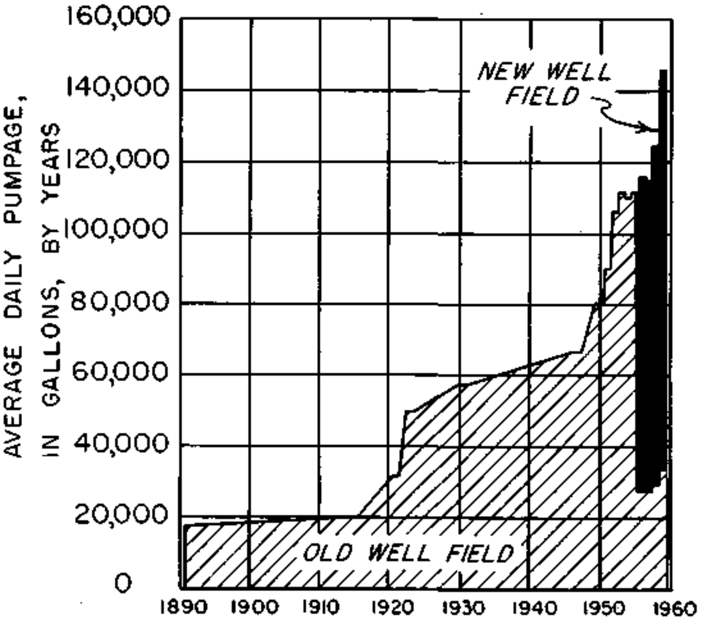


Figure 18. Ground-water pumpage, 1891-1959, at Arcola

Until June 1955 all of the water for the municipal water supply was pumped from wells in the old well field near the water works plant shown in figure 17. As water levels declined in this area, however, undeveloped portions of the aquifer away from the center of pumpage were explored by test drilling and in May 1955 two new wells, 3.8g and 34.5a, were constructed about 2500 and 5000 feet, respectively, northeast of the old well field. Since May 1955 approximately 75 per cent of the total ground-water withdrawal has been from the new wells. During December 1959 well 4.4e1 in the old well field was continuously pumped for one week and wells 34. 5a and 3. 8g were alternately pumped for the remainder of the month. This is the pumping schedule which the water superintendent intends using in the future.

Fluctuations of Water Levels and Their Significance

Water levels in wells in the old and new well fields declined as ground-water withdrawals increased. A large increase in pumpage starting in 1947 caused water levels in well 4. 4d in the old well field to decline over 30 feet within a period of only 8 years as shown in figure 19A. This decline was three times as much as had been observed during the preceding 25-year period.

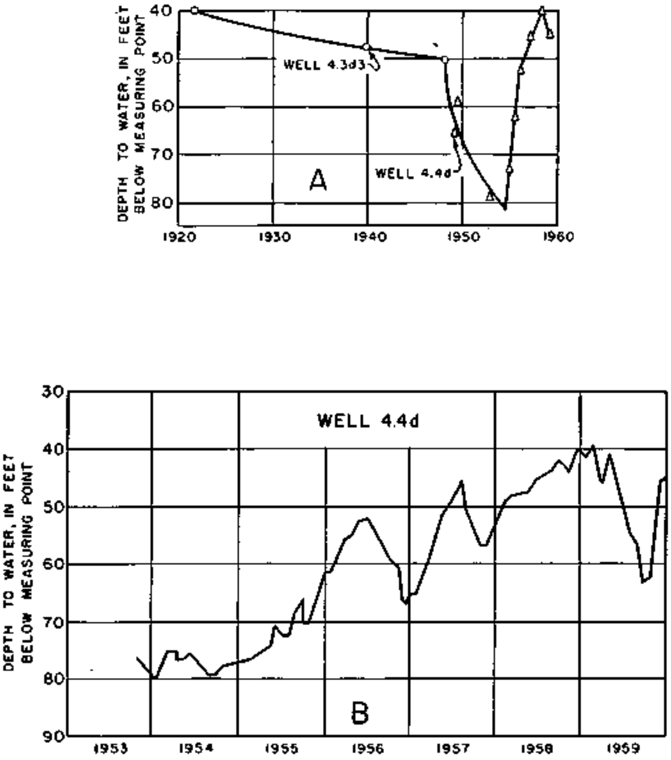


Figure 19. Water levels in wells at Arcola, 1953-1959

As the result of a shift in pumping centers, water levels in the old well field recovered from 1955 to 1959 as shown in figures 19A and 19B. Data for the period prior to May 1955 in figure 19A indicate that water levels in the old well field would have recovered about 60 feet if there were no interference between the old and new well fields. However, recovery was nearly complete in 1959 and was only about 40 feet. Therefore, there is appreciable mutual interference between the old and new well fields. The distance between the old and new well fields is great enough so that daily changes in pumpage from wells in the new field are not recorded in well 4. 4d. However, water levels in well 4. 4d respond to frequent changes in pumpage in well 4. 4e1 located 475 feet away in the old well field.

Water levels in wells with short or interrupted records are summarized in table 8. Records of wells are given in tables 7 and 9.

Table 8. Water Levels in Wells at Arcola

Well Number	Date	Depth to water*	Remarks
DGL 14N8E-			
4.3d1	Jan. 1918	50	City well No. 1
	Oct. 1921	70	Abandoned and sealed in 1940
4.3d3	Jan. 1922	40	City well No. 3
	Mar. 1940	49.5	City well No. 4 pumping
	Mar. 1940	47.5	
	June 1948	50	
	Mar. 1953	73	City well No. 2-A pumping
	Aug. 1953	68.5	
4.3e1	Mar. 1940	47.5	City well No. 4
	Mar. 1940	49.5	City well No. 3 pumping
	June 1948	50	
	Mar. 1953	74	City well No. 2-A pumping
	Aug. 1953	70	
4.4d	Feb. 1949	65	City well No. 1-A
	Jan. 1950	59	
	Mar. 1953	79	City well No. 2-A pumping
	Oct. 1953	76	Recording gage installed Oct. 1953; records available 1953-60
4.4e1	Nov. 1947	54	City well No. 2-A
	Mar. 1953	71.75	
	Jan. 1954	84	
11.6a	Oct. 1953	15	City test hole No. 11-53
4.4f	Jan. 1954	70	
	Jan. 1954	74.75	City test hole No. 12-53
3.8g	Dec. 1955	47.8	City well No. 6
DGL 15N8E-			
34.5a	May 1955	29.5	City well No. 5
	Aug. 1955	32.2	

* Depth in feet below measuring point

Recharge to Aquifer

Recharge to the aquifer at Arcola occurs as vertical leakage of water through the confining bed. Some precipitation reaches the water table and becomes ground water. Part of the water stored in shallow deposits moves downward through the confining bed into the aquifer under the influence of large differentials in head between the water table in shallow deposits and water levels in the aquifer.

The water level in shallow, 10 to 30 feet deep, dug or bored wells fluctuates through a wide range in response to above or below normal precipitation; in drought years many shallow wells go dry. However, water stored in the thick confining bed is available to the aquifer so that drought periods have little influence on water levels in the city wells.

The quantity of leakage through the confining bed varies from place to place and is primarily controlled by the vertical permeability and thickness of the confining bed and the difference between the head in the aquifer and in the shallow deposits.

A comparison of the pumpage graph in figure 18 with the hydrograph in figure 19A shows that water-level decline is directly proportional to the pumping rate. Within a relatively short time after each increase in pumping rate, leakage through the confining bed has increased in proportion to pumpage and has balanced discharge. As the shape and extent of the cone of depression are dependent upon the hydraulic properties of the aquifer and the vertical permeability of the confining bed, these properties must be defined before the yields of wells and the aquifer can be evaluated.

