ISWS/CIR-153/82
Circular 153
STATE OF ILLINOIS
DEPARTMENT OF ENERGY AND NATURAL RESOURCES

A Reassessment of Aquifer Conditions West of Normal Illinois

by SUSAN S. RICHARDS and ADRIAN P. VISOCKY

ILLINOIS STATE WATER SURVEY
CHAMPAIGN
1982

CONTENTS

Printed by authority of the State of Illinois
(6-82-100)

A Reassessment of Aquifer Conditions West of Normal, Illinois

by Susan S. Richards and Adrian P. Visocky

ABSTRACT

In 1980 the town of Normal pumped an average of 1.66 mgd (million gallons per day) of water from 3 production wells, tapping 3 deeply buried sand and gravel aquifers (upper, intermediate, and lower) in the Danvers Buried Valley located west of Normal. The wells were developed in 1974 after a period of extensive exploration and testing. Since the wells went into service in February 1976, pumpage has increased from 1.16 mgd to present levels. Large water level declines (20 to 30 feet) have occurred in a number of wells in the vicinity of Normal's west well field, resulting in some nearby farm wells going dry. These large declines were not predicted, because, as has now been determined, aquifer properties calculated from tests of the production wells (T = 442,000 gpd/ft; S = 0.11) were not representative of regional values. The model originally used in predicting the impact of pumping could not reproduce observed declines. Therefore, a new model, based on combined thicknesses of the intermediate and lower aquifer and representative regional aquifer properties (T = 165,000 gpd/ft; S = 0.001), was used to successfully predict observed declines in nearby observation wells. This new model predicts that pumping an average of 3.88 mgd—depending upon the spacing of the production wells—will cause additional declines of about 30-45 feet in nearby wells tapping the 3 deeply buried aquifers. Such an increased pumpage in Normal's well field will probably have negligible effects on other area pumping centers.

INTRODUCTION

The town of Normal's west well field, located about 8 miles from town, was developed in 1974 after numerous explorations of nearby sites for additional groundwater supplies. Following development of the Normal west well field, large declines in water levels were observed in a number of nearby wells. This report, which investigates these water level declines, is one of many studies that have been conducted on the groundwater resources used by the town of Normal.-

Studies of the groundwater resources used by Normal began as early as 1962. In a report written in October of that year (Walker, 1962), it was estimated that the town well fields in use at that time had a maximum potential yield of 3.6 mgd (million gallons per day), assuming that no prolonged drought occurred and industrial pumpage did not increase. In a later report, Schicht (1966) estimated that the safe yield of these aquifers would be exceeded in the year 2000. In order to meet projected water demands, new sources of water were needed. In an effort to develop additional groundwater supplies for Normal, an extensive groundwater exploration program was conducted along Sugar Creek south of Bloomington in 1965 and 1966. Because of the limited yield available there, this area was abandoned and attention was diverted to other areas. Kempton (1969a) suggested that a preglacial buried bedrock valley present in the area west of Normal and north of Stanford held potential for development of the required additional groundwater supplies. An intensive investigation of the hydrogeology of this area was begun in 1969. The geological investigation revealed that there were three deeply buried aquifers along the eastern edge of the Mackinaw Valley (the ancient Mississippi River system). Aquifer tests conducted in 1970 and 1971 proved favorable, and these deeply buried aquifers were developed in 1974 with a well field located in McLean County along Illinois Routes 9 and 22, between Danvers and Stanford. Production from this well field began in February 1976.

Prior to development of Normal's west well field, a thorough attempt was made to evaluate the impact of the proposed withdrawals from the deeply buried aquifers. Despite the thorough analysis, unexpected declines in water levels were observed after pumping began, and some nearby farm wells went dry. In February 1980, a meeting was held in which representatives of local farmers, State Senator John Maitland, and representatives of the Illinois State Water Survey discussed the problem. A reevaluation of the groundwater resources in the vicinity of Normal's west well field was promised at that time.

This report reevaluates the groundwater resources in the vicinity of the Normal west well field through a review of data in our files regarding previous work. On the basis of this review, a new model has been developed which more accurately predicts observed water level declines.

Acknowledgments

The authors are grateful to the many people who facilitated the data gathering for this study. These include Mr. Joseph Martin, Water Superintendent, Normal; Farnsworth and Wylie, consulting engineers, who provided pumpage data and background information; and the many farmers and residents of McLean and Tazewell Counties who allowed the principal author to measure water levels in their wells. Special thanks are due Mr. and Mrs. Stanley Harms for their generosity and great advance work which made the field work possible.

The project was conducted under the general supervision of Ellis W. Sanderson, Assistant Head, and James P. Gibb, Head, Groundwater Section, Illinois State Water Survey. Pamela Lovett typed the manuscript and the camera copy. Illustrations were prepared by William Motherway, Jr., and John W. Brother, Jr. Gail Taylor edited the manuscript.

HYDROGEOLOGY

Unconsolidated deposits of the Mackinaw Valley, located west of the town of Normal, Illinois, provided the town with an average water yield of about 1.66 mgd in 1980. The Mackinaw Valley is a preglacial bedrock valley which has been filled with sand and gravel and till ranging in thickness from 100 to over 400 feet. The study area (figure 1) is located over the confluence of three tributaries to the Mackinaw Valley which have formed a significant preglacial lowland area ranging from 3 to 10 miles wide (John Kempton, Illinois State Geological Survey, personal communication). The Danvers Valley, the principal tributary valley, trends southwest through the northwest corner of McLean County and into Tazewell County where it joins with the Mackinaw Valley (Piskin and Bergstrom, 1975).

Three major zones of water-bearing sand and gravel (aquifers) within the glacial materials in west central McLean County have been identified by Kempton (1969b). These aquifers are referred to as the upper, intermediate, and Sankoty or lower. All three aquifers are deeply buried in the bedrock valley fill (see figure 2).

The upper aquifer, suggested by Kempton to be a relatively narrow channel fill within the glacial deposits, lies in a narrow strip (about 1 mile wide) trending generally east-west along Route 9 in McLean County (see figure 3). It consists of fine to medium sand ranging in thickness from a featheredge at the boundaries to over 50 feet in the center of the strip. This aquifer thins eastward and is thin or absent in the southeastern portion of T.24N., R.1E., but continues east into the town of Normal where it again thickens and is tapped by Normal Wells 3 and 4. The top of the upper aquifer is usually encountered at elevations of 550 to 600 feet above mean sea level.

The intermediate aquifer extends from approximately the eastern edge of Section 6, T.23N., R.1E. to the Mackinaw River, and reaches a width of over 7 miles on a line just south of Danvers to south of Stanford. This aquifer consists of medium sand and gravel and ranges in thickness from 0 to over 50 feet. The intermediate aquifer both thickens and becomes more extensive towards the southwest. The top of this aquifer is usually encountered at elevations of 490-520 feet above mean sea level.

The lower aquifer, suggested by Kempton to be "Sankoty type," ranges from a fine sand to a coarse sand and gravel. It is the most widely distributed deposit in the valley, ranging up to 9 miles wide. It varies in thickness but averages about 50 feet. Where found, this sand lies immediately above the bedrock surface. The top of the lower aquifer occurs below an elevation of 450 feet above mean sea level.

These three aquifers are commonly separated by glacial till (a non-water-yielding, pebbly, silty, clayey material) of varying thickness. However, in some places, especially in the vicinity of Normal's west well field, the till separating the aquifers is thin or absent as illustrated by the cross section A-A' in figure 2. Therefore, where these aquifers are in direct contact, they act as a single hydrologic unit. Water level data indicate that groundwater in all three aquifers was originally under artesian or leaky-artesian conditions. Since pumping began, water-table conditions have developed in the vicinity of the well field.

