Ground-Water Pumpage and Water-Level Changes in the Milwaukee-Waukesha Area Wisconsin, 1950-61

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Prepared in cooperation with the University of Wisconsin, Geological and Natural History Survey

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By J. H. GREEN *and* R. D. HUTCHINSON

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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ILLUSTRATION

[Plates are in pocket]

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GROUND-WATER PUMPAGE AND WATER-LEVEL CHANGES IN THE MILWAUKEE-WAUKESHA AREA, WISCONSIN, 1950–61

By J. H. GREEN and R. D. HUTCHINSON

ABSTRACT

Artesian water pressure in the deep sandstone aquifer continued to decline throughout most of the Milwaukee-Waukesha area, Wisconsin between 1950 and 1961. Areas of greatest water-level decline were in northeast Waukesha County and in northwest Milwaukee County. The chief cause of the decline was continued heavy pumpage.

The major aquifers of southeastern Wisconsin are the Niagara aquifer, which is primarily Niagara Dolomite of Silurian age, and the sandstone aquifer, which consists of sandstones of Cambrian and Ordovician ages. Locally, the glacial sands and gravels of Pleistocene age also are important aquifers. In the Milwaukee-Waukesha area, the sandstone aquifer is completely artesian, confined above by the Maquoketa Shale. The Niagara aquifer is generally unconfined.

Pumpage from the sandstone aquifer in the Milwaukee-Waukesha area decreased from about 23.3 million gallons per day in 1950 to about 20.9 million gallons per day in 1961. The principal reason for decreased pumpage was substitution of surface-water supply from Lake Michigan. Between 1950 and 1961, the water-level changes in wells in the sandstone aquifer ranged from plus 10 feet at Town of Lake to minus 98 feet in northwest Milwaukee. Except for a small area near Town of Lake, water levels in wells in the Milwaukee-Waukesha area were lower in 1961 than in 1950.

Water-level changes were directly related to the pumpage pattern and pumpage changes. Increased pumpage at Waukesha and in northwest Milwaukee and continued heavy pumpage at Wauwatosa caused widespread water-level declines in northeast Waukesha County and in northwest Milwaukee County. Locally, decreased pumpage at West Milwaukee allowed limited recovery of water levels since 1957.

Estimates of pumpage through the year 1975 indicate a pumpage decrease in the middle 1960's, followed by an increase in the late 1960's and early 1970's. Additional conversion to surface-water supply in Milwaukee County will account for most pumpage decreases. Increased pumpage is most likely in Waukesha County where the population is expanding rapidly and an adequate surface-water supply is not readily accessible. The westward shift of the pumpage pattern may cause an additional water-level decline of about 50 feet at Waukesha but will permit water levels to recover about 100 feet at West Allis by 1975.

Partial or complete conversion to surface-water supplies by municipalities that depend entirely on water from the sandstone aquifer would allow greater use of the sandstone aquifer by isolated suburban developments and industries.

INTRODUCTION

Artesian water levels in the Milwaukee-Waukesha area began declining in the late part of the 19th century coincident with the development of the artesian aquifer. The report by Foley, Walton, and Drescher (1953) indicated that pumpage from deep wells was increasing and was likely to continue increasing in the years after 1950; also, into 1950, artesian water levels continued to decline and were expected to decline more in the future. During the 1950's artesian pressure continued to decline in the Milwaukee-Waukesha area and in surrounding counties of southeastern Wisconsin.

The long-term pumpage increase in the Milwaukee-Waukesha area has lowered water levels in deep wells in a large part of southeastern Wisconsin. The area of declining water levels includes all of Milwaukee and Waukesha Counties and parts of Dodge, Jefferson, Kenosha, Ozaukee, Racine, Walworth, and Washington Counties. Meanwhile, pumpage in the Chicago region has produced deep and extensive cones of depression and diverted part of the water in the sandstone aquifer out of southeastern Wisconsin.

The purposes of this report are to determine effects of ground-water pumpage on water levels in the Milwaukee-Waukesha area for the period 1950–61 and in adjacent counties in southeastern Wisconsin, to determine effects of pumpage in the Chicago region on water levels in southeastern Wisconsin, and to predict possible future trends in ground-water conditions. This report also is intended to provide hydrologic information that will facilitate the planning and development of water resources and to serve as a brief hydrologic background for more detailed studies in southeastern Wisconsin.

This investigation is part of a statewide cooperative program of the U.S. Geological Survey and the University of Wisconsin Geological and Natural History Survey. It was planned and conducted with G. F. Hanson, State geologist, and under the supervision of C. L. R. Holt, Jr., district geologist, Geological Survey.

Pumpage data for municipalities were supplied by the Public Service Commission of Wisconsin. Special thanks are extended to the industries, commercial establishments, and other water users for their time and consideration in furnishing the best possible reports of ground-water withdrawals. Appreciation is expressed also to the many well owners who allowed access for water-level measurements. Without the cooperation of the public-spirited concerns and individuals mentioned above, a ground-water appraisal such as this would not be possible.

GEOLOGIC SETTING

Rock units in southeastern Wisconsin range from Precambrian to Recent in age. Units older than the Niagara Dolomite of Silurian age do not crop out in the Milwaukee-Waukesha area; in the remainder of southeastern Wisconsin, outcrops of rocks older than the Niagara are scarce. In this report, these older formations are described mainly from their subsurface characteristics as determined by the Wisconsin Geological and Natural History Survey from well cuttings.

Rocks of Precambrian age have been identified in only a few wells in southeastern Wisconsin. Where definitely recognized, they are impermeable granite, quartzite, or slate that yield little or no water to wells. The Precambrian rocks form an impermeable basement complex below the younger and more permeable sedimentary rocks.

The Cambrian strata of southeastern Wisconsin consist mostly of sandstone and minor amounts of shale and dolomite. From oldest to youngest, the units are: the Mount Simon Sandstone, the Eau Claire Sandstone, the Galesville Sandstone, the Franconia Sandstone, and the Trempealeau Formation.

