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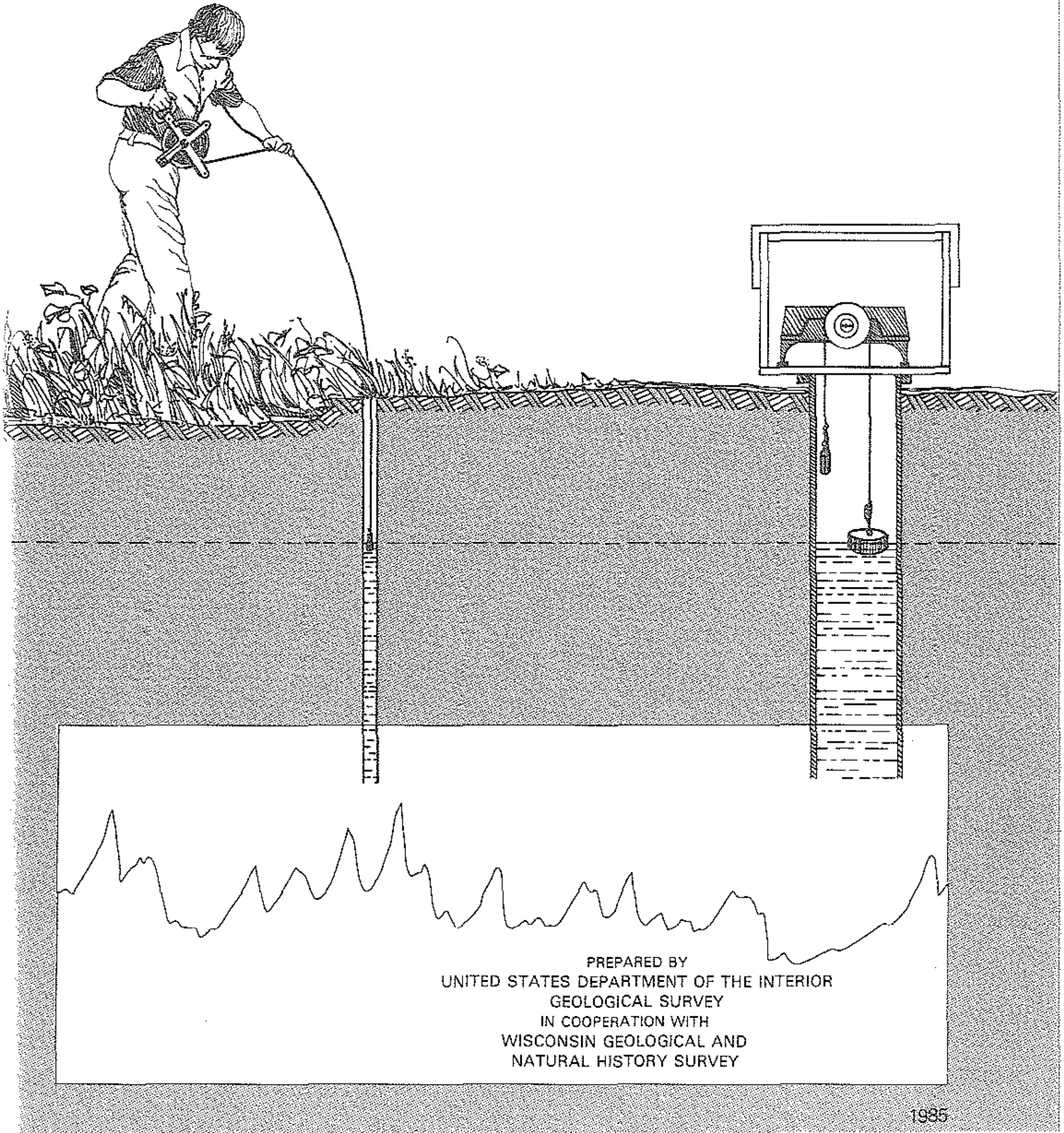
GROUND-WATER FLUCTUATIONS IN WISCONSIN

By Gary L. Patterson, U.S. Geological Survey and
Alexander Zaporozec, Wisconsin Geological and
Natural History Survey



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M. E. Ostrom, Director and State Geologist
Madison, Wisconsin

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INTRODUCTION

Ground water is the source of drinking water for more than 60 percent of the residents of Wisconsin. The water is pumped from wells dug or drilled into water-bearing rock.