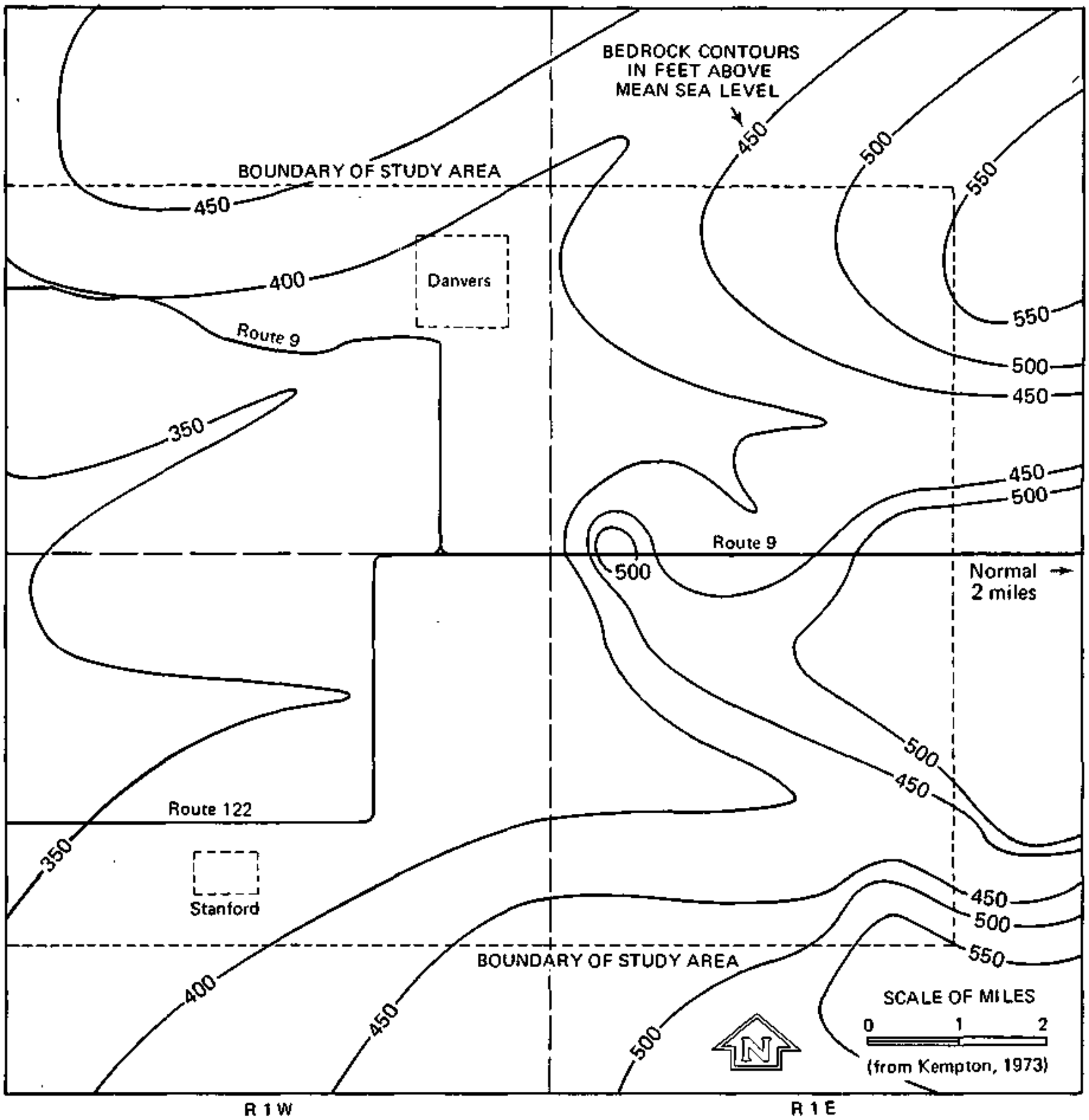


Figure 1. Location of study area

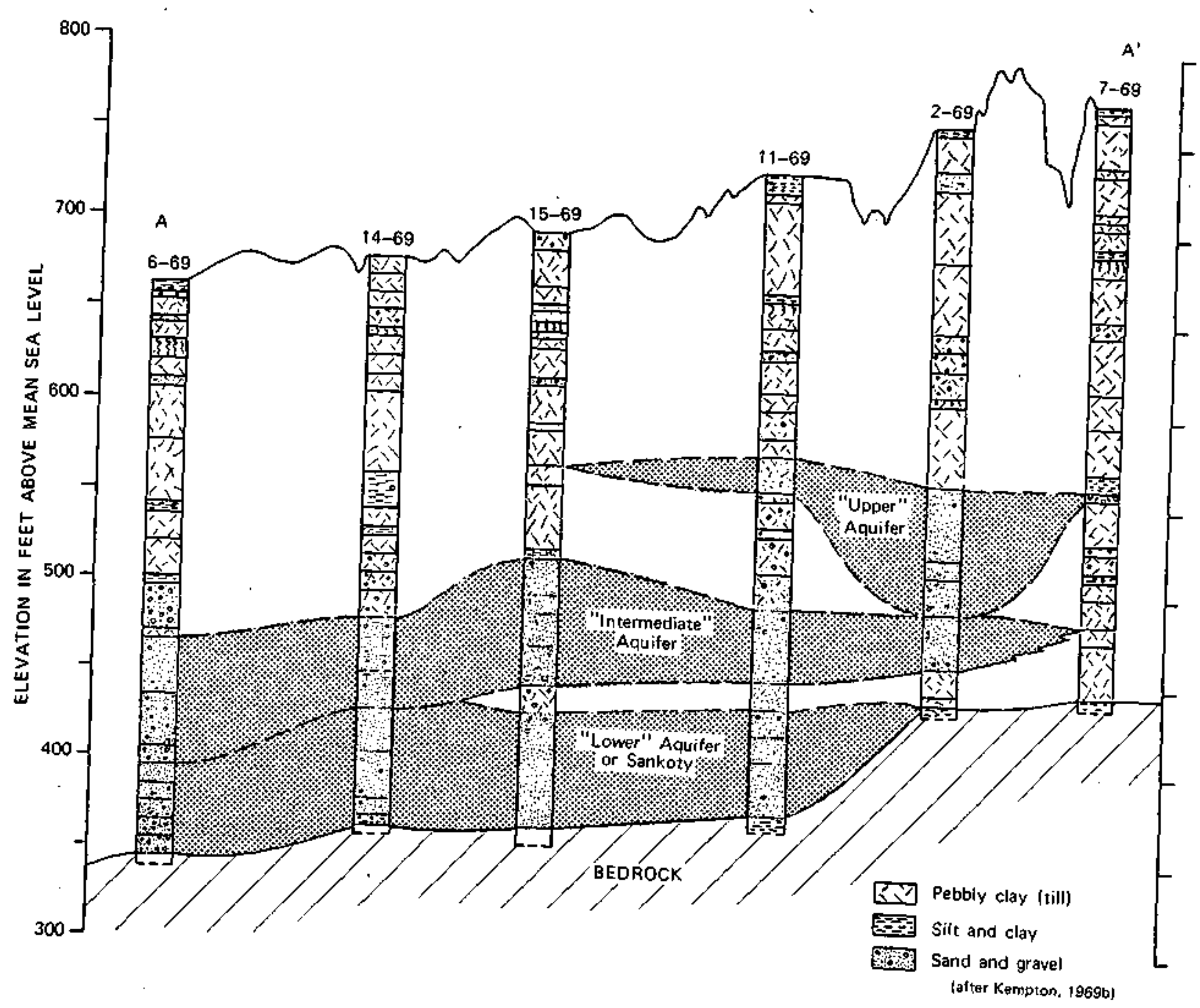


Figure 2. Geologic cross section of the valley fill (after Kempton, 1969b)

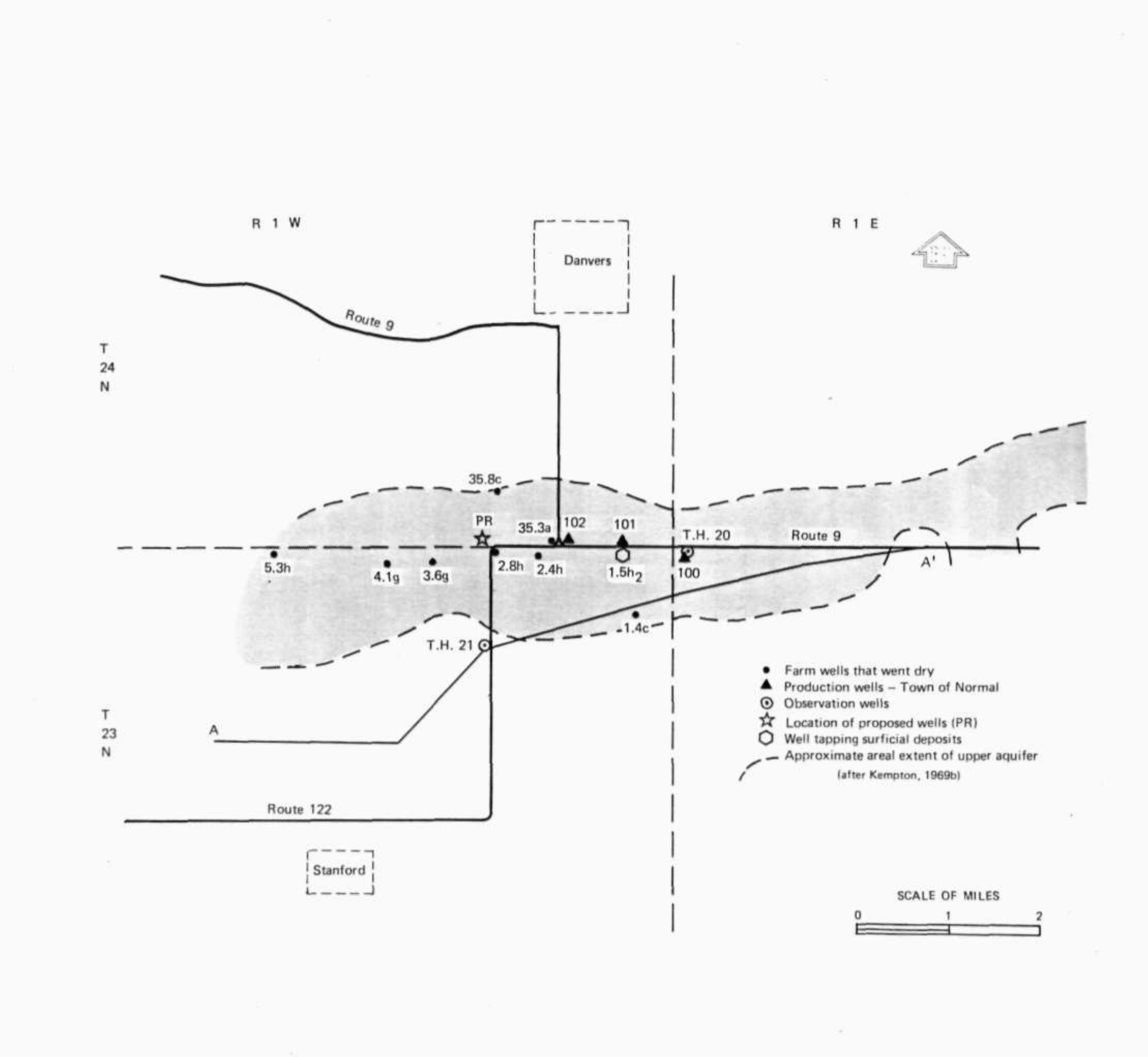


Figure 3. Detail of study area and approximate extent of upper aquifer

The three aquifers provide water to the major groundwater users in the region. The village of Danvers taps the lower aquifer, the villages of Stanford and Minier (located 5 miles west of Stanford) tap the intermediate aquifer, and the town of Normal taps all three aquifers. Additionally, some farm wells are drilled into each of these aquifers.

Recharge to the three aquifers is derived from precipitation. There is some evidence to suggest that the lower and intermediate aquifers derive a large portion of their recharge from the upper aquifer in the area where the upper and intermediate aquifers are hydraulically connected. Recharge to the upper aquifer is derived from percolation of precipitation through the thick surficial deposits.