The Mount Simon Sandstone is almost entirely sandstone which ranges from fine to coarse grained. Some of the beds are dolomitic and a few of the beds contain silt. The Mount Simon is a principal aquifer in southeastern Wisconsin.

The Eau Claire Sandstone is mainly a sandstone, but toward the south it contains increasing amounts of shale. It is generally dolomitic and ranges from fine to medium grained. The Eau Claire contributes some water to wells but its permeability is generally low because of the large amount of interbedded fine-grained materials.

The Galesville and Franconia Sandstones and the Trempealeau Formation are present only in parts of southeastern Wisconsin. These units are mainly sandstone and have interbedded streaks of dolomite and shale. In the Milwaukee-Waukesha area their extent is limited and they do not constitute a principal source of water. Where these units are absent, it is assumed that they were removed by erosion sometime before deposition of younger materials.

The Ordovician strata in southeastern Wisconsin, from oldest to youngest, consist of the following: the Prairie du Chien Group, the St. Peter Sandstone, the Platteville Formation, the Decorah Formation, the Galena Dolomite, and the Maquoketa Shale.

The Prairie du Chien Group is present only in scattered parts of southeastern Wisconsin and is absent in the Milwaukee-Waukesha area.

The St. Peter Sandstone is a fine- to medium-grained fairly well consolidated partly dolomitic sandstone. In the Milwaukee-Waukesha area it is an important source of water to wells.

The Platteville and Decorah Formations and the Galena Dolomite are undifferentiated in well logs and are treated as the Platteville-Galena unit in this report. They are predominantly dolomite but have a basal section of sandy dolomite or dolomitic sandstone. In the Milwaukee-Waukesha area this unit is believed to yield only small amounts of water to wells. West of this area, however, where it directly underlies the glacial drift, permeability is greater and it yields water more freely to wells.

The sandstones of Cambrian and Ordovician ages, principally the Mount Simon, Eau Claire, Galesville, and St. Peter Sandstones, are referred to in this report as the sandstone aquifer. The Platteville-Galena unit is included in the aquifer because it is hydraulically connected with the underlying sandstone (Foley, Walton, and Drescher, 1953).

The Maquoketa Shale is a dolomitic shale having layers of inter-bedded dolomite. It yields very little water to wells and restricts the vertical movement of water.

The Silurian System of southeastern Wisconsin consists of the Niagara Dolomite and the Waubakee Dolomite. They are not differentiated in well logs but form a hydraulic unit and are referred to in this report as the Niagara aquifer. The Niagara aquifer underlies the eastern half of the nine-county area and nearly all the Milwaukee-Waukesha area. Crevices and solution cavities in the dolomite are used extensively as a source of water for shallow wells.

Rocks of Devonian age occur in northeastern Milwaukee and southeastern Ozaukee Counties and are of little importance as aquifers.

Glacial drift of Pleistocene age covers all southeastern Wisconsin. The predominant lithology is an unsorted mixture ranging from clay to large boulders called till. Locally, deposits of water-washed sand and gravel are somewhat sorted and stratified. At these places, the glacial material may be an important source of ground water. At other places, the impervious clayey till retards the vertical and horizontal movement of water. Locally, the Pleistocene sands and gravels yield enough water to be classed as another important aquifer. For convenience in this report and because water levels in the glacial sands and gravels generally coincide with water levels in the underlying bedrock, the sands and gravels are grouped with the materials directly below.

A more comprehensive discussion of the lithologic character of rocks underlying southeastern Wisconsin may be found in Foley, Walton, and Drescher (1953).

The geologic structure of southeastern Wisconsin is a homocline that dips eastward at a rate of less than 50 feet per mile. A geologic section through Jefferson, Waukesha, and Milwaukee Counties (fig. 1) shows the strata penetrated by water wells[1] and their subsurface attitudes projected on the plane of the section. (See pl. 2 for location of section.) In general, folding along the homocline is minor and small faults in the area have no apparent effect on the regional movement of underground water.

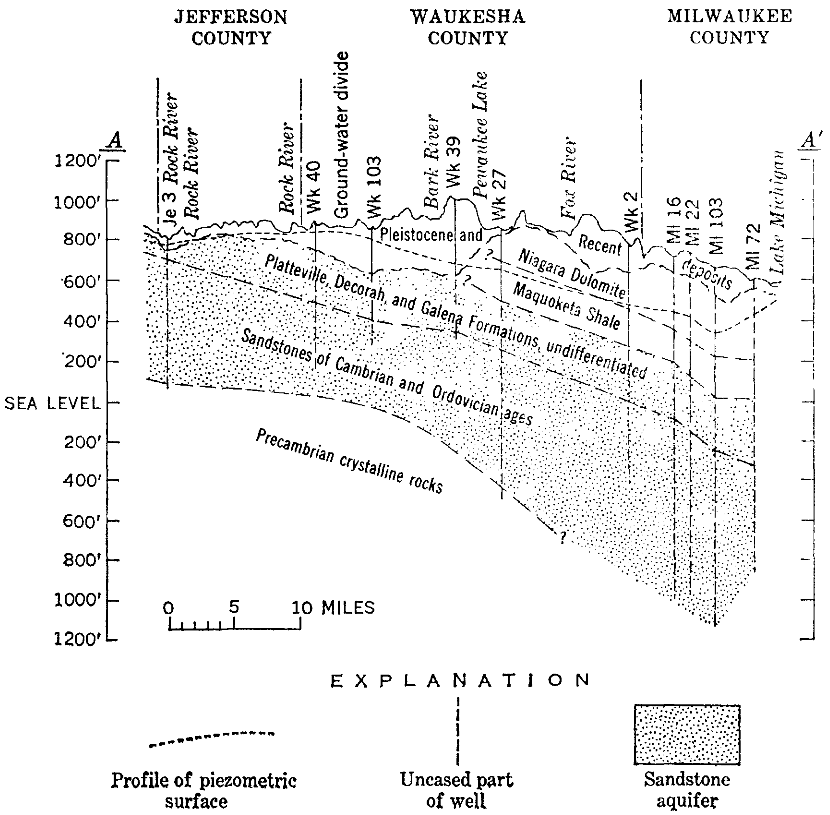

FIGURE 1.—Geologic section through Jefferson, Waukesha, and Milwaukee Counties, and profile of piezometric surface of the sandstone aquifer, October 1961. Geology after Foley, Walton, and Drescher (1953).