In 1977, unusually low ground-water levels caused many wells in Wisconsin to go dry, which forced residents to truck water for livestock and personal needs (Zaporozec, 1980). The low ground-water levels resulted in lowered lake levels and dried wetlands. Fires occurred in dried-out peat, and wildlife habitat was affected. In 1973, unusually high ground-water levels caused foundations to collapse and flooded many basements. The high water levels also inhibited farming by inundating fields, and caused excessive slumping and bluff recession along lakes and streams.

These examples are some of the ways fluctuations in ground-water levels affect the lives of people in Wisconsin. Ground-water fluctuations are related to natural climatic variations and extreme fluctuations can be expected to recur. A better understanding of how much, how often, and why ground-water levels fluctuate can be used to plan new construction and well drilling to minimize problems caused by these fluctuations.

In 1934 and 1935, systematic measurements of ground-water levels were begun in a few wells in southwestern Wisconsin by the Soil Conservation Service, U.S. Department of Agriculture, and in central and northeastern Wisconsin by the Wisconsin Conservation Department (predecessor to the Wisconsin Department of Natural Resources). In 1946, a statewide observation-well network was established by the U.S. Geological Survey in cooperation with the Wisconsin Geological and Natural History Survey. By the end of 1980, measurements were being made in 200 wells located in 68 of the 72 counties of the State (Zaporozec, 1981). Of these wells, 23 were equipped with continuous recorders, 19 were measured weekly, and 158 were measured monthly. Data from these observation wells were summarized by Erickson and Cotter (1983). Water-level records are available from the U.S. Geological Survey or Wisconsin Geological and Natural History Survey for about 225 wells across the State.

This report summarizes statistical analyses of water-level measurements from 11 of these observation wells. The results of these analyses are discussed in terms of extremes in water levels, and how often high and low water levels might be expected to occur. The relation of water-level fluctuations to precipitation and pumping also is discussed, as is the effect of earthquakes on water levels.

This report is intended to provide insight into how and why water levels behave as they do and to provide examples of the kinds of information that can result from systematic water-level measurements. Water-level fluctuations in particular wells are often dependent upon local conditions. Therefore extrapolation of this information to other wells is difficult and is not recommended.

GROUND-WATER CONCEPTS

Occurrence and Movement of Ground Water

The source of ground water is precipitation. When it rains, or when snow melts, the water takes the following paths:

1. some is taken up by plants and trees, and wets the soil;
2. some runs off the surface and enters streams and lakes;
3. some evaporates;
4. the remaining water percolates downward to the water table and enters the ground water.

Definition: PRECIPITATION: The total amount of water received directly from the atmosphere (clouds) in the form of rain, snow, hail, sleet, etc.

A common misconception is that all ground water flows in underground rivers or streams. Although underground streams do exist in Wisconsin, (the stream in Blue Mounds Cave in Dane County, for example) this is not normally true and is, in fact, rare. Instead, ground water fills numerous small openings, such as pores, fractures, and cracks in the rocks.

Ground water is not only stored in rock units but also moves laterally toward streams and lakes. Because it is driven by gravity and difference in head (water pressure) ground water tends to flow toward low-lying areas. Most ground water discharges into streams, lakes, or springs within a few miles of where it originally fell to the ground as rain or snow.

Ground water flows slowly compared to streams, with velocities being measured in feet per day or feet per year as compared to feet per second in streams. The ground-water-flow velocity depends upon the character and extent of the openings in the rock units and the difference in head.