At various depths in the 100 to 200 feet of surficial deposits above these major aquifers, scattered lenses of water-bearing sand and gravel are found in a silty, clayey till. The finer-grained till separates these sand and gravel lenses from the underlying (upper, middle, and lower) aquifers. Groundwater in these lenses occurs under both water-table and artesian conditions. Most farm and domestic wells in this region tap these surficial deposits, as is illustrated by well MCL 23N1W-1.5h2 in figures 3 and 4 (also see the appendix).

TEST DRILLING PROGRAM

John Kempton of the Illinois State Geological Survey (letter report to G. Farnsworth, 1969a) suggested to the town of Normal that the area northwest of Stanford held potential for development of additional groundwater supplies for the town. As a result of his recommendation a cooperative program of groundwater exploration was undertaken by the town of Normal; Farnsworth and Wylie, consulting engineers; the State Geological Survey; and the State Water Survey. Under the supervision of John Kempton, fifteen test holes were constructed in 1969 by the Layne-Western Company to depths ranging from 310 to 385 feet. These holes were located in Sections 10, 13, 15, and 17, T.23N., R.1W.; in Sections 5 and 6, T.23N., R.1E.; in Sections 32, 34, 35, and 36, T.24N., R.1W.; and in Sections 32, 33, and 35, T.24N., R.1E (Woller and Sanderson, in press 1982). Data from these test holes and other wells were studied by Kempton to map the distribution and extent of the aquifers present in the buried valley deposits. Based on aquifer thickness maps constructed by Kempton, two idealized aquifer models were proposed in order to make preliminary estimates of well field production. One model (Ml) represented the middle aquifer by a wedge with an apex angle of 30° and a thickness of 86 feet. The other model (M2) represented the lower aquifer by a semi-infinite strip 13,000 feet wide and 90 feet thick.

In late 1970, two test wells were drilled to test the aquifers for their water-bearing properties. The first well, Test Hole No. 20, is located 85 feet south and 165 feet east of the NW corner, Section 6, T.23N., R.1E. This well was drilled by Layne-Western Company to a depth of 268 feet and is finished in the intermediate aquifer. The second well, Test Hole No. 21, was drilled by Layne-Western Company to a depth

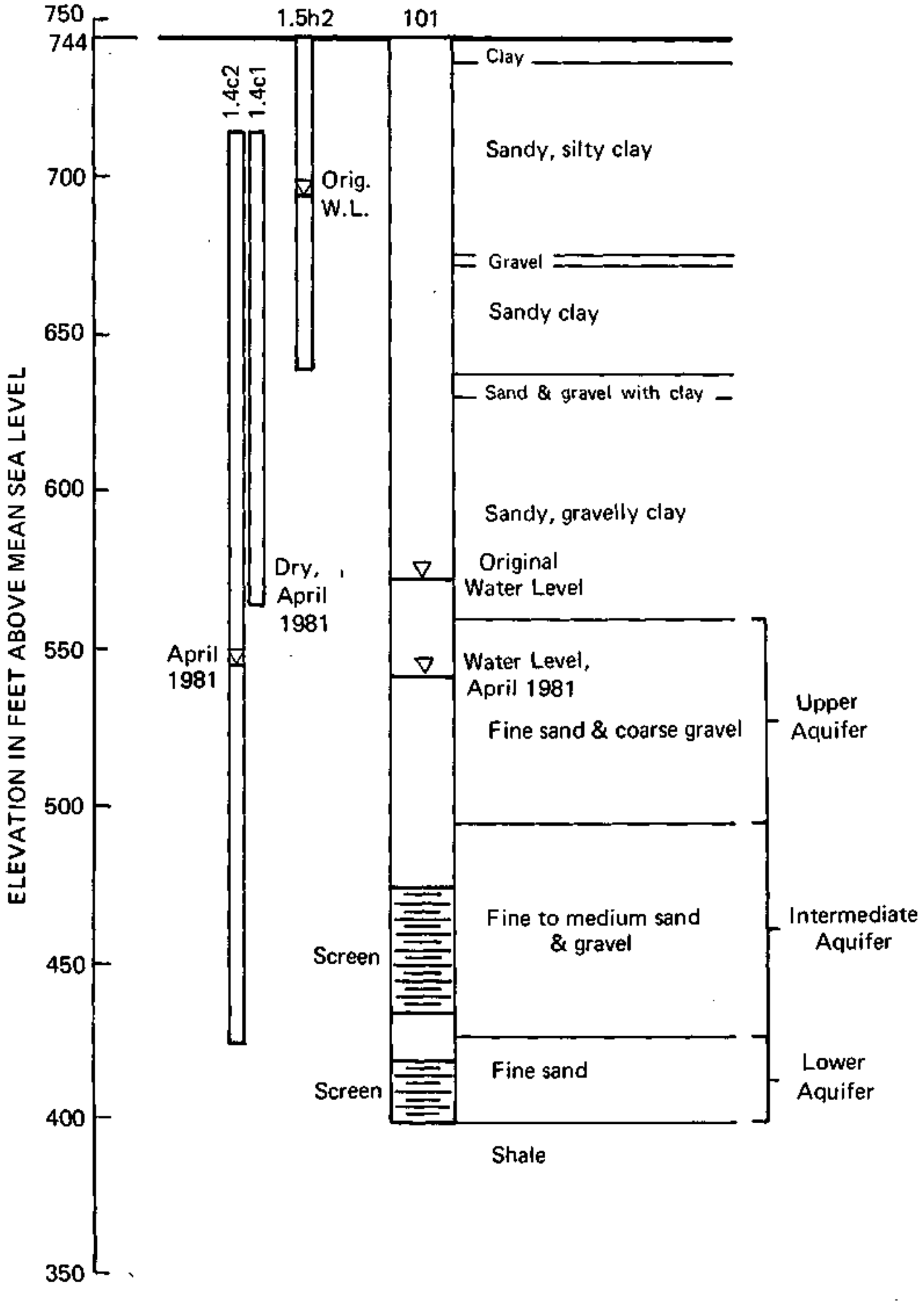


Figure 4. Simplified log of Production Well 101 and examples of domestic wells in surficial (1.5h2)s upper (1.461), and intermediate (1.4c2) aquifers

of 324 feet and is open to the lower aquifer. It is located approximately 75 feet south and 155 feet west of the NE corner of Section 10, T.23N., R.1W. The locations of Test Holes 20 and 21 are shown in figure 3.

A controlled aquifer test using four observation wells was conducted at Test Hole No. 20 on November 24-25, 1970, by representatives of the driller, the State Water Survey, and Farnsworth and Wylie, consulting engineers. The well was pumped at a constant rate of approximately 430 gpm (gallons per minute) for 24 hours. The transmissivity and storage coefficient computed from the test results were 286,000 gpd/ft and 0.01, respectively. Based on the idealized wedge-shaped aquifer model (M1) and the production test data, it was estimated that the intermediate aquifer could yield 1900 gpm (2.7 mgd) on a long-term basis from a properly constructed production well. It was also estimated that a multiple-well field consisting of four wells could develop from 4.0 to 7.0 mgd depending on whether half-mile or mile spacings between the wells were used.

A second controlled aquifer test at Test Hole No. 21 using four observation wells was conducted on January 5-6, 1971, by representatives of the driller, the State Water Survey, and Farnsworth and Wylie. The well was pumped for 24 hours at a constant rate of approximately 575 gpm. The computed transmissivity and storage coefficient were 119,000 gpd/ft and 0.0002, respectively. Based on the idealized semi-infinite strip aquifer model (M2) and the production test data, it was estimated that the deep aquifer was capable of yielding 600 gpm (0.86 mgd) on a long-term basis from a properly constructed production well. For this test, one of the observation wells, located 225 feet west of Test Hole No. 21, was completed at a depth of 106 feet to evaluate the effect of pumpage from the lower aquifer on water levels in the surficial deposits. For the duration of the test, pumping in Test Hole No. 21 had no effect on water levels in the well finished in the surficial deposits. It was therefore concluded that long-term pumping from the lower aquifer would also have no effect on wells finished in surficial deposits.

Based on the test results, the town of Normal decided to construct production wells tapping both the lower and intermediate aquifers. In 1974, Production Wells 100, 101, and 102 were drilled by Layne-Western Company (see figure 3). All three wells are screened in both the middle and lower aquifers. Figure 4 shows a simplified log and construction features of Well No. 101. All three production wells have similar logs and construction features. Well No. 100 was completed in November 1974 to a depth of 346 feet. It is located approximately 100 feet south and 100 feet east of the NW corner of Section 6, T.23N., R.1E. Well No. 101 was completed in September 1974 to a depth of 345 feet. It is located approximately 100 feet north and 2210 feet east of the SW corner of Section 36, T.24N., R.1W. Well No. 102 was completed in October 1974 to a depth of 364.2 feet. It is located at the northeast corner of Routes 9 and 122, approximately 100 feet north and 875 feet west of the SE corner of Section 35, T.24N., R.1W. Controlled aquifer tests were conducted on these three wells on October 1-2, October 22-23, and November 7-8, 1974. Wells 100, 101, and 102 were each pumped for 24 hours at constant rates of approximately 1440 gpm, 1409 gpm, and 1409 gpm, respectively. Computed transmissivities and storage coefficients are shown in table 1. Average values of transmissivity and storage coefficient were 442,000 gpd/ft and 0.11, respectively. On the basis of the production well test data and on the assumption that the combined aquifers could be represented by an idealized semi-infinite strip (M3) 11,000 feet wide and 125 feet thick, it was determined that each of the wells could safely pump 1000 gpm (1.44 mgd) on a long-term basis. With two wells, Nos. 100 and 102, each operating continuously at 1000 gpm (a total of 2000 gpm or 2.8 mgd) for 1 year without recharge, it was predicted that a maximum of 10 feet of interference could be expected in Well No. 101. In light of the very good test results, it was expected that pumping would have only a moderate impact on water levels in the area.