HYDROLOGY

The source of all underground water in southeastern Wisconsin is precipitation that falls upon the land surface in the area. Part of the

[1] In Wisconsin, wells are numbered serially within each county. The prefixes Je, Wk, and Ml are abbreviations of the county names.

precipitation leaves the area as surface runoff, part is returned to the atmosphere by evaporation and by plant transpiration, and the remainder percolates downward through the soil and into the underlying material where it moves slowly through pore spaces in the subsurface strata. These underground spaces provide the reservoir from which water is obtained by wells.

The character of rocks determines how fast and how much water can be released to wells and to streams. Generally the shale and crystalline rock yield very little water except where the rocks are fractured. Dolomite, ordinarily dense and impervious, yields water where it is creviced or contains interconnected solution cavities. Sand, gravel, and sandstone are relatively permeable and generally yield water freely to wells.

NIAGARA AQUIFER

Ground water in the Niagara aquifer lies relatively near the land surface, and the aquifer has been developed as a source of domestic, industrial, commercial, and municipal supply. Well yields are erratic and dependent upon the size and number of crevices and solution cavities that are tapped by wells in the Niagara aquifer.

Most of the ground water in the Niagara aquifer occurs under water-table conditions; that is, it is unconfined and at atmospheric pressure. In some areas, however, the water is confined in fractures and by overlying glacial clays. Plate 1 is a piezometric map of the Niagara aquifer for the winter period of 1961–62. Where the ground-water contours are sharply contorted, their shape is mainly controlled by the land-surface topography and the water is generally unconfined. In these areas, ground-water movement generally conforms to the direction of surface drainage. Examples of this occur throughout Washington and Ozaukee Counties. At other places the contours are less contorted and apparently bear little relation to topographic features. In central Kenosha County, where the Des Plaines River and its tributaries are crossed by the 700- and 750-foot contours, water in the Niagara aquifer is at least partly confined by glacial till.

Water levels in wells tapping the Niagara aquifer in the Milwaukee-Waukesha area in winter 1961–62 were at or near the September 1950 stage over much of the area. Known extremes of water-level changes in wells amounted to as much as 18 feet of decline in northeast Milwaukee County and 39 feet of recovery in downtown Milwaukee over the same period. The cone of depression centered in downtown Milwaukee in 1950 had shifted to the northeast by 1961 and was near the 1950 depth.

Pollution of the Niagara aquifer has become a major problem in heavily urbanized areas of southeastern Wisconsin, especially where water occurs under water-table conditions. The pollutants may be from refuse dumps, leaky septic systems, sewage effluents from municipalities and industries, and several other sources.

A complete appraisal of the Niagara aquifer is not possible at present. Additional data collection and analyses are necessary for a more comprehensive study of the aquifer. The U.S. Geological Survey, in cooperation with the Wisconsin Geological and Natural History Survey, began a detailed hydrologic study of Racine and Kenosha Counties in 1962, but interpretive information is not yet available. Future work contemplated by these agencies includes detailed water studies in additional southeastern Wisconsin counties.

SANDSTONE AQUIFER

The sandstone aquifer is a principal source of water for municipal, industrial, and commercial uses in the Milwaukee-Waukesha area. Although large quantities of water may be developed from the sandstone aquifer, wells must be drilled to considerable depths. Consequently, individual domestic use is limited because sufficient supplies of water generally can be found at less depth in the glacial drift or in the Niagara aquifer.

The piezometric surface of the sandstone aquifer (pl. 2) is relatively near the land surface in the western part of the area and is deeper toward Lake Michigan. West of the edge of the Maquoketa Shale, ground water in the sandstone aquifer occurs under water-table conditions or only partly confined by glacial materials. Where the Maquoketa shale overlies the sandstone aquifer, the ground water is almost completely confined (pl. 2 and fig. 1).

The ground-water divide shown on plate 2 is the line through southeastern Wisconsin where water levels of the sandstone aquifer are at their highest altitude above mean sea level. The divide runs approximately north-south and separates the eastward and the westward movement of underground water. Ground water moves laterally and downward from points of higher to points of lower altitude, that is, from higher toward lower water-level contours. In the eastern part of the area, much of the ground water is moving radially toward the area of concentrated pumpage around metropolitan Milwaukee. In southern Walworth and Kenosha Counties, movement is southeastward toward the areas of heavy pumpage in and around Chicago.

Recharge to the sandstone aquifer occurs primarily west of the area overlain by the Maquoketa Shale. Thus, the principal recharge area for the sandstone aquifer in the Milwaukee-Waukesha area is the strip of land between the ground-water divide and the edge of the shale, an area of about 570 square miles (pl. 2). The sandstone recharge area is underlain entirely by the Platteville-Galena unit. This unit appears to have sufficient vertical permeability to allow water to move downward into the sandstone.

A small amount of water moves downward through the Maquoketa Shale to recharge the sandstone aquifer. Also, some recharge to the sandstone aquifer occurs by downward movement of water in uncased or uneffectively cased wells tapping both the Niagara and sandstone aquifers.

PUMPAGE AND WATER-LEVEL TRENDS IN THE SANDSTONE AQUIFER

PUMPAGE 1950–61

In the Milwaukee-Waukesha area, the average pumpage from the sandstone aquifer was about 20.9 mgd (million gallons per day) during 1961. About 9.9 mgd was used as municipal supplies. The remaining 11 mgd was pumped for use by industry, commerce, and nonmunicipal public water supplies.

Foley, Walton, and Drescher (1953, p. 81) determined that average pumpage from the area was 23.3 mgd in 1950 and estimated that pumpage would increase to 27.6 mgd in 1960. The average daily pumpage in 1961 was less than that in 1950 and considerably below the projected pumpage for 1960. The pumpage decrease between 1950 and 1960 is attributed mainly to increased use of surface water and decreased use of ground water. An accounting for the decreased pumpage is given in the table as follows.