Table 9. Records of Production Wells at Areola

			Casing		Screen			Specific	
Well Number	Date Drilled	Depth (feet)	Depth (feet)	Dia. (inches)	Length (feet)	Dia. (inches)	Yield (gpm)	capacity (gpm/ft)	Remarks
DGL 14N8E-									
4.3d1	1914	100	94	8	6	7.5	25	0.3	City No. 1; well abandoned because of clogged screen
4.3d2	1914	100	94	8	6	7.5	25	0.3	City No. 2; well abandoned because of clogged screen
4.3d3	1921	100	94	12	6	11.5	25	0.3	City No. 3; well abandoned because of clogged screen
4.3e1	1921	100	94	12	6	11.5	25	0.3	City No. 4; well abandoned because of clogged screen
4.4e1	1945	122	101	10	21	10.	125	9	City No. 2-A
4.4d	1947	103	89	10	14	10.	106	2.5	City No. 1A; recording gage installed Oct. 1953; records available
11.6a	1953	86	77	6	9	5.5	61	2.5	City No. TW 11-53
3.8g	1955	118	93	30-12	25	8	125	8.0	City No. 6
DGL 15N8E-									
34.5a	1955	106	81	30-12	25	8	200	8.5	City No. 5

Table 10. Coefficients of Transmissibility and Permeability for Aquifer at Arcola

Well Number	Date	Length of test (hours)	Pumping rate (gpm)	Method of Analysis	Specific capacity (gpm/ft)	Coefficient of transmissibility (gpd/ft)	Saturated thickness (feet)	Coefficient of permeability (gpd/sq ft)
DGL 14N8E-								
4.3d3	3/27/40	7	87	Specific capacity	2.8	3,200	9	356
4.3e1	3/27/40	7	52-80	Specific capacity	2.5	2,200	8	275
4.4d	1/11/50	3	56-115	Specific capacity	4.3	4,000	12	333
34.5a	5/11/55	9	205	Time-drawdown	25	18,000	30	600
3.8g	12/30/55	7	125	Time-drawdown	19.5	18,300	28	660

Hydraulic Properties of Aquifer

During the period 1940 to 1955, five pumping tests were made at Arcola to determine the hydraulic properties of the aquifer. The equations and method used to analyze data for one of the tests are given in figure 20. Early time-drawdown data unaffected by leakage through the confining bed and by geohydrologic boundaries were used in computations. Estimates of the coefficient of transmissibility of the aquifer were also made by substituting in the nonequilibrium formula, specific capacity data, a coefficient of storage of 0.001, and well-construction data. Specific capacity data were adjusted for the effects of partial penetration and well loss before they were used to determine the coefficient of transmissibility.

A summary of the coefficients of transmissibility and permeability obtained from the tests is given in table 10. These data indicate that the coefficient of transmissibility ranges from 2200 to 18, 300 gpd/ft and the coefficient of permeability ranges from 275 to 660 gpd/sq ft. The smaller values of T and P reflect thinner or less permeable deposits near the edge of the aquifer; whereas the larger values reflect much thicker and more permeable deposits near the center of the aquifer. Based on the results of the tests, the geology of the area, and the method of proportional parts, the average coefficient of transmissibility of the part of the aquifer with a saturated thickness of 20 feet is estimated to be about 10, 000 gpd/ft.

The coefficient of storage could not be accurately determined from the test data because observation wells were not available during the tests. However, computations using the coefficients of transmissibility determined from the test data, well-construction data, and the nonequilibrium formula, indicate that the coefficient of storage is in the order of magnitude of 0.001.

Geohydrologic Boundaries of Aquifer

Geologic conditions limit the extent of the aquifer at Areola. As shown in figure 16 the permeable sand and gravel deposits are bounded on the northeast and southwest by relatively impervious deposits of till which delimit the aquifer and act as barrier boundaries.

The effects of barrier boundaries on the drawdown in a well are apparent in figure 20. The water level in well 3.8g declined at an initial rate under the influence of the pumped well only. The time-rate of drawdown increased twice, about 5 minutes after pumping started and about 25 minutes after pumping started, as the effects of image wells associated with barrier boundaries

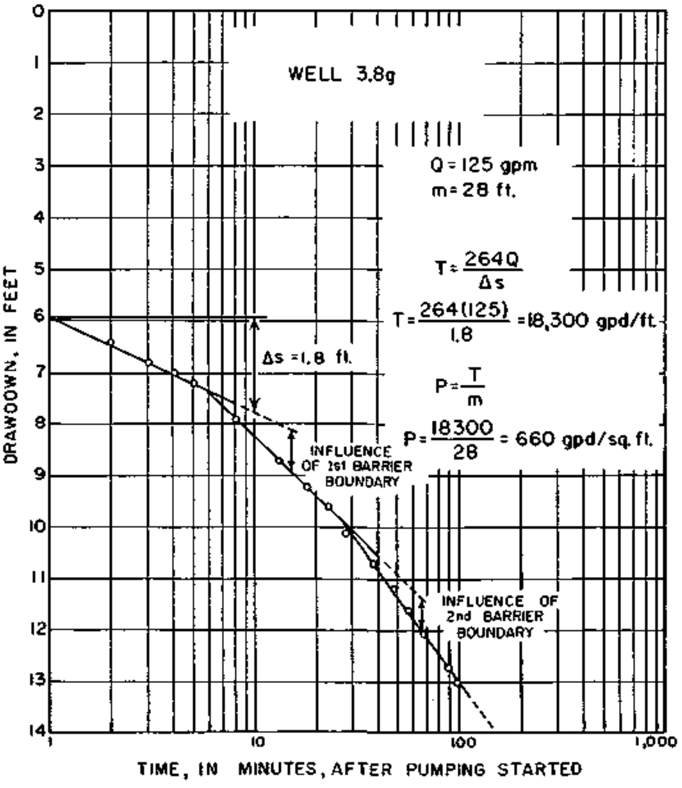


Figure 20. Graph of results of pumping test at Areola

became measurable. Unfortunately late time-drawdown data are influenced by leakage through the confining bed in addition to the barrier boundaries and the exact location of the barrier boundaries cannot be determined from pumping test data alone. Based on geologic data and the results of pumping tests, the effective distance between barrier boundaries is estimated to be 400 feet. The orientation of idealized barrier boundaries is shown in figure 21.

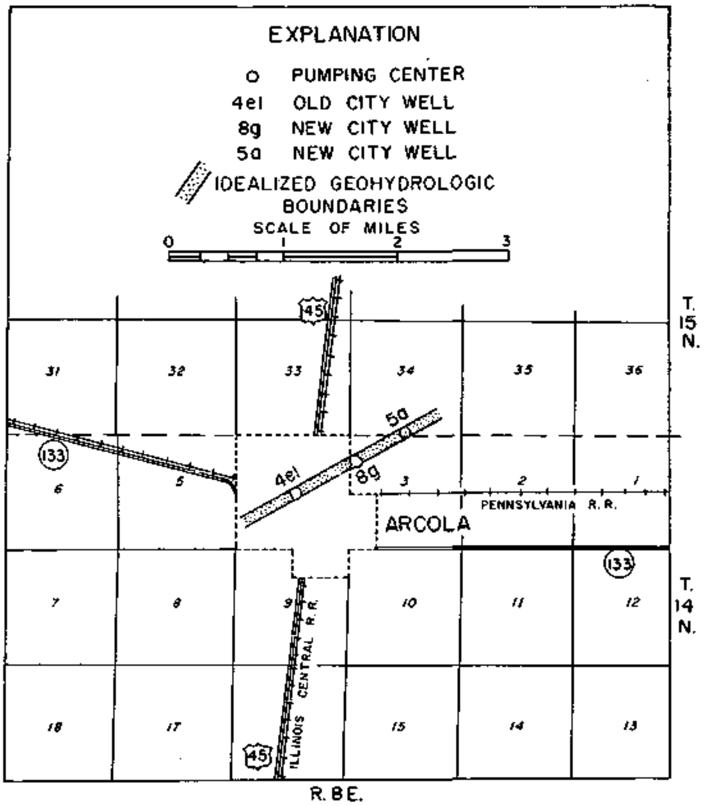


Figure 21. Map showing location of pumping centers and idealized geohydrologic boundaries of the aquifer at Arcola

Vertical Permeability of Confining Bed

The vertical permeability, P', of a confining bed often can be determined from the results of pumping tests by using formulas derived by Hantush and Jacob (1955) and methods described by Walton (1960). However, most drawdown data collected during pumping tests made at Arcola are affected by barrier boundaries and it is impossible to isolate the effects of the leakage through the confining bed. The vertical permeability of the confining bed cannot be determined from available pumping test data. Records of past pumpage and water-level decline and a model aquifer were used to estimate the vertical permeability of the confining bed.

Model Aquifer

The results of geologic and hydrologic studies indicate that it is possible to simulate complex aquifer conditions at Areola with an idealized model aquifer. The model aquifer is a rectilinear strip of sand and gravel 400 feet wide, 20 feet thick, bounded on the sides and bottom by impermeable material and overlain by a confining bed 70 feet thick. The orientation of the model aquifer in relation to Areola is shown in figure 21. Based on pumping test data the average coefficients of transmissibility and storage of the model aquifer are 10,000 gpd/ft and 0.001, respectively.