Water-Level Fluctuations

The upper surface of the ground water, the water table, is not at the same depth throughout the State. The water table tends to be nearest the land surface in valleys and wetlands, and deepest beneath hills and ridges. It generally resembles a subdued version of the surface topography.

The altitude of the water table does not remain constant, but fluctuates almost continuously, rising or declining within a relatively short period of time. The rises reflect recharge from precipitation and spring snowmelt, whereas the declines reflect discharge to streams and springs, or withdrawal from wells.

The character of fluctuations in a well depends on several factors, including the amount and intensity of precipitation, proximity to streams or lakes, depth to the water table, vegetation, topography, and the water-transmitting properties of the earth materials near the well.

Water levels vary seasonally in addition to the short-term variations resulting from recharge by rainfall. Water levels rise relatively rapidly in the spring due to recharge from snowmelt and rains. They gradually decline throughout the summer, when uptake by plants and evaporation exceeds precipitation and less water is available for infiltration to the water table. Commonly, a small rise occurs in the fall due to fall rains and a reduction in evapotranspiration. A decline during the winter generally follows when the precipitation is stored on the land surface as snow, and the frozen ground inhibits infiltration.

Definition: EVAPOTRANSPIRATION: Water withdrawn from a land area by evaporation from water surfaces and from moist soil, and by plant transpiration.

Consecutive years of above or below normal precipitation result in even longer cycles of gradual ground-water level changes, upon which the short-term fluctuations or seasonal variations may be superimposed.

Pumping of ground water from a well can alter the natural recharge-discharge relations. When ground water is discharged by pumping a well, the water level declines in the area around the well. This lowering is relatively small at most domestic wells, but may be great in areas of heavy municipal pumping.

Aquifers

An aquifer is a water-saturated rock unit that will yield sufficient quantities of water to wells or springs so that they can be used as practical sources of water supply. There are two main types of aquifers: water table (unconfined) and artesian (confined). The upper surface of a water-table aquifer is the water table itself. At this surface, the water in the pores of the aquifer is at atmospheric pressure as if it were in an open tank. An artesian aquifer is one where the rock unit comprising the aquifer is overlain by a layer of rock with relatively low permeability. Because of this confining layer, the water at the top of the artesian aquifer is under greater than atmospheric pressure.

When a well is dug or drilled into a water-table aquifer, the water in the well will rise to near the level of the water table, because both the aquifer and the well are open to atmospheric pressure. When a well penetrates an impermeable layer into an artesian aquifer, the water in the well will rise to some level above the top of the aquifer because the well is open to atmospheric pressure and the water in the aquifer is at greater-than- atmospheric pressure. The water level in the well then represents the artesian pressure of the aquifer.

Most of Wisconsin's wells obtain water from one of four principal aquifers: the sandstone, Galena-Platteville, Niagara dolomite, and sand-