Pumpage from the sandstone aquifer in 1961 and changes related to pumpage in 1950

[In millions of gallons per day [1]]

Pumpage, 1961	-----	20. 9
Pumpage, 1950 (from Foley and others (1953), p. 80)	23. 3	
Increased pumpage of preexisting users, 1950–61	+2. 9	
Pumpage of new users 1950–61	+1. 9	
	28. 1	
Decreased pumpage of continuing users, 1950–61	−4. 0	
Discontinued pumpage 1950–61	−3. 4	
Pumpage 1961, by difference	-----	20. 7

[1] In wells that are open in both the sandstone and the Niagara aquifers, it is not possible to determine the amount of water pumped from each. For these wells, all production is assumed to come from the sandstone aquifer.

Between 1950 and 1961, pumpage from the sandstone aquifer in the Milwaukee-Waukesha area decreased by about 2.4 mgd (fig. 2). The peak of water withdrawals was in 1948 and pumpage decreased nonuniformly during the 1950-61 period. Pumpage decreased most rapidly in the late 1950's.

The curve between 1950 and 1961 was drawn partly from reported pumpage data and partly from long-term hydrographs. Hydrographs do not show the amount of water being pumped but indicate the effects on water levels of regional changes in pumping rates.

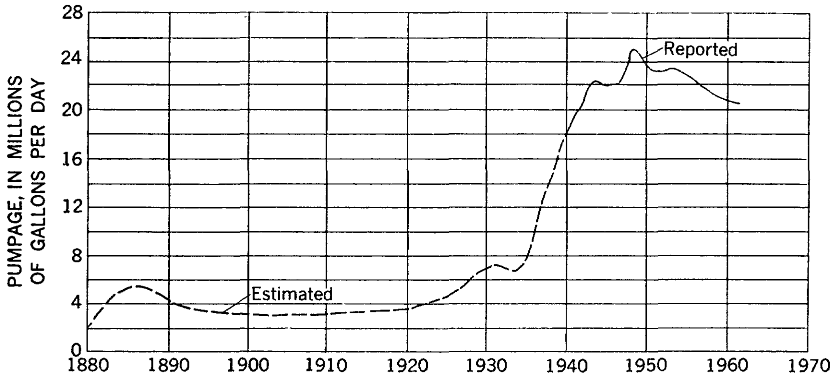

FIGURE 2.—Estimated and reported pumpage from wells tapping the sandstone aquifer in the Milwaukee-Waukesha area, 1880–1961. Pumpage from 1880–1950 after Foley, Walton, and Drescher (1953).

Simplified hydrographs of four deep wells in the Milwaukee-Waukesha area showing the water-level trends between 1947 and 1962 are plotted in figure 3. Only the yearly highs and lows are plotted. Locations of the wells are shown in figure 4. The rate of decline in water levels decreased in 1949 (fig. 3). Water levels in well Ml–22 in West Allis were lowest in 1957 and rose slightly between 1958 and 1962, because of decrease in pumping in West Milwaukee.

The geographical distribution of pumpage from the sandstone aquifer in the Milwaukee-Waukesha area is shown in figure 4. Eleven pumpage centers are shown by graphical representations of ground-water withdrawals in the years 1950 and 1961. The centers are located at points of concentrated pumpage. Effects of concentrated pumpage in such centers as Waukesha, Wauwatosa, downtown Milwaukee, and West Milwaukee can be seen on the piezometric surface map (pl. 2).

Part of the pumpage from the sandstone aquifer was dispersed and could not be grouped conveniently into any of the centers. The total amount of this pumpage was about 0.4 mgd in 1961.

Pumpage increased between 1950 and 1961 at Waukesha, Menomonee Falls, Greendale, and Oak Creek centers because of greater demands for municipal supplies. In the northwest Milwaukee area, increased pumpage was due to many new industrial wells put into use after 1950. In the northeast Milwaukee area, increased pumpage was mainly due to one industrial and two commercial wells and to a small number of wells in the city of Glendale. At Pewaukee, pumpage increased only slightly. Pumpage decreased between 1950 and 1961 at four of the centers. At Wauwatosa, decreased pumpage was due to discontinued or diminished use of several industrial wells. The

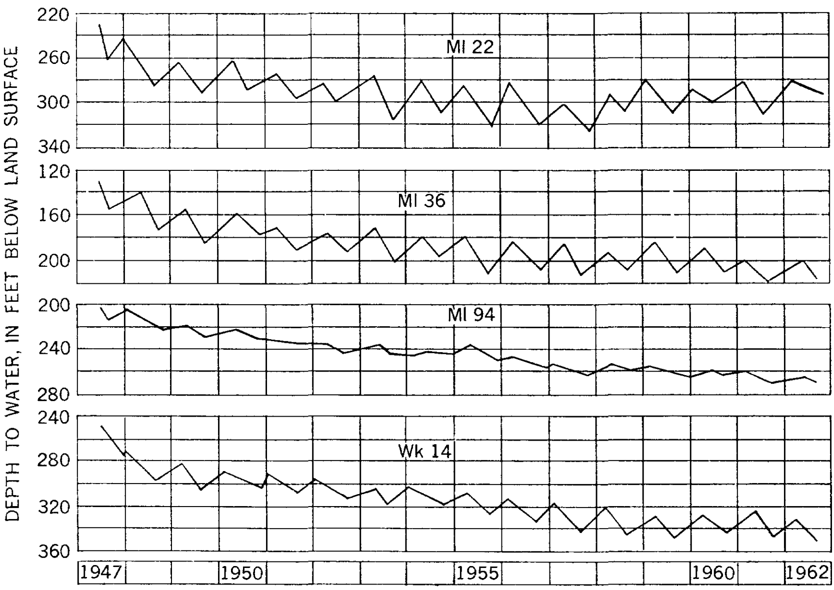

FIGURE 3.—Hydrographs of four wells tapping the sandstone aquifer in the Milwaukee-Waukesha area.

city of Wauwatosa increased its pumpage slightly. At Town of Lake, the municipal wells were abandoned when Lake Michigan water was made available by Milwaukee. At West Milwaukee and in downtown Milwaukee, many industrial and commercial wells were abandoned or their production was curtailed by well owners.