The water-level decline at wells 4. 4d, 34. 5a, and 3. 8g from 1922 to 1955 was computed using the model aquifer, calculated hydraulic properties of the aquifer, the image-well theory, the steady-state leaky artesian formula described by Jacob (1946), estimated pumpage data, and several assumed values of the vertical permeability of the confining bed. The computed declines were then compared with actual declines and that vertical permeability which gave computed declines equal to actual observed declines was assigned to the confining bed.

Ground-water withdrawals from 1922 to 1955 were grouped into one center of pumping in the old well field. The center of pumping, wells 3.8g, 4.4d, and 34.5a, and the barrier boundaries were drawn to scale on a map and the image wells associated with the geohydrologic boundaries were located. The distances between wells 4. 4d, 3. 8g, and 34. 5a, the pumping center, and image wells were scaled from the map. The water-level decline at wells 4.4d, 34.5a, and 3.8g resulting from pumpage at the pumping center was determined using the steady-state leaky artesian formula to compute the effects of the real and image wells.

The actual declines in wells 4.4d, 3.8g, and 34.5a from estimated original nonpumping water-level elevations are 42, 30, and 17 feet, respectively. Water-level declines of 45 feet in well 4.4d, 32 feet in well 3. 8g, and 19 feet in well 34.5a computed by using a vertical permeability of 0. 04 gpd/sq ft compare favorably with actual declines. The vertical permeability of the confining bed is therefore estimated to be 0. 04 gpd/sq ft. Thus, the effects of two barrier boundaries and leakage through the confining bed on the response of the aquifer at Areola to development of wells can be simulated by using the model aquifer described earlier and a vertical permeability of 0.04 gpd/sq ft. The model aquifer may be used to predict with reasonable accuracy the effects of future ground-water development and the practical sustained yield of the existing 3-well system.

Theoretical Effects of Pumping

The barrier boundaries at Arcola distort cones of depression and greatly increase the drawdown in wells. On the other hand, recharge from the vertical leakage of water through the confining bed limits the spread of the cone of depression and decreases the drawdown in wells. The model aquifer was used to evaluate the influence of the barrier boundaries and vertical leakage on water-level decline.

Theoretical time-drawdown graphs illustrating the effects of barrier boundaries and vertical leakage on water-level decline are given in figure 22. Distances from a pumped well to an observation point of 2500 feet, to a barrier boundary of 200 feet northwest of the observation point, and to a barrier boundary of 200 feet southeast of the observation point were assumed in constructing the graphs. The graphs show the amount of interference that will occur at an observation point 2500 feet from a pumped well at any time from 1 to 400 days assuming an infinite aquifer with no recharge (A), a finite aquifer 400 feet wide recharged by vertical leakage (B), and a finite aquifer 400 feet wide with no recharge (C).

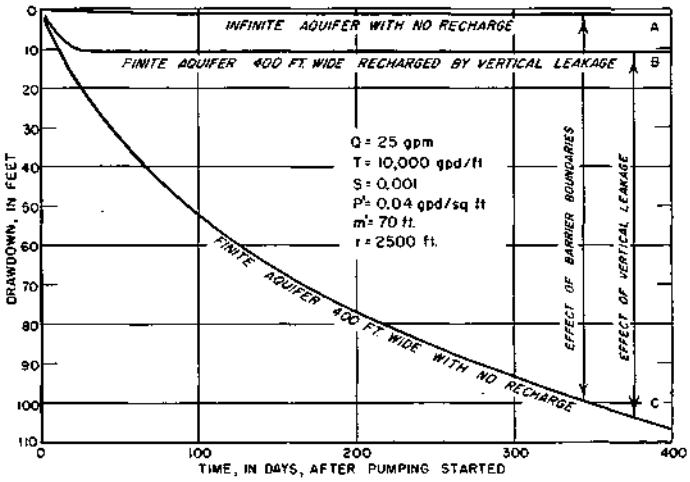


Figure 22. Graphs of theoretical time-drawdown (A), time-drawdown considering barrier boundaries (B), and time-drawdown considering barrier boundaries and vertical leakage (C) for the aquifer at Arcola

Curves A and C show that, with no recharge, interference in an infinite aquifer 400 days after pumping started is less than two feet, whereas the interference in a finite aquifer 400 feet wide 400 days after pumping started is over 50 times as much, or more than 100 feet. Drawdown is still continuing at an appreciable rate 400 days after pumping started in the finite aquifer with no recharge. In an aquifer recharged by vertical leakage, however, the maximum drawdown is only 10. 5 feet and equilibrium conditions prevail about 30 days after pumping started.

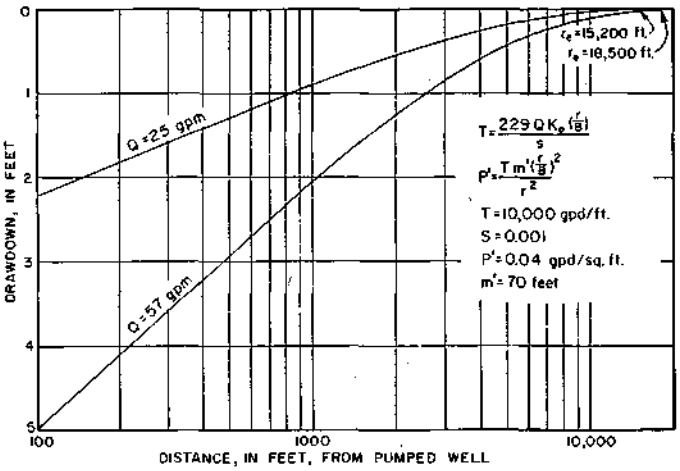


Figure 23. Theoretical distance-drawdown relationship in an infinite aquifer having hydraulic properties determined for the aquifer at Areola

Figure 23 shows the amount of interference that will occur in an infinite aquifer under steady-state leaky artesian conditions at distances of 100 feet to about 3. 5 miles from a well pumping continuously at 25 and 57 gpm. The drawdowns given occur at equal distances from the pumped well in all directions. The graphs assume that recharge by vertical leakage through the confining bed balances discharge. The virtual radii of cones of depression for pumping rates of 25 and 57 gpm are shown to be about 15,000 and 18, 500 feet, respectively. The theoretical drawdown at any distance is directly proportional to the pumping rate. Thus, if the pumping rate was 115 gpm the drawdown at any distance would be twice that shown by the curve constructed for a pumping rate of 57 gpm in figure 23. The distance-drawdown graphs were used to compute the effects of the real and image wells associated with the model aquifer.

Practical Sustained Yield of 3-Well System

The practical sustained yield of existing well fields at Areola is dependent upon the hydraulic properties and thickness of the aquifer, the vertical permeability and thickness of the confining bed, the geohydrologic boundaries, and the spacing of wells and well fields.

The multiple-well system at Areola consists of 3 wells spaced 2500 feet apart in the more permeable parts of the aquifer as shown in figure 21. These wells, 4.4e1, 3. 8g, and 34. 5a, are 122, 118, and 106 feet deep, respectively. The maximum drawdowns that can occur without dewatering the aquifer below the well screens in these wells are 76, 66, and 75 feet, respectively. Computations made with the model aquifer indicate that a maximum of 137 gpm can be pumped from the 3-well system without eventually lowering water levels below tops ot screens. The practical sustained yield of the 3-well system can be developed by pumping wells 4.4el and 34. 5a at 57 gpm and well 3. 8g at 25 gpm. Any other combination of pumpage will result in excessive drawdown in the center well of the 3-well system. Thus, the practical sustained yield of the existing 3-well system is about 137 gpm or 200,000 gpd.

The rate of ground-water withdrawal increased from 115,000 gpd in 1957 to 146,000 gpd in 1959. If pumpage continues to increase in the future at this rate, it is estimated that the practical sustained yield of the existing 3-well system will be exceeded by 1963.

TALLULA

The municipal water supply for the village of Tallula is obtained from a horizontal collector in a shallow sand and gravel aquifer which averages 3. 5 feet in thickness and 300 feet in width. Recharge to the aquifer is from precipitation and a recharge well connected to a lagoon. Average daily withdrawals from the collector increased from about 7000 gallons in 1955 to about 29,000 gallons in 1959. As the result of increased withdrawals, water levels declined to critical stages during summer months in 1959.