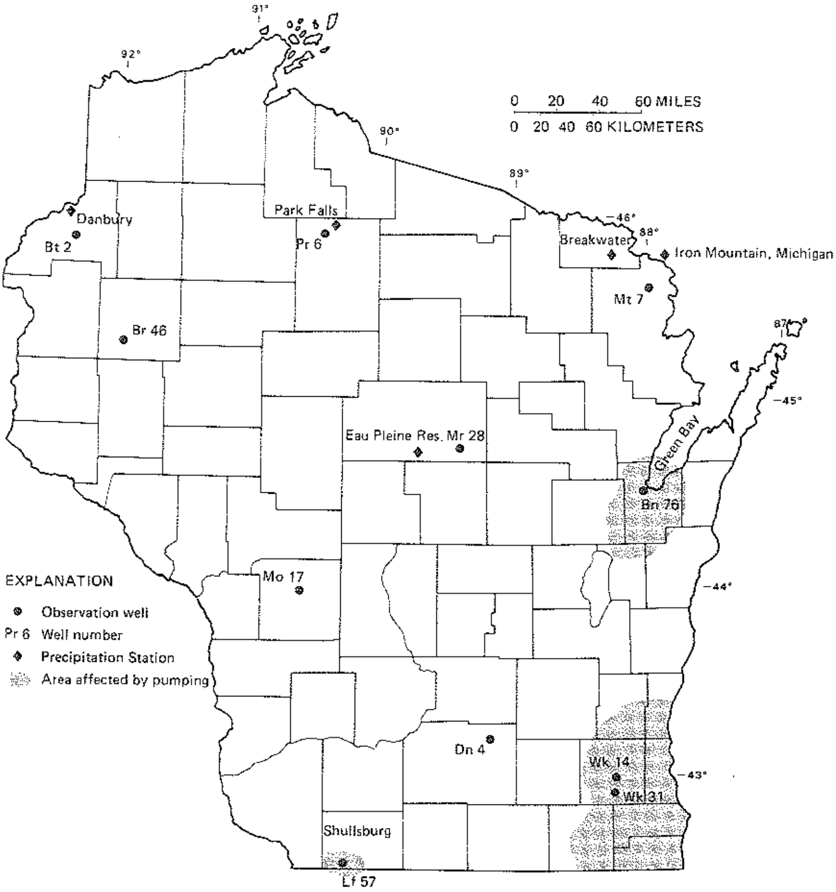

Figure 1. Location of observation wells and precipitation stations.

and-gravel aquifers. Water in these aquifers can occur under either water-table or artesian conditions depending on the geologic conditions at that location.

WATER-LEVEL FLUCTUATIONS IN WISCONSIN WELLS

Water-level records for the 11 wells are discussed in this report. These wells are widely spaced throughout the State (fig. 1), and represent various hydrologic and geologic environments. Eight of these wells are water-table wells, three are in the sandstone aquifer (Br-46, Dn-4, Mo-17), one is in the Galena-Platteville aquifer (Lf-57), and four are in the sand-and-gravel aquifer (Bt-2, Mr-28, Mt-7, Pr-6). Seven of the water-table wells represent natural conditions and one, Lf-57, is affected by pumping. The other three wells are artesian; two are in the sandstone aquifer (Bn-76, Wk-14) and one is in the Niagara dolomite aquifer (Wk-31). One artesian well, Wk-31, represents natural conditions, but the other two, Bn-76 and Wk-14, are affected by pumping.

From 25 to 45 years of water-level measurements are available for each of the 11 wells described in this report. These measurements were supplemented with estimated values when measurements were not made at least monthly. All of the values were then analyzed in terms of their extremes, averages, amplitudes, and other simple statistics. The results of these analyses are summarized in table 1 (p.13-14).

Definition: AMPLITUDE: The absolute value of the difference between the lowest and the highest water level, referenced to a specified period of time.

Wells Unaffected by Pumping

Water-Table Aquifers

Two general characteristics of water-table aquifers are: (1) water levels fluctuate less with greater depth to water, and (2) water levels in recharge areas fluctuate more than those in discharge areas. The average water levels for the seven water-table wells unaffected by pumpage (table 1) range from 2.27 to 44.05 ft below land surface, and the average annual amplitudes range from 0.59 to 6.36 ft. Note that with the exception of Dn-4, the average annual amplitude decreases as the average water level deepens. Excluding Dn-4, the deepest water table is at Bt-2, which has the smallest average annual amplitude of 0.59 ft, while the shallowest water table is at Pr-6, which has the largest average annual amplitude of 2.51 ft. Dn-4, which has a deeper water level than the others, also has the largest annual amplitude. This reflects the second general characteristic because Dn-4 is in a recharge area farther from discharge than the other wells.

The above general characteristics are valid for short-term fluctuations, but the difference between the maximum and minimum recorded levels shows that they are not valid over long periods of time because long-term fluctuations are more dependent upon regional characteristics. Although the average annual amplitudes range from 0.59 to 6.36 ft, the differences between the maximum and minimum recorded levels range from 4.77 to 26.72 ft, and have no relation to depth.