Pumpage from the sandstone aquifer is minor throughout the remainder of southeastern Wisconsin compared to that in the Milwaukee-Waukesha area. The largest water users are municipalities. Of these, only pumpage at the cities of Hartford, in Washington County, and Burlington, in Racine County, have an appreciable effect on the movement of ground water. Hartford used about 0.8 mgd in 1961, only part of which was from the sandstone aquifer; the remainder was from the Niagara aquifer. The effect of withdrawals from the sandstone aquifer at Hartford is shown on plate 2 as a small depression in the piezometric surface. Burlington used about 0.7 mgd in 1961, all from the sandstone aquifer. As shown on plate 2, near Burlington, the ground-water contours are deflected several miles westward, probably as a result of the municipal pumping. This deflection may be caused partly by additional recharge in northeast Walworth County where a sizeable reentrant occurs in the edge of the Maquoketa Shale. From the reentrant, a ridge of high piezometric pressure extends eastward into southeastern Waukesha County.

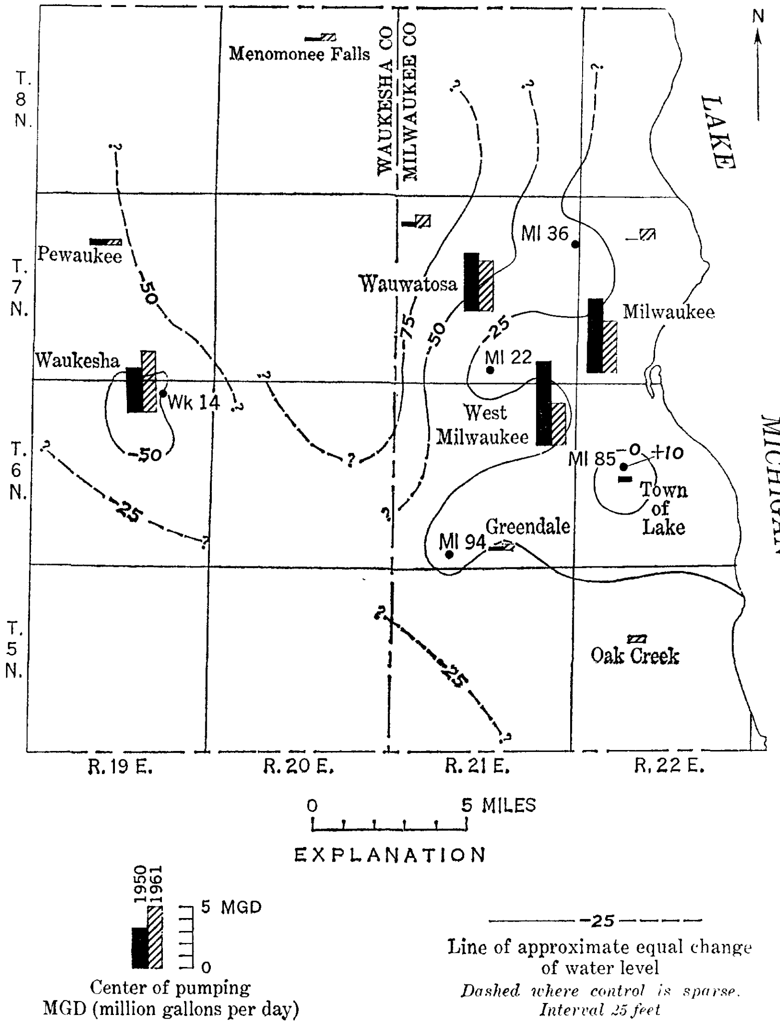

FIGURE 4.—Pumpage distribution and approximate change of piezometric surface in the sandstone aquifer between 1950 and 1961.

Pumpage from the sandstone aquifer in the Chicago region is affecting water levels in southeastern Wisconsin (pl. 2). In 1959, pumpage in the Chicago region was about 64 mgd from the sandstone aquifer (Sasman and others, 1961, p. 10). This was an increase over past years, and pumpage continued to increase during 1961 (Russell, 1963, p. 19).

WATER-LEVEL CHANGES 1950–61

Figure 4 shows the change of piezometric surface, as indicated by changes in water levels in wells, between 1950 and 1961 in the sandstone aquifer. The map shows only the algebraic sum of changes from 1950 to 1961 and does not indicate water-level trends in 1961.

The map was constructed by contouring water-level changes in individual deep wells and by comparison of the 1950 piezometric map (Foley, Walton, and Drescher, 1953, pl. 6) with the 1961 piezometric map (pl. 2). Accuracy is greatest in central Milwaukee County and near the city of Waukesha where water-level control was adequate. In other parts of the area, control was either inadequate or completely lacking. Contour lines of piezometric-surface change are not extended through areas of poor control.

The greatest change shown in figure 4 is a decline of more than 75 feet in northwestern Milwaukee County and eastern Waukesha County. Most of the area that has declines greater than 75 feet is away from major pumping centers. Part of this decline is inferred to be the result of residual declines from overlapping cones of pumping influence at Waukesha and in central Milwaukee County (pl. 2). Part of the decline was caused by increased withdrawals in the northwest-Milwaukee pumpage center. The greatest measured decline was 98 feet in the northwest-Milwaukee center.

Declines of 50 feet or more occurred at the city of Waukesha and were primarily the result of increased withdrawals, about 1.2 mgd, at that pumpage center. The hydrograph of Wk–14 (fig. 3) at Waukesha, shows continued downward trends of water levels throughout the 1950–61 period. The greatest measured decline at Waukesha was 60 feet in one of the city wells.