Geography

Location and Extent of Study Area

Tallula is located near the southwest corner of Menard County in west-central Illinois, 18 miles northwest of Springfield as shown in figure 1. State Highway 123 and the Gulf, Mobile and Ohio railroad pass through the village.

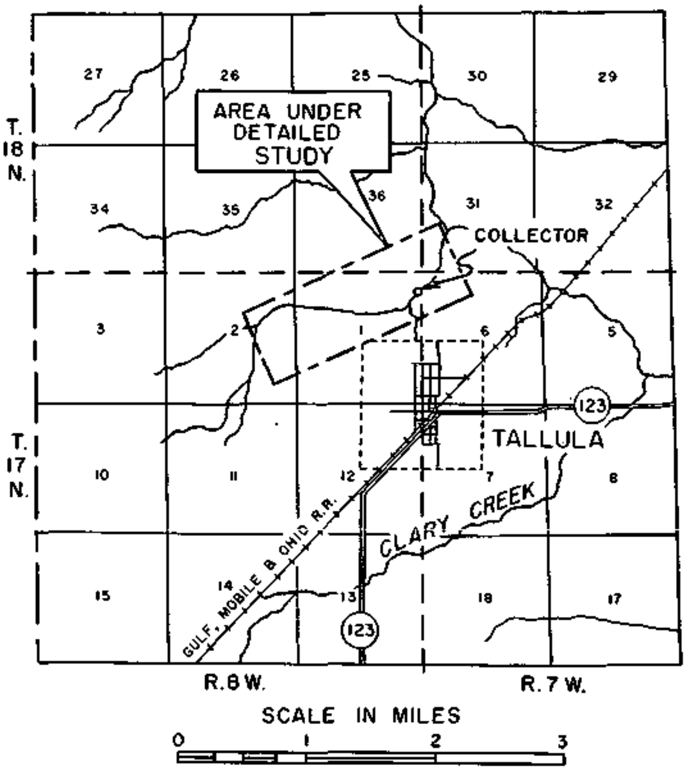


Figure 24. Map showing location of study area and collector at Tallula

Detailed study was confined to a rectangular area, hereafter referred to as "the area, " of about 1 square mile along the flood plain and within the drainage basin of the West Fork of Clary Creek northwest of the village in T. 17 N., T. 18 N., R. 7 W., R. 8 W. as shown in figure 24. The area is situated between 89°55' and 90°00' west longitude and between 39°55' and 40°00' north latitude.

Topography and Drainage

The land surface within the area ranges from an elevation of about 630 feet in Tallula and along the divide of the drainage basin, to about 560 feet on the flood plain of Clary Creek near the northeast corner of the area. Drainage is largely northeastward to Clary Creek and to Sangamon River about 12 miles north of the area.

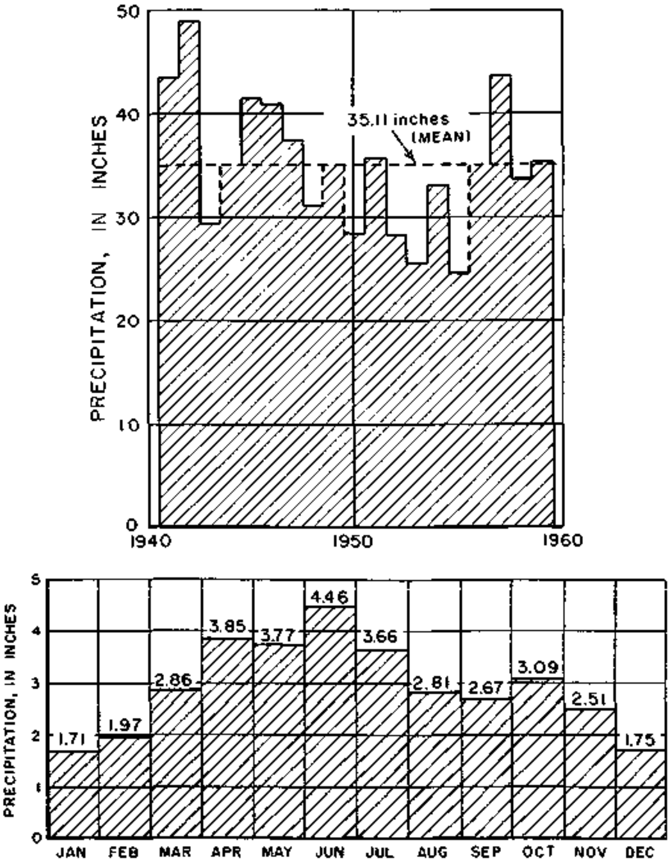


Figure 25. Annual and mean monthly precipitation at Tallula

Climate

Graphs of annual (1941-1959) and mean monthly precipitation in figure 25 were compiled from precipitation data collected by the U. S. Weather Bureau at the city of Petersburg, about 7 miles northeast of Tallula. According to these records the mean annual precipitation is 35.11 inches. Precipitation is greatest during April, May, June, and July and exceeds 3.5 inches. December, January, and February are the months of least precipitation, each having less than 2 inches.

The occurrence of the annual maximum and minimum precipitation amounts expected on an average of once in 5 and once in 50 years, based on data in the Atlas of Illinois Resources, Section 1, is given below:

	Lowest annual precipitation expected (inches)	Highest annual precipitation expected (inches)
Once in 5 years	29	41
Once in 50 years	23	53

The mean annual snowfall is 21 inches. On the average about 24 days a year have 1 inch or more of ground snow cover; about 12 days a year have 3 inches or more of ground snow cover.

Based on records collected by the U. S. Weather Bureau at Springfield, the mean annual temperature is 52.4 F. June, July, and August are the hottest months with mean temperatures of 71.9°F, 76.3°F, and 74.0°F, respectively. January is the coldest month with a mean temperature of 29.4°F. The mean length of the growing season is about 180 days.

Geology

The municipal water supply is obtained from a horizontal collector on the flood plain of Clary Creek about 1/2 mile north of the corporation limits of Tallula. The collector penetrates a thin sand and gravel aquifer that ranges in thickness from 2.5 to 4.5 feet and is encountered at an average depth of 16 feet below land surface. The average thickness of the aquifer is 3.5 feet, but it probably increases northward in the more deeply incised, wider part of Clary Creek valley. This aquifer is not very permeable and consists of stratified beds of sand, gravel, and silt in various mixtures.

Alluvial clay, silt, and fine sand (confining bed) overlie the aquifer; the sand content of the alluvium increases with depth. Patches of pebbly glacial till probably overlie the aquifer at places in the valley. The average saturated thickness of the confining bed is 10 feet.

As shown in figure 26, the sand and gravel aquifer is inferred to be from 150 to 370 feet wide in the vicinity of the collector. The aquifer extends beneath the flood plain of Clary Creek and has an average width of 300 feet. Bordering the flood plain are alluvial terraces; some of the terraces extend 10 to 15 feet above the flood plain. The higher terraces merge into glacial till of Illinoian age on the uplands. The geologic cross section A-A' in figure 26 can be considered to represent in a general way the geologic relations at most places in the area. The aquifer is overlain by a confining bed and under natural conditions ground water occurs under leaky artesian conditions.