Artesian Aquifers

The only artesian well unaffected by pumping is Wk-31. The average water level is 132.86 ft and its average annual amplitude is 2.22 ft. Wk-31 is in a recharge area similar to Dn-4 of the water-table group. However, the average annual amplitude is much smaller than that of Dn-4. This may be a reflection of the greater depth to water, but more likely it is evidence of another general characteristic, which is that artesian aquifers often fluctuate less than water-table aquifers.

It should be noted that although the above general characteristics are valid for most wells, there are exceptions because of the many local environmental factors.

Probability of Occurrence of Water Levels

Table 2 (p.15) shows the probability of any given water level being equaled or exceeded in 1 year on eight wells unaffected by pumping. Two separate analyses were made, one with the highest and one with the lowest monthly water level of each year for the period of record. Although this type of analysis does not help predict whether water levels will be high or low in a given year, it does help estimate the probability of how high or how low water levels may be in either case.

For example, table 2 lists the 10 percent, 5 percent, and 2 percent high and low water levels for well Mr-28. These values indicate if water levels are generally high, there is a 10-percent chance of the water level rising to within 15.5 ft of the land surface, a 5-percent chance of rising within 14.4 ft below land surface, and a 2-percent chance of rising within 13.2 ft below land surface in any year. Conversely, if the water levels are generally low, there is a 10-percent chance of the water level dropping to 24.5 ft or more below land surface, a 5-percent chance of dropping to 25.5 ft or more below land surface, and a 2-percent chance of dropping to 26.4 ft or more below land surface.

This type of information can be used to help plan well depths and pump settings or building construction. The following examples are shown schematically in figure 2. Suppose a new water well is needed near Mr-28. If the water level is high, say about 15 ft below land surface, the driller may decide to drill 10 feet below the water table and stop. The 25-ft deep well with the pump at the bottom would provide enough water during relatively wet years, but during dry years there is a 10-percent chance that the water level would drop to within 6 in. of the well bottom and a 5-percent chance that the well would go dry. This level would not provide enough water for most domestic purposes (fig. 2a).

As a second example, suppose a large office building is planned near Mr- 28, and the site investigation and building plans were made during a dry year when the water table was about 25 ft below land surface. The builders, not knowing the range of water-level fluctuations, may construct a basement in the building, perhaps down to 20 ft below land surface. This would be no problem during dry years, but during wet years the water table would rise above the bottom of the basement and could cause flooding or structural damage (fig. 2b).

With information like that provided in table 2, the well driller in the first example would know how deep he had to drill and set the pump for better assurance of a water supply in dry years and the builder in the second example could modify plans so as to set the basement above the water table in wet years.

Wells Affected by Pumping

Two areas, southeastern Wisconsin and the Green Bay area (fig. 1), provide examples of the effect of heavy municipal pumping on water levels, and one area near Shullsburg in Lafayette County provides an example of the effect of mine dewatering on water levels. Statistical information on wells in each of these areas is shown at the bottom of table 1. These data largely represent the

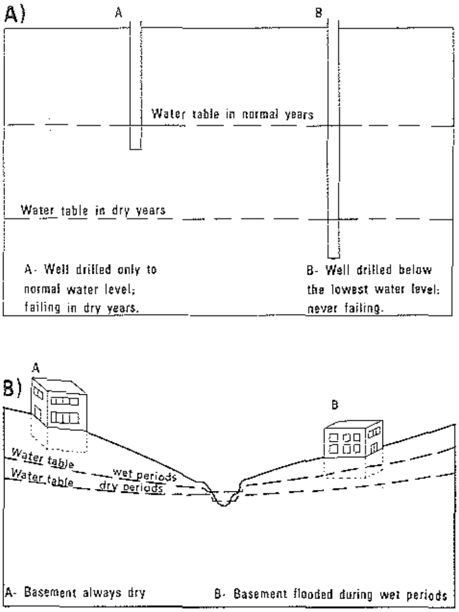

Figure 2. Effect of water-level changes on (a) wells and (b) basements of buildings

historical pattern of pumping rather than natural fluctuations. The following discussion is based on the water-level hydrograph for each well and the fluctuations are discussed in terms of the pumping history.