Other declines of more than 50 feet occurred throughout a large area of northeastern Waukesha and northwestern Milwaukee Counties surrounding the area of greatest declines.

Water-level declines exceeding 25 feet were common in about half of Milwaukee County. Continued, though decreased, withdrawals from the three major pumping centers in central Milwaukee County caused the declines in that area. If pumping had continued at the 1950 rate, water-level declines would have been greater.

A change in the distribution of pumpage between 1950 and 1961 in eastern Milwaukee County has caused the water-level decline indicated by the sinuous shape of the 25-foot contour line (fig. 4). The pumpage center in northeast Milwaukee increased its withdrawals from a negligible amount in 1950 to about 0.8 mgd in 1961. The 25-foot contour line has shifted eastward toward this center and toward downtown Milwaukee where pumpage was about 4.4 mgd in 1961. In this area, the hydrograph of Ml–36 (fig. 3) shows a downward trend of water levels between 1950 and 1961.

The decreased decline in water levels north of well Ml–36 is probably due to recharge through several wells open in both the Niagara and sandstone aquifers in the city of Glendale.

At West Milwaukee and West Allis, water levels in 1961 were more than 25 feet lower than those in 1950 (fig. 4). Greater declines occurred, but decreased pumping during the 1950's allowed a localized recovery of water levels. The hydrograph of Ml–22 (fig. 3) shows that the decline was about 35 feet between late 1950 and late 1957. Water levels, however, recovered about 15 feet between late 1957 and late 1961, leaving a net decline at Ml–22 of about 20 feet for the 1950–61 period.

Most of the deep wells in West Allis and West Milwaukee, including abandoned and producing wells, tap both the Niagara and sandstone aquifers and probably allow some recharge to the sandstone aquifer. A single well as West Milwaukee, however, pumps nearly a third (1.1 mgd of 3.4 mgd) of the water from that pumpage center—all from the sandstone aquifer. Pumpage from this well probably caused water-level declines to be greater at West Milwaukee than near Ml–22 in West Allis.

In southern Milwaukee County, the water-level declines of more than 25 feet are attributed mostly to increased pumpage at the cities of Greendale and Oak Creek. The hydrograph of Ml–94 (fig. 3), near Greendale, indicates a gradual decline of water levels throughout the period between 1950 and 1961.

Water levels in Town of Lake rose between 1950 and 1961 with little change in water levels in the surrounding area (fig. 4). Town of Lake pumped water until the middle 1950's and probably lowered the water level below the level of 1950, but when pumpage was discontinued, water levels recovered above the 1950 level. Measured recovery between 1950 and 1961 was 10 feet. Both municipal wells are cased through the Niagara aquifer and neither should be supplying recharge water to the sandstones.

Through 1961, water levels of nonpumping wells tapping the sandstone aquifer remained above the base of the confining Maquoketa Shale except in one municipal well at Waukesha.

PUMPAGE 1961–75

Estimates of future pumpage from the sandstone aquifer in the Milwaukee-Waukesha area depend on estimates of future population and industrialization and on the economic availability of water from other sources, such as Lake Michigan or the Niagara aquifer.

The Southeastern Wisconsin Regional Planning Commission has projected the population trends of Milwaukee and Waukesha Counties from 1960 through 1980 (1963, p. 62 and 72). The projected population of Milwaukee County might increase from about 1,035,000 in 1960 to between 1,325,000 and 1,450,000 by 1975, and the population of Waukesha County might increase from about 155,000 in 1960 to between 265,000 and 455,000 by 1975. These mathematical projections are based on what was considered to be a normal trend between 1950 and 1960.

At the Waukesha pumpage center, where all municipal water supply was obtained from the sandstone aquifer in 1961, the city water usage may increase to about 10 mgd by 1975 (J. H. Kuranz, manager and chief engineer, Waukesha Water Utility, oral commun., 1963). If supplies from the Niagara aquifer are not developed, the 10 mgd most likely will be withdrawn from the sandstone aquifer. Influx of additional industry into the Waukesha area could cause this figure to be even higher.

Pumpage at Pewaukee remained relatively stable between 1950 and 1961 (0.21 and 0.24 mgd, respectively). At this rate, pumpage should not exceed 0.3 mgd by 1975.

At Menomonee Falls a new well in the glacial drift was put into production in August 1961. The well was tested at 2,000 gpm (gallons per minute) and pumped an average of about 0.66 mgd in 1962. Because a proved adequate supply of water is available from the glacial drift, pumpage from the sandstone aquifer probably will decrease between 1961 and 1975 in the Menomonee Falls area.

At the pumpage center in northwest Milwaukee, the trend in 1961 was toward increased pumpage. A straight-line projection indicates that withdrawals in 1975 will be at a rate of nearly 2 mgd.

In northeastern Milwaukee the trend in 1961 was toward pumpage increases. The major industrial user (0.65 mgd), however, ceased pumping in 1962 because of unsuitable water, and the city of Glendale converted to Lake Michigan water in 1963. By late 1963, pumpage at this center was only about 0.1 mgd compared to 0.75 mgd in 1961. Barring unforeseen industrial development in the area, pumpage is likely to remain near the 0.1 mgd level in 1975. Nearby, surface-water supplies from Lake Michigan are adequate for municipal uses.

At Wauwatosa, municipal water supplies were obtained entirely from Lake Michigan after February 1964 (J. L. Nash, superintendent, Wauwatosa Water Department, oral commun., 1964). Wauwatosa pumped about 3.4 mgd of ground water in 1961. Because sufficient surface water is available at the Wauwatosa pumpage center, the reduction in ground-water pumpage may be permanent. Pumpage at this center may be as low as 1 mgd in 1975.

At West Milwaukee and in downtown Milwaukee, most wells have been in use since 1950. In these pumpage centers, water levels are deepest (pl. 2) and water users tended toward abandonment of old and inefficient wells in favor of municipal supplies from Lake Michigan. Combined pumpage at these two centers probably will not exceed 6 mgd by 1975.