Table 1. Aquifer Properties Determined from Tests on Wells 100, 101, and 102

Production Well No.	Transmissivity (gpd/ft)	Storage coefficient
100	340,000	0.18
101	516,000	0.06
102	470,000	0.09
Average	442,000	0.11

WATER LEVELS AND PUMPAGE

To assess the effect of the development of the Normal west well field on water levels in the aquifers of the area, water levels before and after pumping began were studied.

Since February 1971 water levels have been measured periodically by the Illinois State Water Survey in Test Holes No. 20 and No. 21. Before pumping began, water levels in these wells fluctuated less than 2 feet (see figure 5). Pumping in Wells 100, 101, and 102 began in February 1976 and averaged 1.16 mgd for that first year. Annual average pumpage increased to 1.66 mgd in 1980. Figure 5 illustrates the effect of pumpage on water levels in Test Holes No. 20 and No. 21: water levels declined steadily as pumpage increased. Presently, water levels in Test Holes 20 and 21 are approximately 30 and 25 feet, respectively, below original static levels.

Regional water levels were studied by comparing the pre-development water levels with the post-development water levels (see the appendix). Pre-development water level data were obtained from drillers logs of wells drilled before 1976 in the area of interest. Post-development water level data were collected during a survey conducted between April 3 and 9, 1981, before spring recharge occurred.

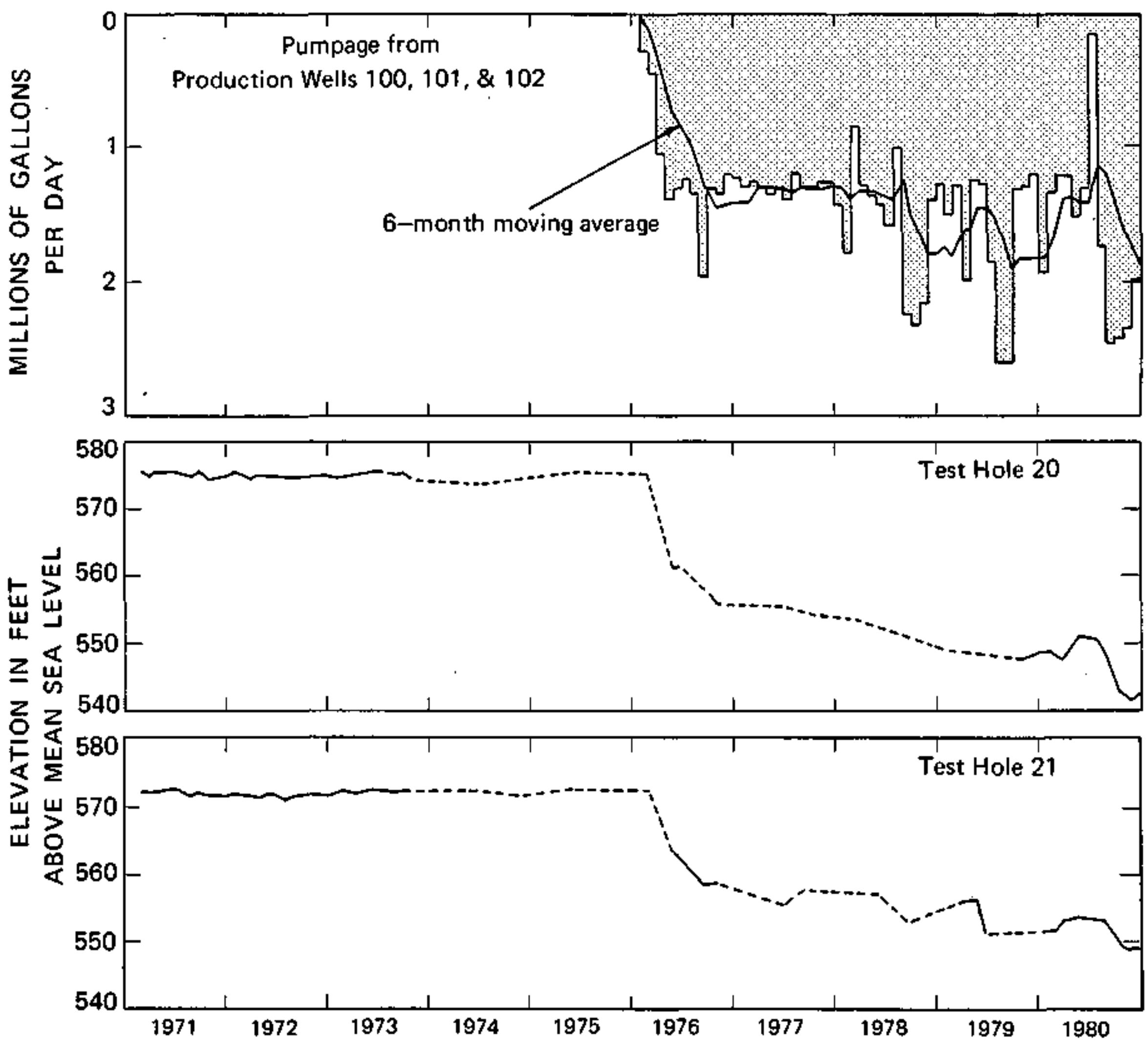


Figure 5. Pumpage and water levels in the Normal west well field

Figure 6 is a map of the approximate piezometric surface of the lower and middle aquifers prior to the start of pumping in the Normal well field. This map was constructed on the basis of pre-development water level data for wells tapping the lower and middle aquifers. Upon examination of available historic water level data, no significant difference in head between the two aquifers could be determined. It was therefore assumed that these aquifers act as a single hydrologic unit. This piezometric map indicates that groundwater in these two aquifers moves predominantly to the west and southwest towards the Mackinaw Buried Valley. Also seen in figure 6 is a local cone of depression caused by pumpage at Danvers. The pre-development piezometric surface generally reflects the bedrock topography.

Figure 7 is a map of the approximate piezometric surface of the lower and middle aquifers for April 1981. This map is based on data collected during April 3-9, 1981 and reflects not only the Danvers pumpage but also the Normal well field. It shows that water levels have been lowered in the vicinity of Normal's well field as a result of pumping, and that some water that formerly flowed towards the Mackinaw Buried Valley is being diverted into Normal's well field. One interesting feature of this map is the small mound seen to the west of Normal's production wells. The location of this mound in an area where the upper and intermediate aquifers are connected may reflect the influence of recharge from the upper aquifer to the intermediate and lower aquifers.

Figure 8 shows the magnitude of the difference in pre-development and April 1981 water levels. The greatest change in water levels occurred in the vicinity of the well field, where declines of over 30 feet are observed. No significant decline in water levels is observed beyond a radius of about 2 to 3 miles from Normal's wells.

Water levels also were measured in wells tapping the surficial deposits during the survey period. No significant changes of water levels in these shallower wells were noted when current water levels were compared with historic data. Therefore, as predicted, pumpage in the lower and middle aquifers appears to have little or no effect on wells drilled into the shallower aquifers. This is illustrated by Well MCL 23N1W-1.5h2 in figure 4. This well, finished in a sand and gravel lens in the surficial deposits, is still in use, even though it is located only about 700 feet from Well No. 101. Fluctuations of water levels in these wells are seasonal and can be expected to vary as much as 10 feet between wet and dry seasons.

RECHARGE

Recharge to aquifers in the vicinity of the Normal well field occurs locally as percolation of precipitation through the thick till. The quantity of recharge through these thick surficial deposits varies from place to place and is controlled by the vertical hydraulic conductivity and thickness of the surficial deposits. Comparisons of pumpage and

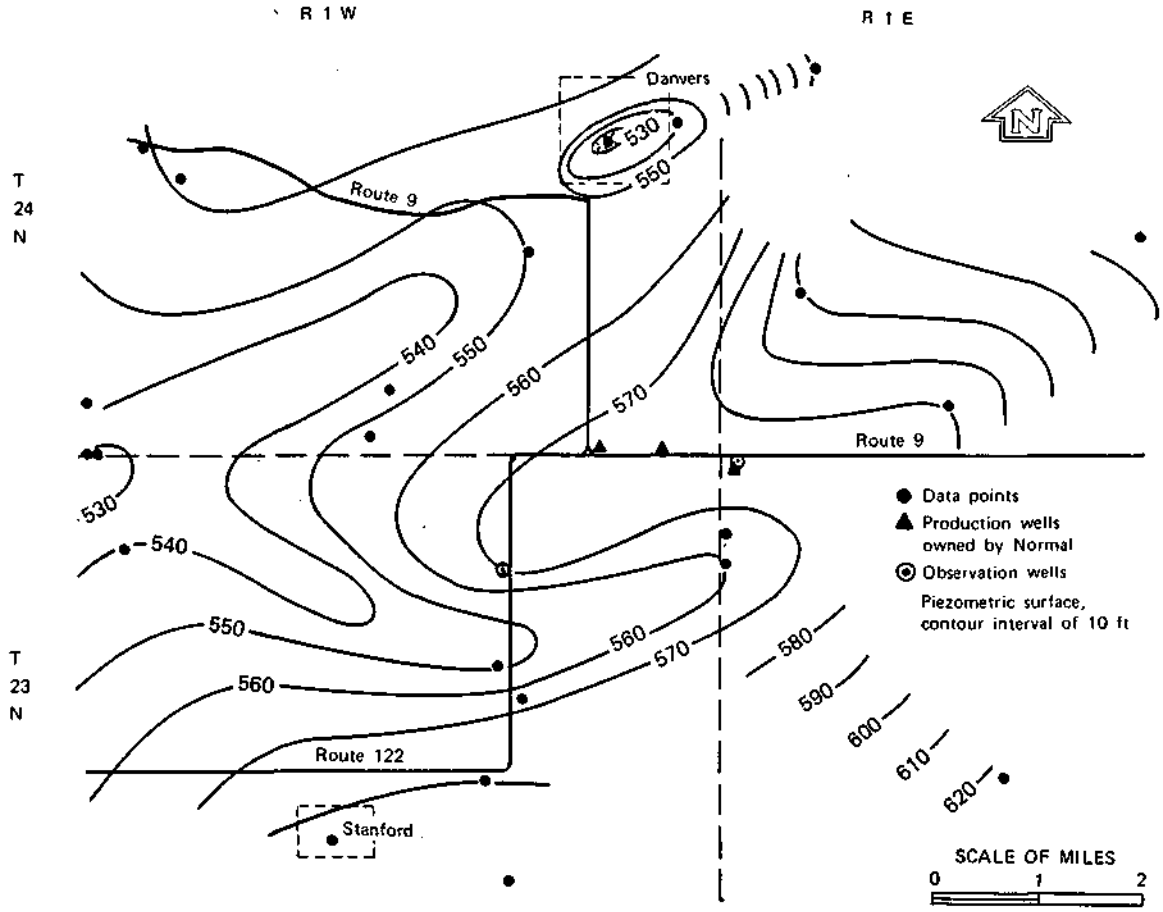


Figure 6. Approximate piezometvic surface of the lower and intermediate aquifers immediately before development