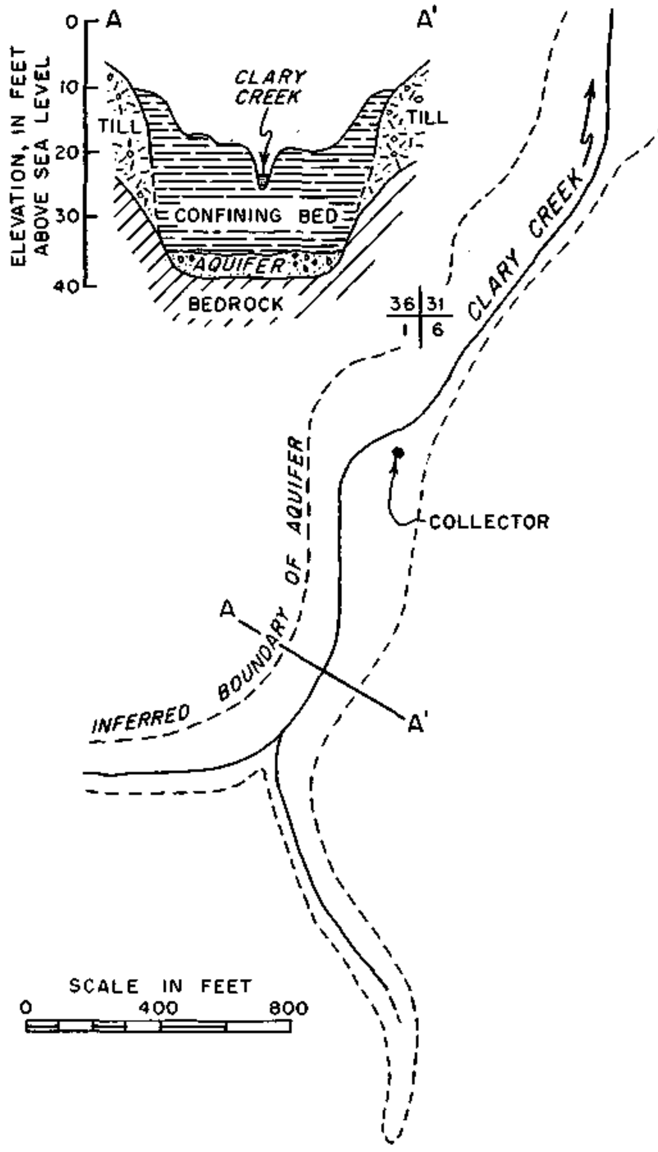


Figure 26. Map and geologic cross section showing thickness and areal extent of aquifer at Tallula

The aquifer is contained in a narrow valley cut into bedrock of Pennsylvanian age. The bedrock is relatively impermeable and consists predominantly of shale with alternating thin beds of limestone, sandstone, siltstone, fire clay, and coal.

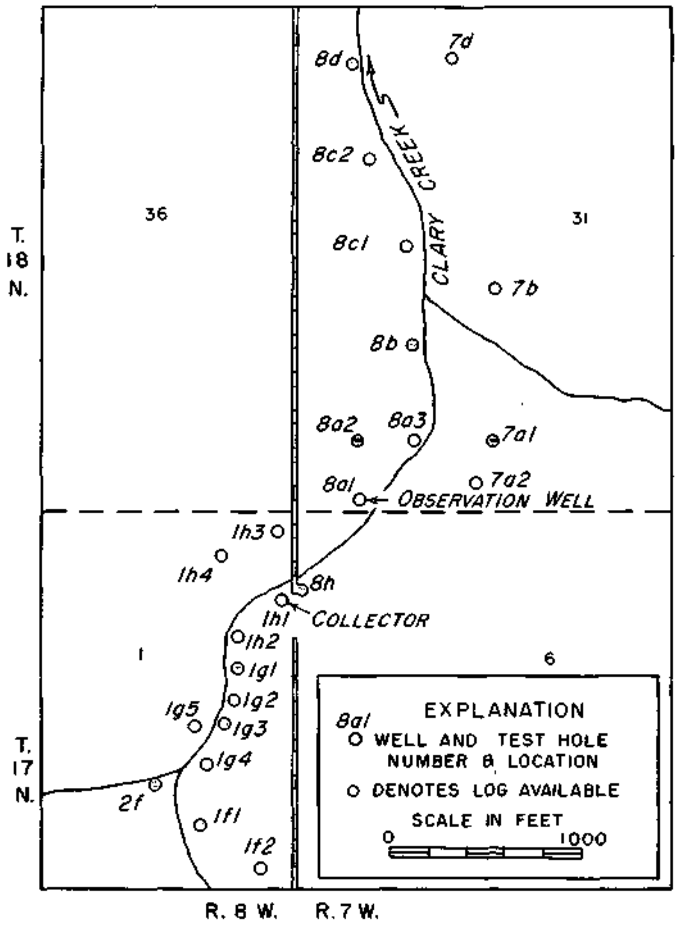


Figure 27. Map showing location of wells and test holes at Tallula

The location of wells and test holes for which geologic and hydrologic data are available is shown in figure 27. Logs of wells and test holes are given in table 11.

Table 11. Logs of Wells and Test Holes at Tallula

Well Number	Formation	Thickness (feet)	Depth (feet)
MEN 17N8W-			
1.1h1	black silt	8	8
	sandy clay	3.5	11.5
	sand and gravel	5	16.5
1.1h2	top soil, silt and clay	15	15
	gravel	3	18
1.1g1	top soil, silt and clay	19	19
	gravel	3.5	22.5
1.1g2	top soil, silt and clay	16	16
	gravel	4	20
MEN 17N8W-			
1.1g3	top soil, silt and clay	16.5	16.5
	gravel	3.5	20
1.1g4	top soil, silt and clay	14.5	14.5
	gravel	3.5	18
1.1f1	top soil, silt and clay	19	19
1.2f1	top soil, silt and clay	18	18
1.1g5	top soil, silt and clay	15	15
	gravel	3	18
1.1h3	top soil, silt and clay	18	18
	gravel	4	22
1.1h4	top soil, silt and clay	15	15
	gravel	3	18
1.1f2	top soil, silt and clay	15	15
	gravel	3	18
6.8h1	top soil, silt and clay	15	15
	gravel	3	18
MEN 18N7W-			
31.8a1	top soil, silt and clay	16	16
	gravel	4	20
31.8a2	top soil, silt and clay	15.5	15.5
	gravel	3.5	19
31.8a3	top soil, silt and clay	14	14
	gravel	4	18
31.7a1	top soil, silt and clay	16	16
	gravel	4	20
31.7a2	top soil, silt and clay	15	15
	gravel	3	18
31.8b	top soil, silt and clay	17.5	17.5
	gravel	2.5	20
31.8c1	top soil, silt and clay	15.5	15.5
	gravel	3.5	19
31.8c2	top soil, silt and clay	17.5	17.5
	gravel	4.5	22
31.8d	top soil, silt and clay	17	17
	gravel	4	21
31.7d	top soil, silt and clay	16	16
	gravel	4	20
31.7b	top soil, silt and clay	17	17
	gravel	4	21

Ground-Water Withdrawals

The first attempt to develop an adequate municipal water supply for Tallula was made between 1952 and 1955 when 5 dug wells, 2 feet in diameter and averaging 20 feet in depth, were constructed along Clary Creek. The sustained yield of the well field was not sufficient to meet the needs of the village and in May 1955 one of the dug wells was reconstructed into a horizontal collector.

The horizontal collector consists of a 6-foot diameter concrete caisson from which 2 horizontal 8-inch diameter vitrified perforated clay pipe laterals are projected near the bottom. The concrete caisson extends from 9. 5 feet above to 26 feet below land surface and is capped by a concrete cover with a manhole for accessibility to the interior of the collector. One horizontal lateral (upper lateral) projects from the collector at a depth of 18 feet below land surface and is 478 feet in length. The other horizontal lateral (lower lateral) projects from the collector at a depth of 21 feet below land surface and is 310 feet in length. The laterals were placed in a trench excavated through the aquifer. After the laterals were placed, the trench was backfilled with gravel to a depth of about 15 feet below land surface and with clay and topsoil from a depth of 15 feet to the original land surface. The locations of the concrete caisson and the laterals are shown in figure 28.

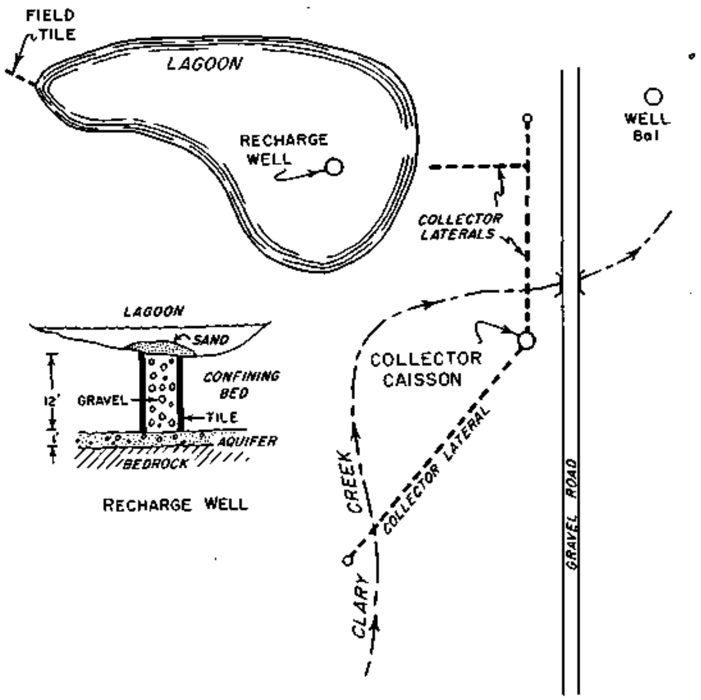


Figure 28. Location and construction features of collector and recharge well

Initial planning was based on the assumption that the municipal water demand would increase from 15,000 gpd to 25,000 gpd within 10 years. During the first year of operation, 1955, the water demand averaged only 9000 gpd, but the withdrawal rate steadily increased and in 1959 an average of 29,000 gpd were pumped from the collector. The average daily metered pumpage from the collector between 1957and 1959 is shown in figure 29A. From June 1957 through April 1959 withdrawals averaged 20, 000 gpd and the maximum daily pumpage exceeded 24,000 gallons only in June 1958 when 28, 000 gpd were pumped. In the summer of 1959 an average of over 37, 000 gpd were pumped and as a result water levels declined below the top of the upper lateral in the collector.