The pumpage centers at Greendale and Oak Creek are primarily municipal. Ground-water withdrawals should increase because of the growing population and the possibility of industrial expansion in these areas. Combined pumpage at these centers may be as much as 4 mgd by 1975.

From the above discussion it is evident that most pumpage increases are expected in areas of growing population where surface-water supplies are not available. Where surface water is readily available, ground-water use may decrease. Influx of new industry could cause some estimates to be too low, whereas expanded use of lake-water facilities or development of ground water from the other aquifers could cause some estimates to be too high.

CALCULATED WATER-LEVEL CHANGES 1961–75

The pumpage changes predicted above for the Milwaukee-Waukesha area will cause changes of artesian water levels. The magnitude of water-level changes by 1975 was calculated for two observation wells, Wk–14 in Waukesha and Ml–22 in West Allis (fig. 4). Calculations were based on aquifer characteristics determined by Foley, Walton, and Drescher (1953, p. 74), water-level trends previous to 1961 in the two observation wells, and estimated pumpage changes in the four major pumpage centers. The nonequilibrium formula (Ferris and others, 1962, p. 92–98, and Foley, Walton, and Drescher, 1953, p. 74) was used for all calculations and the recharge boundary in western Waukesha County was taken into account. If all the estimated pumpage changes hold true and the overall pumpage pattern remains the same, the water level at Wk–14 will decline about 50 feet and the water level at Ml–22 will recover about 100 feet by 1975.

INTERFERENCE BETWEEN WELLS

Graphs have been prepared to show how pumping at different rates and times will influence the water levels in wells at different distances. Figures 5 and 6 show the theoretical distance-drawdown and the time-drawdown relations of sandstone-aquifer wells in the Wauwatosa area. Figure 5 shows the amount of drawdown or water-level decline at distances of 1,000–20,000 feet from a well pumping continuously at 1 mgd for 30 days, 1 year, and 10 years. The solid curve is adjusted for a recharge boundary in western Waukesha County; the dashed curve is not adjusted. Figure 6 shows the amount of drawdown at any time from 50 to 4,000 days at 0.5 mile, 1 mile, and 5 miles from a well pumping 1 mgd continuously. The solid curves are adjusted for a recharge boundary in western Waukesha County; the dashed curves are not adjusted.

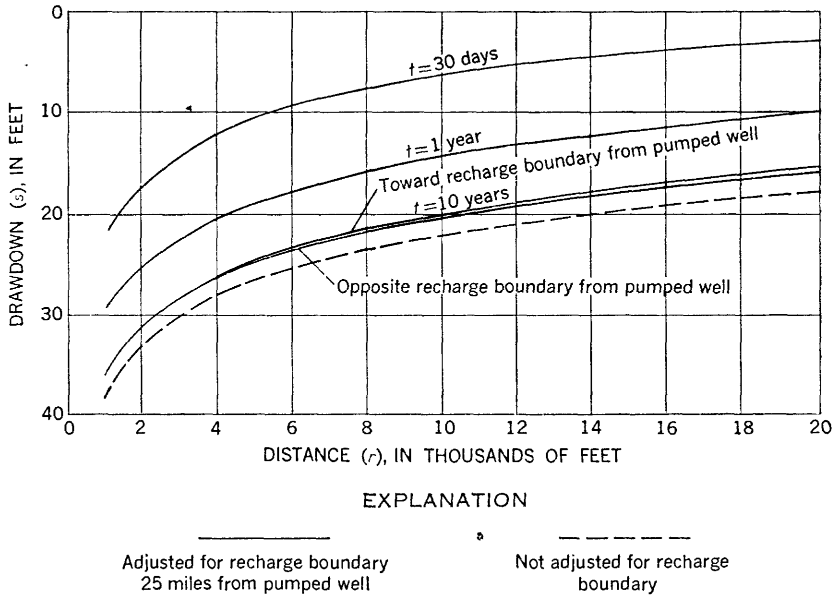

FIGURE 5.—Distance-drawdown curves in the sandstone aquifer underlying the Milwaukee-Waukesha area. After Foley, Walton, and Drescher (1953). Q=695 gpm, T=23,800 gpd per ft, S=0.00039.

In both figures, the upper limb of each solid curve shows the drawdown at points on a straight line from the pumped well to the recharge line; the lower solid limb shows the drawdown along a straight line opposite the recharge boundary from the pumped well. The graphs are drawn on the assumed pumping rate of 1 mgd, or 695 gpm.

As an example of the use of figures 5 and 6, a new well at Wauwatosa pumping 1 mgd continuously for 1 year would cause a water-level decline of about 14 feet in another well 2 miles away and about 18 feet in a well only 1 mile away. In figure 6, the same new well would cause the water level to decline only 11 feet in a well 5 miles away, even after pumping continuously for 3 years. In the nonequilibrium formula (the basis of the graphs in figures 5 and 6), the drawdown of water level (s) is directly proportional to the amount of water withdrawn (Q). For other values of withdrawal, the drawdown can be found by multiplying the drawdown from the graph by the proportional amount of pumpage per day. Additional information concerning aquifer coefficients (T and S) and their practical applications may be found in Foley, Walton, and Drescher (1953).

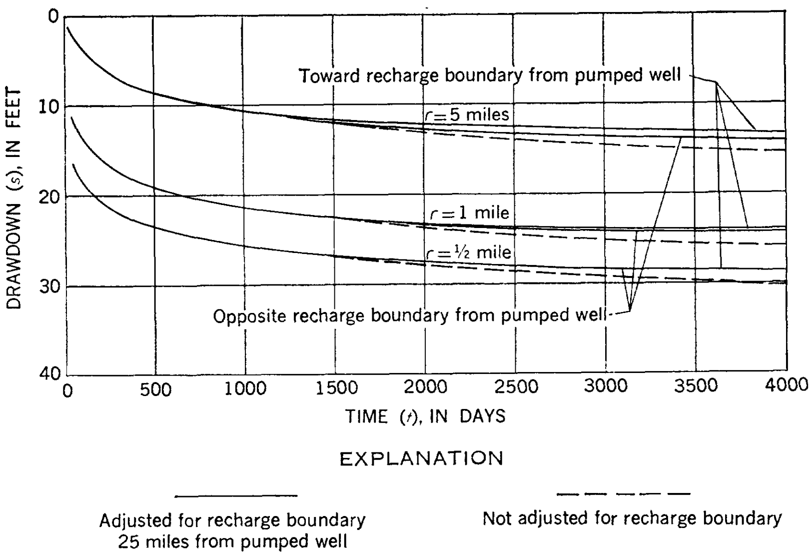

FIGURE 6.—Time-drawdown curves in the sandstone aquifer underlying the Milwaukee-Waukesha area. After Foley, Walton, and Drescher (1953). Q=695 gpm, T=23,800 gpd per ft, S=0.00039.