Well Bn-76

Bn-76 is a well located in the city of Green Bay. Municipal pumping began in the Green Bay-DePere area in the late 1800s when the artesian water level in the sandstone aquifer was reported to be about 95 ft above land surface (Weidman and Schultz, 1915). The water-level hydrograph for Bn-76 (fig. 3) shows that in 1951 the artesian water level had declined to about 215 ft below land surface. This decline resulted from heavy pumping of municipal and industrial wells. The hydrograph shows considerable seasonal variation in pumping and precipitation, superimposed on a steady decline until 1957 when it had declined to between 200 and 250 ft below land surface. In 1957, the city of Green Bay converted from a well-water supply to withdrawal of water from Lake Michigan. Termination of this large withdrawl of ground water resulted in a rapid rise in water level (fig. 3). By 1961, the water level in Bn-76 had recovered to about 50 ft below land surface. Since 1961, there has been a gradual decline, due to increased pumping from nearby industrial and municipal wells.

Well Wk-14

Wk-14 is a well located in the city of Waukesha. Pumping from the sandstone aquifer in the area began in the late 1800s. In 1915, the reported artesian water level in the sandstone aquifer was at or within 40 ft of land surface (Weidman and Schultz, 1915, p. 611). The hydrograph for Wk-14 (fig. 4) shows that in 1947 the water level had dropped to about 260 ft below land surface. This drop resulted from a regional lowering of water levels in the sandstone aquifer caused by pumping in the Waukesha-Milwaukee area. This pumping has continued to the present and, as shown on the hydrograph, has resulted in a continued decline of water levels. The 1980 water level in Wk-14 was between 450 and 475 ft below land surface. The average rate of decline at this well has been about 6 ft per year.

Although pumping from the sandstone aquifer has affected an area of more than 40 mi² around Milwaukee and Waukesha, water levels in the overlying Niagara dolomite aquifer have not been affected.

The stratigraphic relation between the Niagara dolomite and sandstone aquifers is shown schematically in figure 5. The two aquifers are separated by a confining formation called the Maquoketa Shale. Wk-14 is drilled into the sandstone aquifer, and Wk-31 is drilled only into the Niagara dolomite aquifer. The hydrographs of the two wells show the steady water-level decline in the sandstone, whereas the water level in the dolomite shows no decline and has fluctuated naturally.

Well Lf-57

Well Lf-57, located near Shullsburg in Lafayette County within the lead-zinc mining district of southwestern Wisconsin, shows the effect of different rates of mine dewatering. Before 1950 when pumping began, water levels in the area were reported as being 60 to 70 ft below land surface (Weidman and Schultz, 1915). The hydrograph for Lf-57 (fig. 6) begins in 1952 and shows a gradual decline in water level from about 65 ft to about 95 ft below land surface in late 1957. In 1958, lead-zinc production was stopped in the nearest mine and enlargement of the shaft was begun. Pumping was increased to allow grouting of the walls of the enlarged shaft. This increased pumping rate is reflected on the hydrograph by a sharp drop in water level between late 1957 and late 1959 to about 130 ft below land surface.