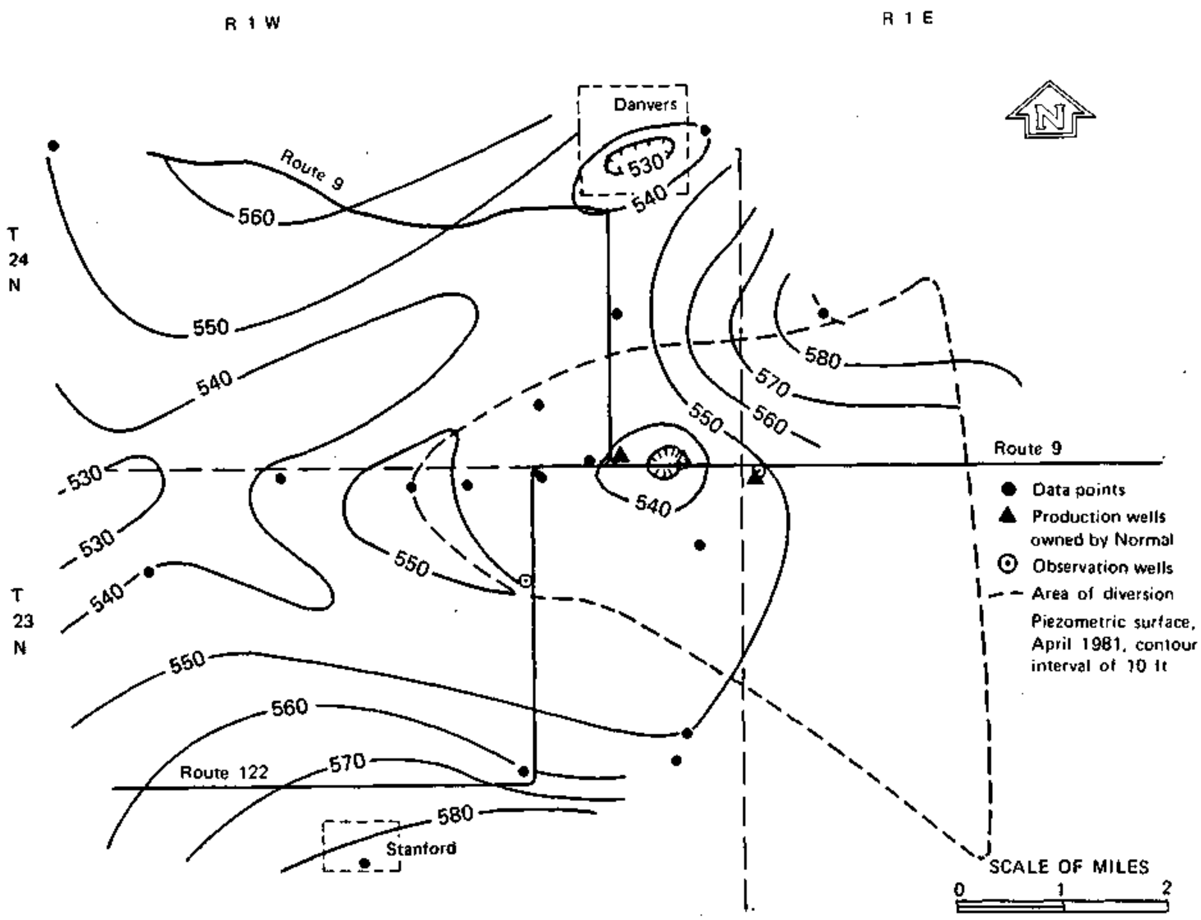


Figure 7. Approximate piezometric surface of the lower and intermediate aquifers, April 1981, and. area of diversion

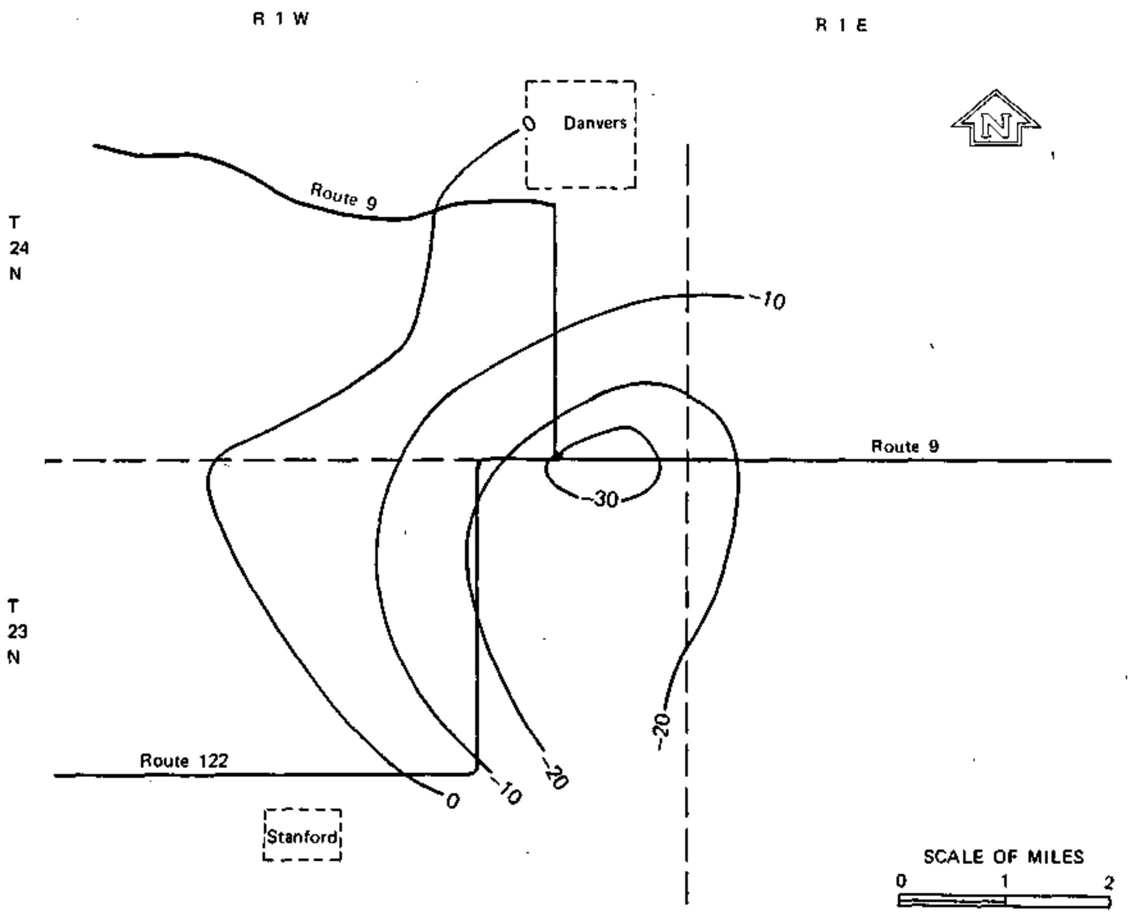


Figure 8. Changes in water levels by April 1981 in wells tapping the lower and intermediate aquifers

water level graphs (see figure 5) indicate that water level declines have been directly proportional to 6-month average pumping rates and that recharge has balanced discharge.

The rate of recharge to the intermediate and lower aquifers in the vicinity of Normal's west well field was estimated through use of the area of diversion and the 6-month average discharge rate (1.5 mgd) for April 1981. The area of diversion was delineated using the piezometric surface map in figure 7 and the aquifer thickness map in figure 9. The approximate boundaries of the area of diversion are shown in figure 7. The quotient of the quantity of discharge (recharge) and the area of diversion (17 square miles) is the rate of recharge, computed to be approximately 88,000 gpd/mi^2. This rate of recharge is at the lower end of the range of recharge rates (52,000-500,000 gpd/mi^2) given by Walton (1965) for drift aquifers. Table 2 lists examples of recharge rates for drift aquifers in Illinois.