SUMMARY AND CONCLUSIONS

Heavy pumpage from the sandstone aquifer caused decline of the artesian water level throughout most of southeastern Wisconsin between 1950 and 1961. Concentrated ground-water pumpage near the cities of Milwaukee and Waukesha caused the greatest water-level declines near those areas. Pumpage in the Chicago region was responsible for part of the artesian-pressure decline in southern Kenosha and Walworth Counties.

Future artesian-pressure trends will depend upon the magnitude of local water demands and the source from which the water is obtained. The substituted use of lake water for well water already has allowed recovery of artesian pressure in parts of Milwaukee County. Continuation of this trend will cause additional recovery by 1975. Increased heavy pumping at Waukesha will cause further artesian-pressure decline in Waukesha County. Between 1961 and 1975, the distribution of pumpage from the sandstone aquifer is expected to shift westward toward the recharge area. Unforeseen events, such as rapid influx and concentration of new industries, may alter the anticipated trend of pumping and water levels.

Where surface water is not available, new wells should be spaced at adequate distances from centers of concentrated pumpage to assure minimum interference between wells. New wells will cause less artesian-pressure decline if they are located closer to the recharge area—farther westward. For the Milwaukee area, a favorable location for expanded use of water from the sandstone aquifer is toward the south and southwest where water-level declines have been least in the past 11 years.

An adequate water supply for the Milwaukee-Waukesha area is available from surface and subsurface sources. The combined use of these two sources could be an effective means of reducing or stopping artesian-pressure declines. Communities currently dependent on ground water, but located near a surface-water distribution system, might consider alternating uses of the two supplies. Ground water could be used during periods of high water demand such as summer and early autumn. The periods of low water demand then might be supplied by surface water without overtaxing the intake and distribution systems. This alternation of supply would allow recovery of artesian pressure during part of each year instead of continued pressure decline throughout the year and would improve efficiency of the surface-water system by allowing the system to operate near full capacity for the entire 12 months of each year.

Total use or alternate use of surface water by organized communities in the Milwaukee-Waukesha area would reduce demands on the sandstone aquifer. The resultant water-level rise would make water from that aquifer more readily available to small suburban housing developments, industries demanding water of constant temperature and quality, and water users of all types lying outside the municipal distribution systems.

Additional ground-water supplies might be developed from the Niagara aquifer or the glacial drift, as has been done by Menomonee Falls, Hartford, and numerous industries.

SELECTED REFERENCES

Alden, W. C., 1918, The Quaternary geology of southeastern Wisconsin, with a chapter on the older rock formations: U.S. Geol. Survey Prof. Paper 106, 356 p., 39 pls., 21 figs.

Audini, R. E., Berkstresser, C. F., Jr., and Knowles, D. B., 1959, Water levels in observation wells in Wisconsin through 1957: Wisconsin Geol. and Nat. History Survey Inf. Circ. 4, 192 p., 160 figs., 4 tables.

Bergstrom, R. E., and Hanson, G. F., 1962, Ground-water supplies in Wisconsin and Illinois adjacent to Lake Michigan, *in* Am. Assoc. Adv. Sci., Great Lakes Basin—a symposium: Am. Assoc. Adv. Sci. Pub. 71, p. 251–268.

Drescher, W. J., Dreher, F. C., and Brown, P. N., 1953, Water resources of the Milwaukee area, Wisconsin: U.S. Geol. Survey Circ. 247, 42 p., 25 figs., 15 tables.

Drescher, W. J., 1956, Ground water in Wisconsin: Wisconsin Geol. and Nat. History Survey Inf. Circ. 3, 37 p., 5 figs., 4 tables.

Ferris, J. G., Knowles, D. B., Brown, R. H., and Stallman, R. W., 1962, Theory of aquifer tests: U.S. Geol. Survey Water-Supply Paper 1536–E, p. 69–174, figs. 17–45, 6 tables.

Foley, F. C., Walton, W. C., and Drescher, W. J., 1953, Ground water in the Milwaukee-Waukesha area, Wisconsin: U.S. Geol. Survey Water-Supply Paper 1229, 96 p., 8 pls., 27 figs., 16 tables.

Natural Resources Committee of State Agencies, 1956, The natural resources of Wisconsin: An inventory by the Natural Resources Committee of State Agencies, p. 118–130, 3 figs., 5 tables.

Russell, R. R., 1963, Ground-water levels in Illinois through 1961: Illinois State Water Survey Div., Rept. Inv. 45, 51 p., 42 figs.

Ryling, R. W., 1961, A preliminary study of the distribution of saline water in the bedrock aquifers of eastern Wisconsin: Wisconsin Geol. and Nat. History Survey Inf. Circ. 5, 23 p., 6 figs., 2 tables.

Sasman, R. T., Prickett, T. A., and Russell, R. R., 1961, Water-level decline and pumpage during 1960 in deep wells in the Chicago region, Illinois: Illinois State Water Survey Circ. 83, 43 p., 10 figs., 5 tables.

Southeastern Wisconsin Regional Planning Commission, 1963, The population of southeastern Wisconsin: Planning Rept. 4, 100 p., 42 tables.

Thwaites, F. T., 1923, The Paleozoic rocks found in deep wells in Wisconsin and northern Illinois: Jour. Geology, v. 31, no. 7, p. 529–555.

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