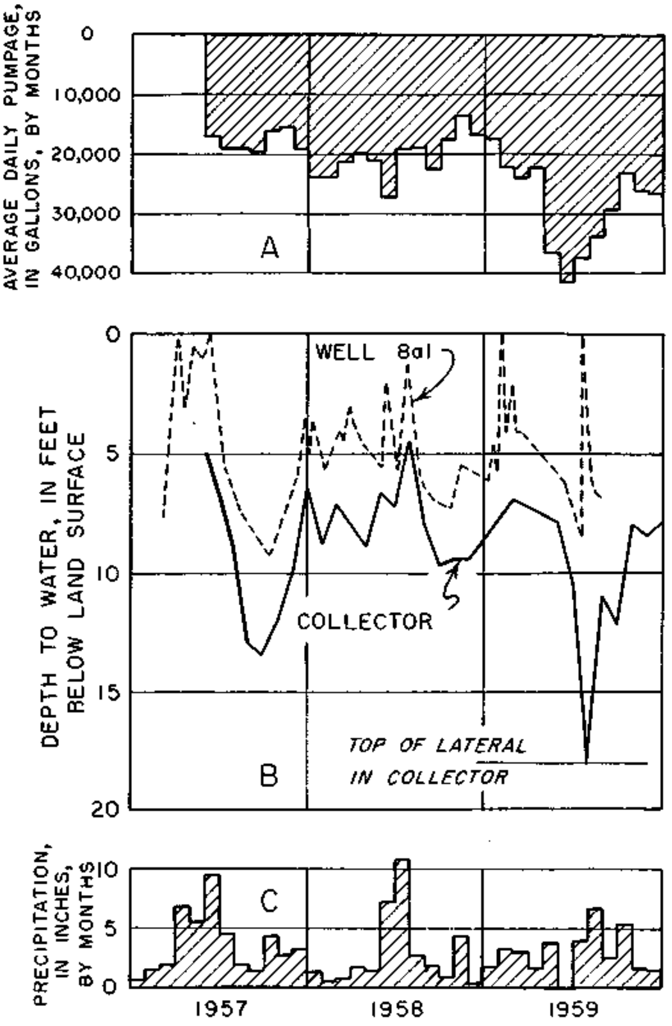


Figure 29. Ground-water pumpage (A), water levels in wells (B), and precipitation (C) 1957-1959 at Tallula

Fluctuations of Water Levels and Their Significance

A recording gage was installed on well 8al, located 700 feet northeast of the collector, in March 1957. Water-level fluctuations in well 8al March 1957 to October 1959 are shown in figures 30-32. The extent to which water levels decline during dry periods and recover during periods of abundant precipitation is evident. Minimum water levels are recorded during summer and fall months when pumping is greatest and recharge is least. Maximum water levels generally occur in June and July after the spring recharge period.

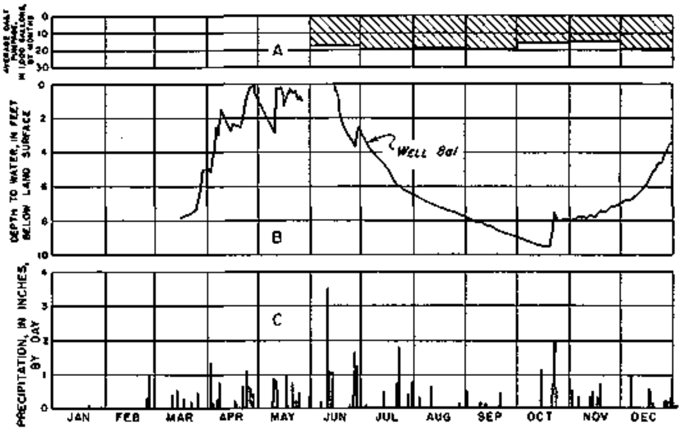


Figure 30. Ground-water pumpage (A), water levels in well 8al (B), and precipitation (C) during 1957 at Tallula

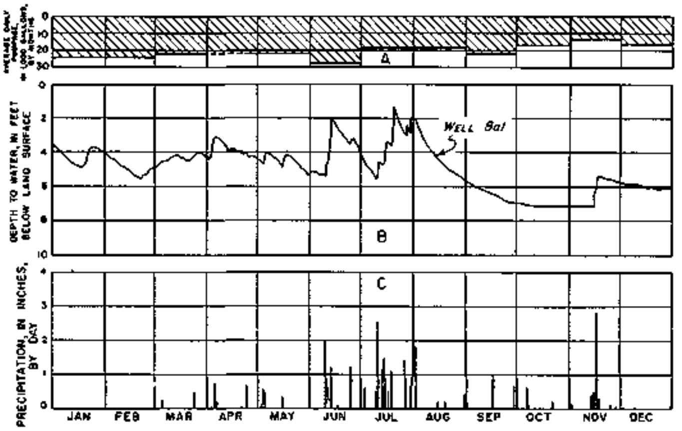


Figure 31. Ground-water pumpage (A), water levels in well 8al (B), and precipitation (C) during 1958 at Tallula

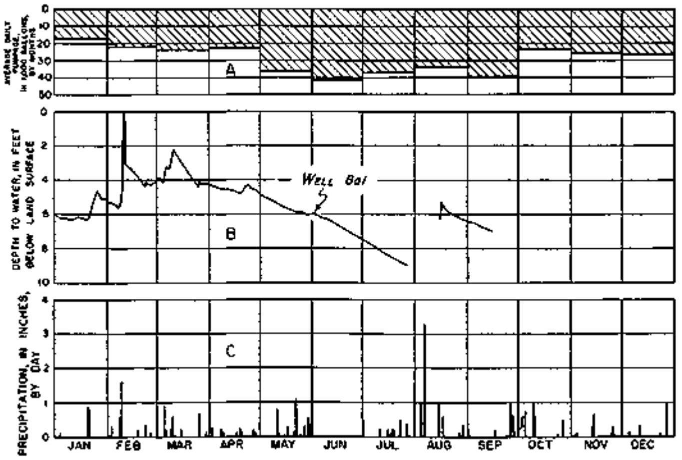


Figure 32. Ground-water pumpage (A), water levels in well 8al (B), and precipitation (C) during 1959 at Tallula

No serious continuing downward trend in yearly maximum water levels in well 8al has resulted from pumping the collector. The water table recovered in February 1959 to the maximum stage recorded in April 1957 indicating that water pumped 1957-1958 was replenished in full.

Yearly minimum water levels in well 8a1, 1957-1959, are not critical and are several feet above the top of the aquifer. However, as a result of a record high pumping rate of over 37, 000 gpd during the summer months of 1959, water levels declined below the upper lateral in the collector in July as shown in figure 29B. The water levels in well 8a1 and in the collector are greatly influenced by the recharge well discussed in the following section.

Recharge to Aquifer

Precipitation percolating to the water table and then through the confining bed recharges the aquifer. Some recharge may occur by the induced infiltration of surface water in Clary Creek. Because of the small area and silted condition of the stream bed, a low streamflow, and the presence of clayey materials beneath the stream bed, very little recharge from Clary Creek can be expected especially during summer, fall, and winter months.

Large amounts of water enter the aquifer through a recharge well constructed in 1957. As shown in figure 28, a lagoon 7 feet deep fed by field tile and surface drainage is connected to the aquifer through a concrete tile filled with gravel. The recharge well is about 60 feet from the end of one of the laterals in the collector.