Table 2. Recharge Rates for Glacial Drift Aquifers in Illinois

Location	Recharge rate (gpd/sq mi)	Character of deposits above aquifer	Aquifer
Libertyville, Lake County	52,000	Glacial drift, largely till, and shaly dolomite	Glacial sand and gravel
Woodstock, McHenry County	127,000	Glacial drift, largely till	Glacial sand and gravel
Near Joliet, Will County	200,000	Glacial drift, largely silt and sand	Glacial sand and gravel
Champaign-Urbana, Champaign County	115,000	Glacial drift largely till	Glacial sand and gravel
Havana region, Mason and Tazewell Counties	258,000	Glacial drift, largely till	Glacial sand and gravel
	279,000	Glacial drift, largely till	
	500,000	Glacial drift, largely sand and gravel	
	486,000	Glacial drift, largely sand and gravel	
Panther Creek Basin, Woodford, Livingston and McLean Counties	380,000	Glacial drift, largely till	Glacial drift

(from Walton, 1965)

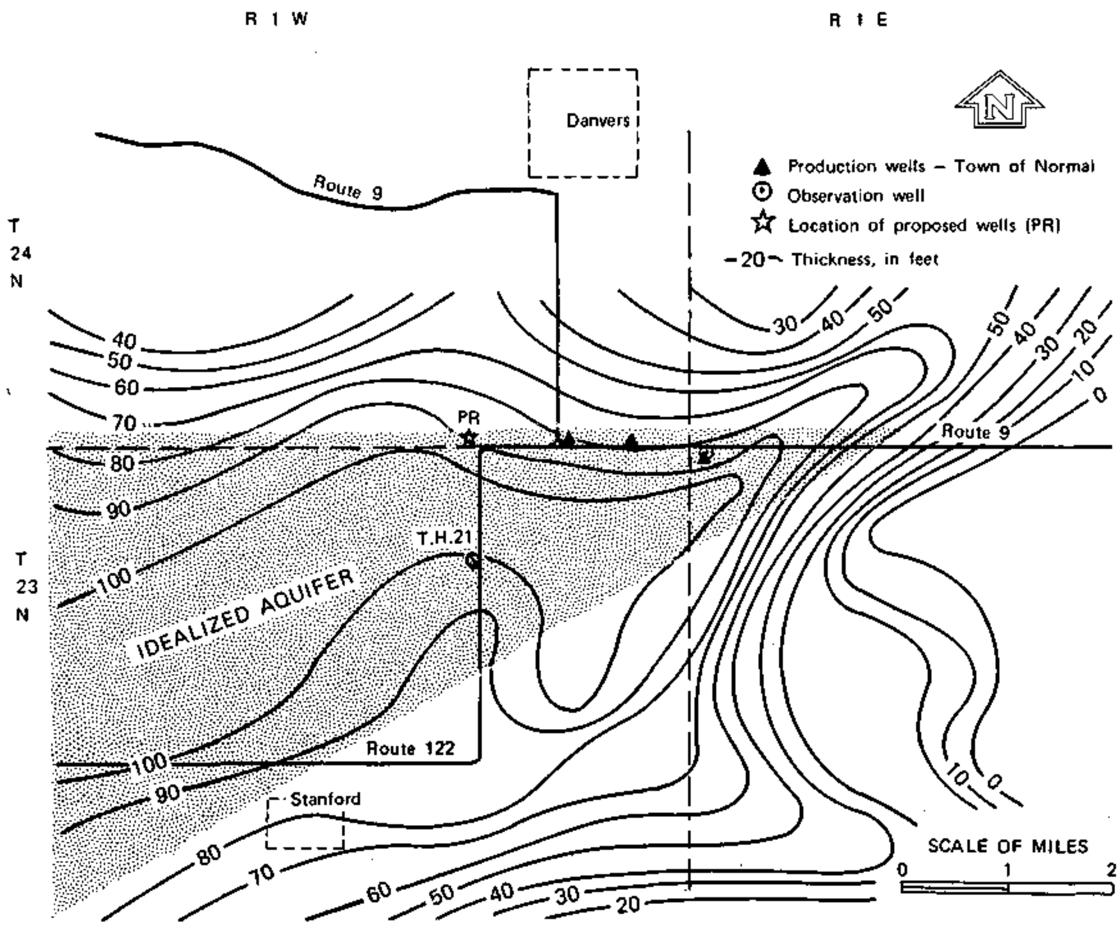


Figure 9. Combined thickness of the lower and intermediate aquifers

As shown in table 2, the aquifers at Champaign-Urbana are most similar geologically to the lower and intermediate aquifers west of Normal. The recharge rate (88,000 gpd/mi^2) for the intermediate and lower aquifers near Normal is relatively low compared to that given for Champaign-Urbana (115,000 gpd/mi^2).

Another approach used to estimate a recharge rate is to examine only the area where the upper aquifer is directly connected to the intermediate aquifer (see figures 2 and 4). If recharge to the intermediate and lower aquifers were derived entirely from the upper aquifer, the rate of recharge for that area would be the quotient of the quantity of discharge (1.5 mgd) and the area of the upper aquifer lying within the area of diversion (about 7 square miles). The recharge rate thus derived would be 214,000 gpd/mi^2. This recharge rate is also well within the range of recharge rates to drift aquifers given by Walton (see table 2) but is on the higher end of the range for deeply buried aquifers. It is our judgment that the actual recharge rate lies between 88,000 gpd/mi^2 and 214,000 gpd/mi^2.

Based on the geological and water level information and estimated recharge rates, it seems likely that the recharge rate to the lower and intermediate aquifers is locally greater where the upper aquifer is directly connected.

REEVALUATION

As previously discussed, a thorough aquifer testing program was conducted before the Normal west well field was developed. An evaluation of the impact of development was made in 1974 on the basis of the test results and available geologic data.

Analysis of data from the aquifer tests on Wells 100, 101, and 102 indicated that the combined aquifer (the lower and intermediate) had relatively high average values of transmissivity (T = 442,000 gpd/ft) and storage coefficient (S = 0.11). During the tests, no evidence of hydrologic boundaries was noted.

The aquifer model M3, which was used to predict the impact of pumping, represented the aquifers by a semi-infinite strip 11,000 feet wide and 125 feet thick. The aquifers were assumed to be homogeneous. The width of the semi-infinite strip in this model was less (by 2,000 feet) than that of the model M2 used in modeling Test Hole No. 21 and more conservative in concept than the 30° wedge used in model Ml for modeling Test Hole No. 20. The idealized aquifer thickness used in M3 is greater than that in either Ml or M2 to simulate the wells being screened in both the lower and intermediate aquifers. The effect of pumpage on the surficial deposits was not considered at this time because water levels in the 106-foot well used during aquifer testing at Test Hole No. 21 indicated that pumping the lower aquifer would not affect water levels in the surficial deposits. This idealized aquifer model (M3) was used in an attempt to predict drawdowns under actual rates of pumpage, assuming no recharge for 6 months. Drawdowns predicted using the model are compared with observed drawdowns in table 3.

Table 3. Observed and Predicted Drawdowns from Model 3

	Q (gpm)	Drawdowns in T.H. No. 21 (ft)	
		Predicted	Observed
December 1976	980	2.2	18
December 1980	1280	3.9	26

Observed drawdowns were much greater than predicted. This model (M3) therefore did not reflect the actual hydrologic conditions.

Reexamination of the distribution and extent of the aquifers as mapped by Kempton (1969b, unpublished) revealed that Wells 100, 101, and 102 are located in an area where the upper aquifer is directly connected to the intermediate aquifer (see figure 2). Because of the connection of the upper aquifer with the middle and lower aquifers at this location, aquifer properties calculated from the test results were not representative of regional values. The contribution from this upper aquifer resulted in high values of transmissivity (T), which, because of the limited areal distribution of the upper aquifer, were much higher than could be expected regionally. Additionally, upon test pumping, the upper aquifer converted from artesian conditions to water table' conditions, resulting in a relatively high value for the storage coefficient (S). However, these water table conditions existed only in the vicinity of the well field. Regionally, a representative value of S would be artesian and, hence, much lower. During tests of the wells, no boundary effects were observed in the data. The calculated radius of influence, using a transmissivity of 442,000 gpd/ft and a storage coefficient of 0.1, would have been only 1700 feet at the end of the test. Therefore, the radius of influence would not have reached the edges of the upper aquifer during testing. However, under long-term pumping conditions the radius of influence has encountered boundaries, and a different interpretation is necessary.

The lowering of water levels that occurred in the upper aquifer as a result of long-term pumping in the new well field had the effect of causing some farm wells that were drilled into the upper portion of the upper aquifer to go dry. The distribution of these wells is shown in figure 3. Note in figure 4 that a farm well (MCL 23NlW-1.4cl) located south of Well No. 101 tapped the upper aquifer. After pumping began, water levels declined below the bottom of this well, causing it to go dry. A new well at this site was drilled (MCL 23N1W-1.4c2) and finished in the lower aquifer.

This interference effect on the upper aquifer was not predicted, because the connection of the upper aquifer with the intermediate aquifer in the well field vicinity was not readily apparent. Rather, it was thought that the conditions found at the test wells were similar to those elsewhere in the study area. From the simplified log of Well No. 101 shown in figure 4, it is not apparent that there are three distinct aquifers present, yet all three deep aquifers—the upper, the intermediate, and the lower—are present at that location. Because of the limited areal extent of the upper aquifer, values for T and S calculated from production tests on Wells 100, 101, and 102 should not be considered as representative of regional values. Modifications to the original model (M3), with values of T and S more representative of regional values and with different periods of recharge assumed, were attempted but failed to accurately simulate observed drawdowns.

Because of the failure of the original model (M3) to explain observed declines in the well field, a new idealized aquifer model (M4) was developed. This model (M4) is based on the combined thicknesses of the intermediate and lower aquifers. Data suggest that a wedge-shaped model with an apex angle of 30° is reasonable (see figure 9). A regional value of transmissivity (T = 165,000 gpd/ft) was determined by multiplying the estimated average aquifer thickness (m = 75 feet) by a regional value of hydraulic conductivity (K = 2,200 gpd/ft^2). The regional value of hydraulic conductivity is an average of hydraulic conductivities computed from area aquifer tests (table 4). An artesian storage coefficient of S = 0.001 was assumed. Average values of T and S calculated from the production tests on Wells 100, 101, and 102 were used to predict interferences between wells in the well field. Table 5 shows the agreement between drawdowns predicted by this new model with actual observed drawdowns.

It was concluded that this new model (M4) reasonably simulated observed drawdowns, and furthermore could reasonably predict the impact of increasing pumpage in the future.

IMPACT OF FUTURE DEVELOPMENT

To examine the impact of increased pumpage and possible expansion of the Normal west well field, the new model was used with two pumping schemes. For both schemes, three wells would pump continuously at 900 gpm each (total of 3.88 mgd). In the first scheme, the three wells would be Wells 100, 101, and 102. In the second scheme, these wells would be Wells 100 and 102 and a new well (PR) located in the southeast corner of Section 34, T.24N., R.1W. (see figure 3). It was assumed no recharge to the aquifer would occur for 6 months. Table 6 presents the results predicted by the new model. These are worst-case examples; the pumping rate used here is more than twice the present average pumpage.

Table 4. Regional Summary of Aquifer Properties

Aquifer test	Transmissivity, gpd/ft (T)	Saturated thickness, ft (m)	Hydraulic conductivity, gpd/ft^2 (K)
Stanford No. 3	89,100	40	2,400
Danvers No. 3	38,500	32	1,200
Normal 100	340,000	139	2,400
Normal 101	516,000	230	2,200
Normal 102	470,000	173	2,700

Average K = 2,200 gpd/ft^2

Table 5. Observed and Predicted Drawdowns from Model 4

	Six-month moving average, pumpage (gpm)	Drawdowns in T.H. #21, ft	
		Predicted	Observed
July 1976	670	14.1	14
December 1976	980	20.8	18
December 1977	900	19.2	18
December 1978	1210	25.4	22
December 1979	1260	26.7	24
December 1980	1280	27.2	26

Table 6. Effects of Pumping Schemes Predicted by Model 4

	T.H. 20	T.H. 21	Private well*
Pumping Scheme No. 1 (3.88 mgd) Wells 100, 101, and 102			
Predicted drawdowns (ft)	82	57	70
Currently observed drawdowns (ft)	38	24	30
Additional expected drawdowns (ft)	44	33	40
Pumping Scheme No. 2 (3.88 mgd) Wells 100, 102, and PR			
Predicted drawdowns (ft)	76	56	66
Currently observed drawdowns (ft)	38	24	30
Additional expected drawdowns (ft)	38	32	36

*The private well considered here is located near the NW corner of the junction of Route 122 & Route 9 in Section 35, T.24N., R.1W., about 790 feet west of Well No. 102.

The data indicate that the combined middle and lower aquifers are probably capable of producing about 3.9 mgd (more than double the present production), but not without some adverse effects. If pumpage is increased, the area of diversion will increase and additional declines in water levels will occur.

An enlarged area of diversion would be necessary in order to capture enough recharge to balance increased pumpage. The area of diversion in April 1981 was approximately 17 square miles. Pumpage for that period averaged about 1.5 mgd. In order to balance pumpage of 3.88 mgd, an area of diversion of 44 square miles would be required, assuming a recharge rate of 88,000 gpd/mi^2.

In addition to an enlarged area of diversion, an increase in pumpage would cause additional water level declines. Again, as is illustrated in figure 8, these declines would be greatest in the vicinity of the pumping wells. The magnitude of declines resulting from increases in pumpage decreases as distance from the pumping wells increases.

Under the pumping schemes described above (Q = 3.88 mgd), water levels would be at or above the top of the intermediate aquifer in the vicinity of the pumping wells. Therefore, farm wells drilled into the intermediate or lower aquifers would not fail as a result of increased pumpage. However, the additional dewatering of the upper aquifer that would result would make the upper aquifer useless as a dependable source of water in the vicinity of Normal's west well field. The private well listed in table 6 is about 230 feet deep, and is finished in the upper aquifer. Water levels in this well are presently about 193 feet below ground surface. An additional 36-40 feet of drawdown in this well would cause it and probably some other area farm wells still tapping the upper aquifer to go dry, or to lose production capacity.

In the study area, almost all of the expected water-level declines resulting from pumpage increases are due to boundary effects. The closer the center of pumpage is to the boundaries, the greater the drawdowns to be expected in the aquifers. This can be illustrated by the predicted drawdowns for the private well shown in table 6. Although the private well would be closer to the pumping wells in the second scheme, the center of pumpage is farther from the boundaries. Therefore, when the second scheme is used, the expected drawdowns in this well are less than those predicted for the first scheme.

Currently, water levels in other area pumping centers (Danvers, Stanford, and Minier) are not affected by pumping from the Normal west well field. Little or no interference is expected at those pumping centers should Normal increase the pumpage from its west well field. If pumpage from Normal's west well field should increase to as much as 3.88 mgd, interference at Danvers and Stanford should be no more than a few feet, and at Minier there should be none.

CONCLUSIONS

The three deeply buried sand and gravel aquifers found in the unconsolidated glacial deposits west of the town of Normal, Illinois, now , provide the town with an average of 1.66 mgd (about 66% of Normal's total water use). Prior to development of these aquifers by Normal's wells, an extensive program of exploration and aquifer evaluation was undertaken to determine their extent and potential yield.

In 1974, the town of Normal had 3 production wells built and tested. Since 1976, when Normal first began pumping from the west well field, daily withdrawals have increased from an average of 1.16 mgd in 1976 to an average of 1.66 mgd in 1980. Pumping has caused large water level declines (20 to 30 feet) in wells located near the Normal west well field, causing some farm wells in the vicinity of the Normal wells to go dry. These declines were larger than those predicted from the original idealized aquifer model (M3).

Upon reevaluation of the groundwater conditions in the vicinity of the town of Normal's west well field, a new idealized aquifer model (M4) was developed. The new model is based upon the combined thicknesses of the lower and intermediate aquifers. It predicts observed drawdowns reasonably well, based on average 6-month pumping rates.

The new model (M4) was also used to predict the impact of increased pumpage, and of expansion of the Normal west well field by addition of a well located 1 mile west of the present well field. The new model predicted that under increased pumpage (3.88 mgd), and depending upon the spacing of the production wells, additional water level declines of 30-45 feet could be expected in the vicinity of the well field. Additionally, wells on some farms (including some recently deepened because of water-level declines) could go dry. The effects of increased pumpage in Normal's west well field on other area pumping centers would be minimal.

Continued monitoring of water levels and pumpage in the three deeply buried aquifers (upper, intermediate, and lower) is recommended in order to validate the new idealized aquifer model (M4) presented here. It is also recommended that new wells drilled in the vicinity of Normal's west well field (in about a 3 mile radius) be finished if possible at least as deep as the lower portion of the intermediate aquifer to ensure a dependable groundwater supply.

REFERENCES

Kempton, John P. February 10, 1969a. Distribution of Potential Sand and Gravel Aquifers in Western McLean County, Illinois. Illinois State Geological Survey unpublished letter report to George Farnsworth.

Kempton, John P. 1969b. Unpublished maps and correspondence on file with the Illinois State Geological Survey.

Kempton, John P. 1973. Unpublished maps on file with the Illinois State Geological Survey.

Piskin, Kemal, and Robert Bergstrom. 1975. Glacial Drift in Illinois. Illinois State Geological Survey Circular 490.

Schicht, Richard J. 1966. Ground-Water Availability for the City of Normal. Illinois State Water Survey unpublished open-file, report prepared for Statewide Water Plan.

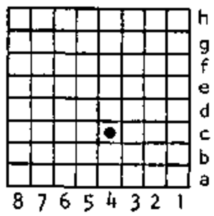
Walker, W. H. October 19, 1962. Groundwater Availability in the Vicinity of Normal, McLean County, Illinois. Illinois State Water Survey unpublished open-file report.

Walton, William C. 1965. Ground-Water Recharge and Runoff in Illinois. Illinois State Water Survey Report of Investigation 48.

Woller, Dorothy, and Ellis Sanderson. In press 1982. Public Groundwater Supplies in McLean County. Illinois State Water Survey Bulletin 60 series.

APPENDIX: WATER LEVEL DATA FOR WELLS

The well-numbering system used in this appendix 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 of a quarter section. A normal section of 1 square mile contains 8 rows of 1/8-mile squares; an odd-sized section contains more or fewer rows. Rows are numbered from east to west and lettered from south to north as shown in the diagram.



The number of the well shown above is MCL 24NlW-23.4c. 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:

McLean MCL   Tazewell TAZ

Symbols shown indicate the following:

† - see text for definitions of aquifer designations
* - well depth sounded
** - well depth reported by owner

Water Level Data for Wells

Well number	Land surface elevation (ft above msl)	Depth of well (ft)	Aquifer Designation†	Water-level elevation (ft above msl) Pre-1976	April 1981	Remarks
MCL 23N1E-						
4.8h	790	86	Surficial	711		
5.3g	790	85	Surficial	740		
5.4d	760	60	Surficial	725		
6.3h	760	90	Surficial	715		
6.8b	720	226	Intermediate	564		
6.8h1	735	268	Intermediate	576	548.6	Test Hole 20
6.8h2	735	345	Intermediate and lower	573		Normal Well No. 100
7.1b	700	45	Surficial	660		
7.8d	700	80	Surficial	655		
7.8h	730	190	Intermediate	560		
8.3d	720				641.1	
8.5h	720	104	Surficial	656		
15.4h	740	107	Surficial	683		
15.8c	730	96	Surficial	684		
16.3a	710	180	Intermediate	625		
17.7b	695	40	Surficial	670		
17.7g	701	71	Surficial	671		
18.5g	700	80	Surficial	660		
19.7a	700	86	Surficial	644		
20.1a	711	75	Surficial	661		
21.2a	710	160	Surficial	685		
21.6g	705	120*	Intermediate		660.3	
MCL 24N1E-						
7.7d	815	70	Surficial	749		
8.1d	810	127	Surficial	750		
18.1a	840	250	Surficial	650		
18.1e	820	271	Intermediate	615		
18.7a	830	198	Surficial		646.0	

Water Level Data for Wells (Continued)