The annual rate of recharge from precipitation to the aquifer cannot be appraised from existing data. Studies made by Schicht and Walton (1961) in drainage basins with geologic conditions similar to those at Tallula indicate that recharge during years of near or above normal precipitation may amount to about 8 inches. Recharge may not exceed 4 inches during dry years. Based on the results of pumping tests and other geohydrologic studies, the area influenced by pumping the collector is estimated to be in the magnitude of 0. 1 square mile. Recharge to the aquifer from precipitation falling within the area of the cone of depression of the collector is estimated to average 36,000 gpd during normal years and 16, 000 gpd during dry years.

Ground-water storage in the confining bed and in the aquifer permits pumping at rates greater than recharge for limited periods. However, because the aquifer and confining bed are greatly limited in areal extent and thickness and the gravity yield of the confining bed is relatively low, the available water in storage is not great. Pumping at rates much above recharge for extended periods will result in the rapid depletion of the aquifer.

Hydraulic Properties of Aquifer and Confining Bed

The coefficient of transmissibility of the aquifer and the vertical permeability of the confining bed were determined from a pumping test made June 25-26, 1952. A group of wells in the vicinity of the collector were used. The effects of pumping well 1h1 were measured in 3 observation wells located 215, 325, and 385 feet northeast of the pumped well. Pumping was started at 11:29 a.m. on June 25 and was continued for a period of about 25 hours at a constant rate of 9 gpm until 12:16 p.m. on June 26.

Drawdowns in the observation wells at the end of the test were plotted on logarithmic paper against the distances, from the respective observation wells to the pumped well, to describe a distance-drawdown graph. The graph was analyzed by means of the steady-state leaky artesian distance-drawdown type curve method described by Walton (1960). Computations are shown in figure 33. The coefficients of transmissibility and permeability of the aquifer are 2750 gpd/ft and 787 gpd/sq ft, respectively.

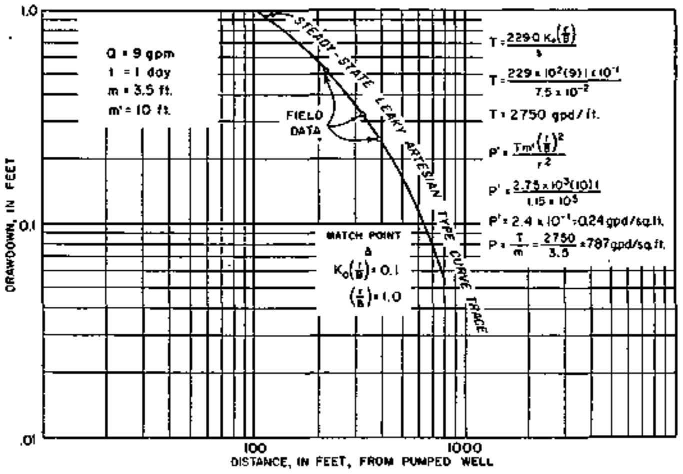


Figure 33. Graph of results obtained from pumping test at Tallula

The cone of depression is distorted by the presence of geohydrologic boundaries so that the hydraulic gradients between the valley walls and the pumped well are flat in comparison to the hydraulic gradients on other sides of the pumped well. However, the cone of depression near the pumped well is not distorted to any great extent on a line parallel to the barrier boundaries. The observation wells are on a line parallel to the barrier boundaries and are therefore approximately equidistant from the image wells associated with the barrier boundaries. The effects of the barrier boundaries on drawdowns in the observation wells are approximately equal for a given time. Thus, the distance-drawdown data for the observation wells reflect the actual gradient toward well 1h1 and they may be used to determine the coefficient of transmissibility of the aquifer.

The actual vertical permeability of the confining bed cannot be determined from the distance-drawdown data because a large part of the total drawdown in the observation wells can be attributed to the effects of the barrier boundaries. Although the hydraulic gradient parallel to the barrier boundaries is approximately the same as it would be if the aquifer were infinite in areal extent, the total drawdown in each observation well is much greater because the aquifer is finite. The steady-state leaky artesian type curve method is valid only for the case in which the aquifer is infinite in areal extent, and the apparent vertical permeability of the confining bed computed in figure 33 is much less than the actual value.

A comparison of the value of P' computed from the test data with values of P' for other confining beds in Illinois given by Walton (1960) indicates that the vertical permeability of the confining bed at Tallula is relatively high.

Leakage during the short-term pumping test lowered the water table very little, and for practical purposes the confining bed was not drained. However, as a consequence of prolonged heavy pumping during the summer and fall months when recharge to the water table is very small, the confining bed will be drained and leakage will not keep up with discharge as it did during the pumping test. Computations of long-term drawdown must take into consideration the draining of the confining bed. The gravity yield of the confining bed cannot be computed from test data. A reasonable estimate of the gravity yield is 0. 05.

Geohydrologic Boundaries of Aquifer

Geologic conditions limit the extent of the aquifer. As shown in figure 26 the permeable sand and gravel deposits are bounded on the northwest and southeast by relatively impermeable deposits of till which delimit the aquifer and act as barrier boundaries. In addition, the aquifer pinches out about 1-1/2 miles southwest of the collector. The location of barrier boundaries often can be determined from the results of pumping tests by using a method described by Ferris (1959). Unfortunately time-drawdown data for the pumping test made June 25-26, 1952, are influenced by leakage through the confining bed in addition to the barrier boundaries. The exact location of the barrier boundaries cannot be determined from pumping test data alone.

Based on geologic information and the results of pumping tests, the effective distance between barrier boundaries in the vicinity of the collector is estimated to be 300 feet. The orientation of idealized barrier boundaries is shown in figure 34.

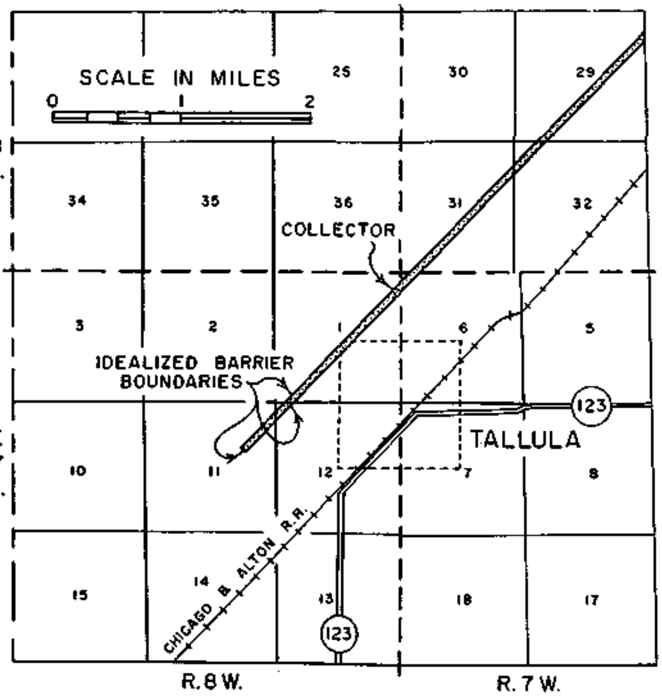


Figure 34. Map showing location of collector and idealized geohydrologic boundaries of the aquifer at Tallula

Figure 35 illustrates the effects of the barrier boundaries on the drawdown in a well near the collector. Distances from a pumped well to an observation well of 100 feet, to one barrier boundary of 50 feet, and to the other barrier boundary of 250 feet were assumed in constructing the graph.

Model Aquifer

The results of geologic and hydrologic studies indicate that it is possible to simulate complex aquifer conditions at Tallula with an idealized model aquifer. The model aquifer is a semi-infinite rectilinear strip of sand and gravel 300 feet wide, 3.5 feet thick, overlain by a confining bed 10 feet thick, and bounded on the sides and bottom by impermeable material. The coefficient of transmissibility of the aquifer is 2750 gpd/ft and the gravity yield of the confining bed is 0.05. The orientation of the model aquifer in relation to Tallula and the collector is shown in figure 34.

Records of past pumpage and water levels were used to test the assumed model aquifer against past performance and thereby establish the validity of this mechanism to estimate the practical sustained yield of the collector. The water-level decline in well 8al from August 1 to October 1, 1957, was computed using the model aquifer, the image-well theory, the nonequilibrium formula, and estimated pumpage data. The computed decline was then compared with the actual decline. The hydrograph of well 8al in figure 30 shows that very little recharge occurred August 1 to October 1 and that for practical purposes all the water pumped during that period was derived from storage in the confining bed. Ground-water withdrawals from the collector averaged 20,000 gpd, August 1 to October 1. The actual decline of water level in well 8a1, August 1 to October 1, was 2.5 feet.

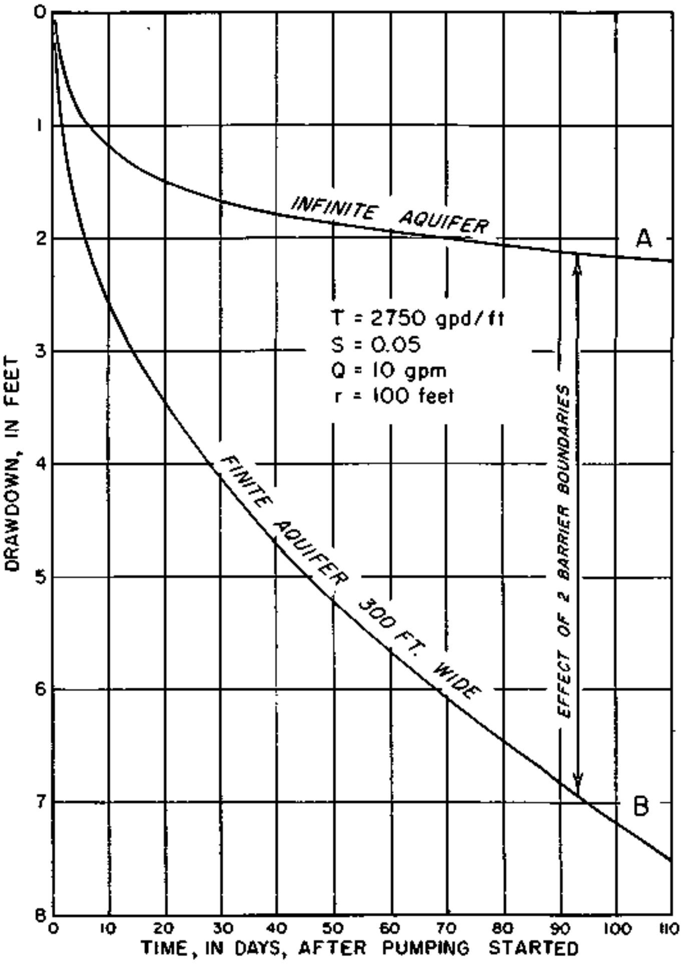


Figure 35. Graphs of theoretical time-drawdown (A) and time-drawdown considering barrier boundaries (B) for the aquifer at Tallula

The image wells associated with the barrier boundaries were located on a map and the distances between well 8a1, the collector, and the image wells were scaled from the map. The water-level decline at well 8al resulting from pumping the collector at an average rate of 20,000 gpd for 61 days was determined using the nonequilibrium formula to compute the effects of the real and image wells. The computed water-level decline at well 8al, 2.7 feet, compares favorably with the actual decline suggesting that the model aquifer can be used to predict with reasonable accuracy the practical sustained yield of the collector.

Simulating Collector with Vertical Well

The drawdown in the horizontal collector cannot be estimated with existing ground-water formulas because of the complex construction features of the collector. However, it is possible to compute the radius of a vertical well that is equivalent to the collector by using the model aquifer and performance data for the collector.

On April 28, 1955, a pumping test was made on the collector. A drawdown of 1. 52 feet was observed 41 minutes after pumping started at a rate of 35 gpm. The model aquifer was used to compute the radius of a vertical well that would have the same specific capacity for a pumping period of 41 minutes as did the collector. Water taken from storage within the caisson was taken into consideration. Computations indicate that the collector is equivalent to a vertical well with a radius of 66 feet.

Practical Sustained Yield of Collector

The rate at which water can be continuously pumped without eventually dewatering the aquifer below the top of the upper lateral in the collector depends in large part upon the rate and distribution of recharge. Large quantities of water enter the aquifer through a recharge well in the lagoon near the collector, as previously discussed. During extended dry periods such as occurred in 1952 the lagoon probably will go dry and the aquifer will receive very little recharge. Records show that Clary Creek was dry from about August 10 to November 25, 1952, a period of 107 days. In extended dry periods water pumped during summer and fall months will be derived from storage within the confining bed above the aquifer.

The rate of pumping that will lower the water level in the collector to the top of the lateral, assuming no recharge for a period of 107 days, can be computed with the model aquifer using the distance-drawdown curve given in figure 36.

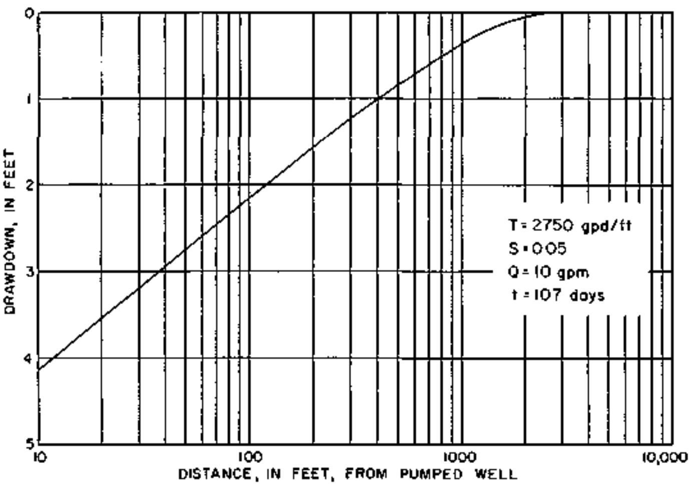


Figure 36. Theoretical distance-drawdown relationship in an infinite aquifer having hydraulic properties determined for the aquifer at Tallula

Computations made simulating the collector with a vertical well having a radius of 66 feet indicate that during extended dry periods the practical sustained yield of the collector is about 11 gpm or 16,000 gpd.

Figure 29 indicates that the yield of the collector is much greater during years of near or above normal precipitation when the lagoon is frequently replenished and artificial recharge is continuous. Water was pumped at an average rate of about 20,000 gpd in 1957 and 1958 without excessive drawdown suggesting that with artificial recharge the practical sustained yield of the collector exceeds 20, 000 gpd. Water levels declined to the top of the lateral in July 1959 when the average withdrawal rate was 37, 000 gpd. Thus, the practical sustained yield of the collector with artificial recharge is something less than 37, 000 gpd. Based on data in figure 29 the practical sustained yield of the collector during years of normal precipitation is estimated to be 20 gpm or 25, 000 gpd.

It is probable that the sand materials in the bottom of the lagoon over the recharge well will clog with time and as a result recharge to the aquifer and the yield of the collector will steadily decline with use. Frequent treatment of filter material over and in the recharge well will be necessary to maintain the yield of the collector at 20 gpm.

CONCLUSIONS

Geohydrologic settings in many areas have heretofore been considered too complex to permit their quantitative description with existing ground-water formulas. The case histories of ground-water development described in this report suggest that it is often possible to appraise ground-water problems with analytical expressions by devising approximate methods of analysis based on idealized models of aquifer situations. By checking computed performance of wells and aquifers with records of past pumpage and water levels, the investigator is assured of reasonably accurate solutions.

With sound professional judgment geohydrologic conditions often can be highly idealized with little sacrifice in accuracy of analysis. In addition, the adequacy and accuracy of basic data are seldom sufficient to warrant a rigorous theoretical and precise quantitative evaluation of ground-water conditions. In many cases, the complexity of geologic conditions dictates that quantitative appraisals derived from any method of analysis can at best be considered only approximations.

It is recognized that methods of analysis described in this report and based on idealized assumptions provide only approximate answers on a bulk basis. Idealized models describe the drawdown least accurately in the immediate vicinity of geohydrologic boundaries and irregularities. In order to quantitatively describe in detail geohydrologic systems having highly complex geometry, the investigator will have to turn to electric analog models which are more versatile in simulating aquifer conditions.

The case histories of ground-water development presented in this report point out the need to place more emphasis on tying together scattered and apparently disconnected studies of wells and aquifers into areal studies. It is apparent that quantitative answers depend primarily upon the accurate description of geologic conditions. In the future, more emphasis should be placed on relating the geology to hydrologic parameters.

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