Well number	Land surface elevation (ft above msl)	Depth of well (ft)	Aquifer Designation†	Water-level elevation (ft above msl) Pre-1976	April 1981	Remarks
MCL 24N1E-(cont'd)						
19.4d	865	240	Surficial	665		
20.1c	820	190	Surficial	680		
21.1g	810	160	Surficial	720		
21.4e	810	203	Surficial	649		
21.6e	810	152	Surficial	703		
22.1a	775	285	Intermediate	625		
22.2f	790	55	Surficial	754		
22.8e	800	120	Surficial	725		
27.3c	790	133	Surficial	710		
28.5d	820	206	Surficial	653		
28.7g	815				665.6	
29.1g1	800	43	Surficial	770	781.0	
29.1g2	800	140	Surficial		675.0	
29.4a	820	212	Surficial	720		
29.4g	845	160	Surficial		769.8	
30.2d	815	305	Intermediate	600	589.6	
29.5b	800	20*	Surficial		792.4	
30.4c	790	195	Surficial	695		
30.6h	830	248	Surficial	616		
31.5a	710	20	Surficial		702.5	
31.6a	720	163	Surficial	607		
32.3c	800	160	Surficial	750		
32.3e	790	157	Surficial	673		
32.5e	760	133	Surficial	737		
33.1f	765	48	Surficial	740		
33.5a	750	88	Surficial	707		
33.7d	780	240	Intermediate	580		
34.6h	780	160	Surficial	660		

Water Level Data for Wells (Continued)

Well number	Land surface elevation (ft above msl)	Depth of well (ft)	Aquifer Designation†	Water-level elevation (ft above msl) Pre-1976	April 1981	Remarks
MCL 23N1W-						
1.3h	740	110	Surficial	680		
1.4c1	715	150**	Upper			Went dry soon after pumping began
1.4c2	715	320	Intermediate		545.0	
1.5h	745	105	Surficial	695		
2.4a	700	80	Surficial	630	647.8	
2.4h1	720	180	Intermediate	567		Went dry in 1976
2.4h2	720	185**	Intermediate		539.4	
2.7a	700	136	Upper	625	638.4	
2.8h1	715	99	Upper	640		Went dry in 1978
2.8h2	715	176	Intermediate		543.0	
3.1h	715	100	Upper	645		
3.6g1	710	137	Upper	635		Went dry in 1976
3.6g2	710	331	Lower		550.2	
4.1e	700	80	Surficial	650		
4.1g1	705	86**	Upper			Went dry in 1978
4.1g2	705	280	Lower		546.8	
4.4h	720	140	Upper	605		
5.3h2	685	90	Surficial	640		
5.3h3	685	290	Intermediate		548.6	
5.7a	680	110	Surficial	593		
6.4a	670	203	Intermediate	545		
6.5a	670	184	Intermediate	548	545.8	
6.7h	670	210	Intermediate	520		
6.7h	670	292	Lower	530		
6.8h	665	292	Lower	525		
7.4a	666	92	Surficial	582		
8.3a	675	85	Upper	602		
8.5d	675	63	Surficial	634		
8.5h	680	90	Upper	635		
9.2d	700	158	Upper	599		
9.8h	700	90	Surficial	640		

Water Level Data for Wells (Continued)

Well number	Land surface elevation (ft above msl)	Depth of well (ft)	Aquifer Designation†	Water-level elevation (ft above msl) Pre-1976	April 1981	Remarks
MCL 23N1W-(cont'd)						
10.1h	693	324	Lower	572	554.2	Normal Test Hole No. 21
10.3h	700	100	Surficial	645		
10.7a	680	77.5*	Surficial		630.1	
11.2a	690	52	Surficial	652		
11.3hl	690	86	Surficial	637		
12.4g	700	77	Surficial	650		
12.5e	695	65*	Surficial		648.0	
13.2d	700	93	Surficial	674		
13.3e	680	82*	Surficial		613.4	
13.5e	690	230**	Lower		548.1	
13.6c	695	250**	Lower		550.3	
14.4h	700	80	Surficial	660		
14.7f	700	217	Intermediate	572		
15.1b	695	295	Lower		556.5	
15.1h	690	186	Intermediate	545		
15.2h	690	82	Surficial	634		
15.2h	695	186	Surficial		632.3	
15.8b	675	114	Surficial	610		
15.8g	677	106	Surficial	618		
15.8h	677	70	Surficial	637		
16.2h	675	85	Surficial	630		
16.8a	670	145	Surficial	622		
17.1a	670	96	Surficial	625		
17.2h	675	98	Surficial	617		
17.5h	671**	90	Surficial	631	624.0	
17.7a	665	74	Surficial	620	614.1	
18.2a	660	109	Surficial	585	608.5	
18.8b	660	130	Surficial	618		
18.8d	660	107	Surficial	592		
18.8g	660	136	Surficial	584		

Water Level Data for Wells (Continued)

Well number	Land surface elevation (ft above msl)	Depth of well (ft)	Aquifer Designation†	Water-level elevation (ft above msl) Pre-1976	April 1981	Remarks
MCL 23N1W-(cont'd)						
20.1h	670	82	Surficial	618		
20.4a	660	88	Surficial	587		
20.8g	660	75	Surficial	585		
21.5c4	680	247	Intermediate	584	594.0	Stanford No. 3
22.2h	680	228	Intermediate	580		
22.6a	660	88	Surficial	610		
24.6a	695	77	Surficial	657		
26.4h	675	62	Surficial	642		
26.8h2	670	197	Intermediate	582		
27.8f	660	90	Surficial	605		
29.4c1	650	65	Surficial	605		
29.4c2	650	95**	Surficial		586.2	
29.5f	660	140	Surficial	597		
30.4h	660	78	Surficial	593		
30.7b1	660	106	Surficial	594		
30.7b2	660	165	Intermediate	567	563.3	
30.8f	660	98	Surficial	602		
32.4f	660	110	Surficial	604		
32.8d	642	70	Surficial	592		
33.4e	655	88	Surficial	619		
MCL 24N1W-						
11.1f	794	176	Surficial	708		
11.2a	802	190	Surficial	702		
11.2a	802	339	Lower	613		
13.4a	820	362	Lower	538	548.7	
15.5g	805	220	Surficial	605		
17.2e	840	286	Surficial	589		
19.1d	770	227	Intermediate	568		
19.4f	772	335	Lower	553		
20.1e	765	235	Surficial	641		

Water Level Data for Wells (Continued)

Well number	Land surface elevation (ft above msl)	Depth of well (ft)	Aquifer Designation†	Water-level elevation (ft above msl) Pre-1976	April 1981	Remarks
MCL 24N1W-(cont'd)						
21.5c	730	159	Surficial	649		
22.2c	781	71	Surficial	741		
23.1g	825	428	Lower	541	522.0	Danvers No. 3
23.1h	830	438	Lower	554		Danvers No. 4
22.5c	790	175	Surficial	710		
26.1b	750	148	Surficial	630		
26.2d	765	250	Intermediate		545.3	
26.7g	750	217	Intermediate	550		
28.1a	730	170	Surficial	590		
28.2a	740	54	Surficial	700	700.9	
29.1h	720	23	Surficial		702.3	
29.5a	702	132	Surficial	598		
30.5d	702	185	Surficial	582		
31.3a	690	134	Upper	600		
31.3g	685	122	Surficial	580		
31.8c2	674	129	Intermediate	545		
33.1d	720	203	Intermediate	537		
33.3a	695	164	Intermediate	555		
34.5d	730	125	Surficial	630		
35.2a	740	364	Intermediate and lower	573		Normal No. 102
35.3a1	734	110	Surficial	644		
35.3a2	734	214	Upper	585		
35.3a3	734	230	Intermediate		543.0	Went dry in 1981
35.6a	720	100	Surficial	646		
35.8e1	745	160				Went dry in 1978
35.8e2	745	260	Lower		544.9	
36.4b	740	100	Surficial	680		
36.5a	740	345	Intermediate and lower	567		Normal No. 101

Water Level Data for Wells (Continued)

Well number	Land surface elevation (ft above msl)	Depth of well (ft)	Aquifer Designation†	Water-level elevation (ft above msl) Pre-1976	April 1981	Remarks
TAZ 23N2W-						
1.1d	670	95	Surficial		580.7	
2.4c	650	153	Upper	602		
2.5h	667	132	Upper	639		
3.3h	660	167	Upper	594		
3.5b	650	121	Upper	614		
4.5h	660	200	Intermediate		551.4	
10.1e1	660	141	Surficial	561		
10.1e2	660	162	Surficial	598		
10.5f	660	133	Surficial	568		
12.1f	660	151	Surficial	610		
12.4a2	660	169	Surficial	589		
13.5h	655	134	Surficial	615		
13.5h	655	168	Intermediate		553.0	
14.3a	645	195	Intermediate	545		
14.5a	640	130	Surficial	560		
15.4b	640	168	Intermediate	542		
22.4b1	635	193	Intermediate		562.0	Minier No. 3
22.4b2	635	193	Intermediate		551.9	Minier No. 4
24.8h	646	105	Surficial	617		
24.1c	660	109	Surficial		581.0	
25.8d	640	100	Surficial	610		
36.2a	625	100	Surficial	585		
TAZ 24N2W-						
1.4b	750	290	Intermediate		549.0	
11.4a	780	340	Intermediate		533.0	
11.6a	780	250	Surficial		600.0	
11.6d	750	315	Intermediate	525		
12.3d	780	256	Surficial		590.0	
13.8f	800	233	Surficial	600		

Well number	Land surface elevation (ft above msl)	Depth of well (ft)	Aquifer Designation†	Water-level elevation (ft above msl) Pre-1976	April 1981	Remarks
TAZ 24N2W-(cont'd)						
14.1e	800	294	Surficial		540.0	
14.2e	803	350	Intermediate	543		
14.2g	790	351	Intermediate	533		
15.3h	750	291	Intermediate		533.0	
24.4h	735	249	Intermediate		549.6	
25.1a	685	120*	Upper		578.8	
33.8a	659	150	Upper	610		
34.3a	670	165	Upper	610		