In late 1959, the enlargement of the shaft was completed and production was resumed. Pumping was decreased, which is reflected on the hydrograph by a sharp increase in water level until mid-1960. Between mid-1960 and 1968, the hydrograph reflects minor variations in pumping rate, while ore production was continued. Mining stopped in the mine nearest to Lf-57 in 1968 but

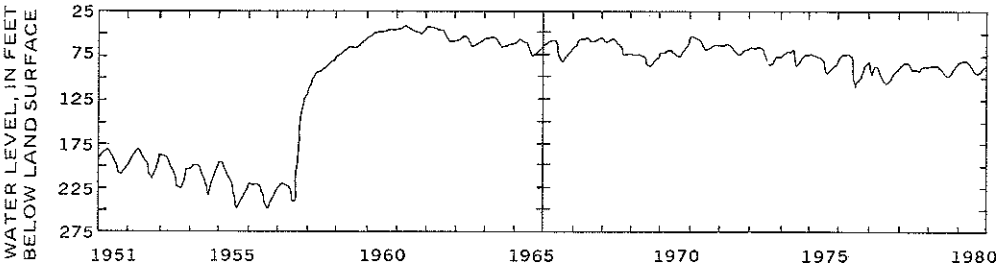

Figure 3. Water-level hydrograph for well Bn-76, 1951-80.

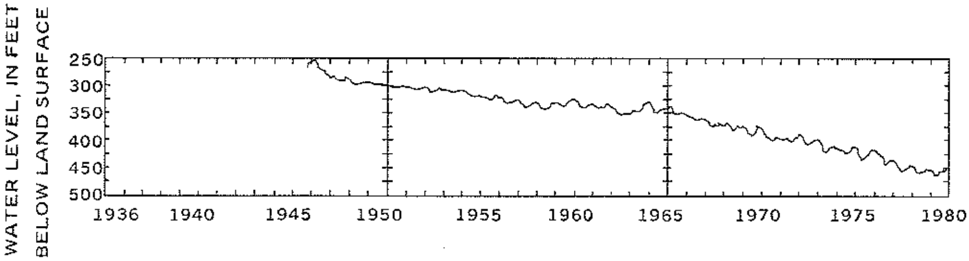

Figure 4. Water-level hydrograph for well Wk-14, 1947-80.

pumping was continued at a slower rate to keep other nearby shafts dry. In 1979, all mining in the area stopped, all pumping stopped, and water levels began to recover.

Relation to Precipitation

Ground water responds to precipitation much like a stream or lake, but because the rate of downward percolation is very slow, the ground-water response is slower and is not as pronounced as that of a stream. The response, measured as a rise in ground-water level, may occur within a few hours or days, or after a longer period of time. The intensity, duration, and distribution of individual rains and seasonal and long-term climatic variations are all reflected in water-level fluctuations.

Unlike precipitation, which can change from low amounts one year to high amounts the next, or vice versa, the change from low-to-high or high-to-low ground-water levels is usually gradual. Minimal water levels rarely occur immediately after maximum levels and vice versa. A number of years may intervene with moderately low or moderately high levels in between.

Even though the relationship between ground-water level and precipitation is shown here on only a few examples, it generally applies to wells throughout the State.

Direct Correlation

The direct relationship between precipitation and ground-water level can be observed on water-table wells in low-lying areas, where the water table is shallow and the response time is short. This relationship is demonstrated by a comparison of the hydrograph for shallow well Pr-6 with the precipitation record at nearby Park Falls, Price County (fig. 7).

The hydrograph shows how the month-to-month variations of rainfall are reflected by the well record. Ground water usually achieves its highest level in the spring as a result of melting snow and rains. Other high levels coincide with rainfall in summer and autumn. No long-term changes of water level are apparent from the hydrograph, although there is a slightly increasing trend since 1949. The ground-water level fluctuates within 6 ft from the land surface and the water level was nearly the same in 1980 as it was 40 years ago.

An analysis of a single year's hydrograph for the same well shows close correlation between daily water-level changes and individual rains (fig. 8). Figure 8 also shows the effect of other factors influencing the infiltration of water. The effect of spring snowmelt is reflected by the continued rise in water level during times of no precipitation. The combined effect of evapotranspiration and lack of soil moisture in the summer is reflected by the general decline in water level despite rainfall and by the lack of water-level increase during small storms which only saturate the soil but which are insufficient to recharge the ground water.

A general explanation of the hydrograph in figure 8 follows. Recharge from melting snow and spring rains is followed by a rapid rise in the water

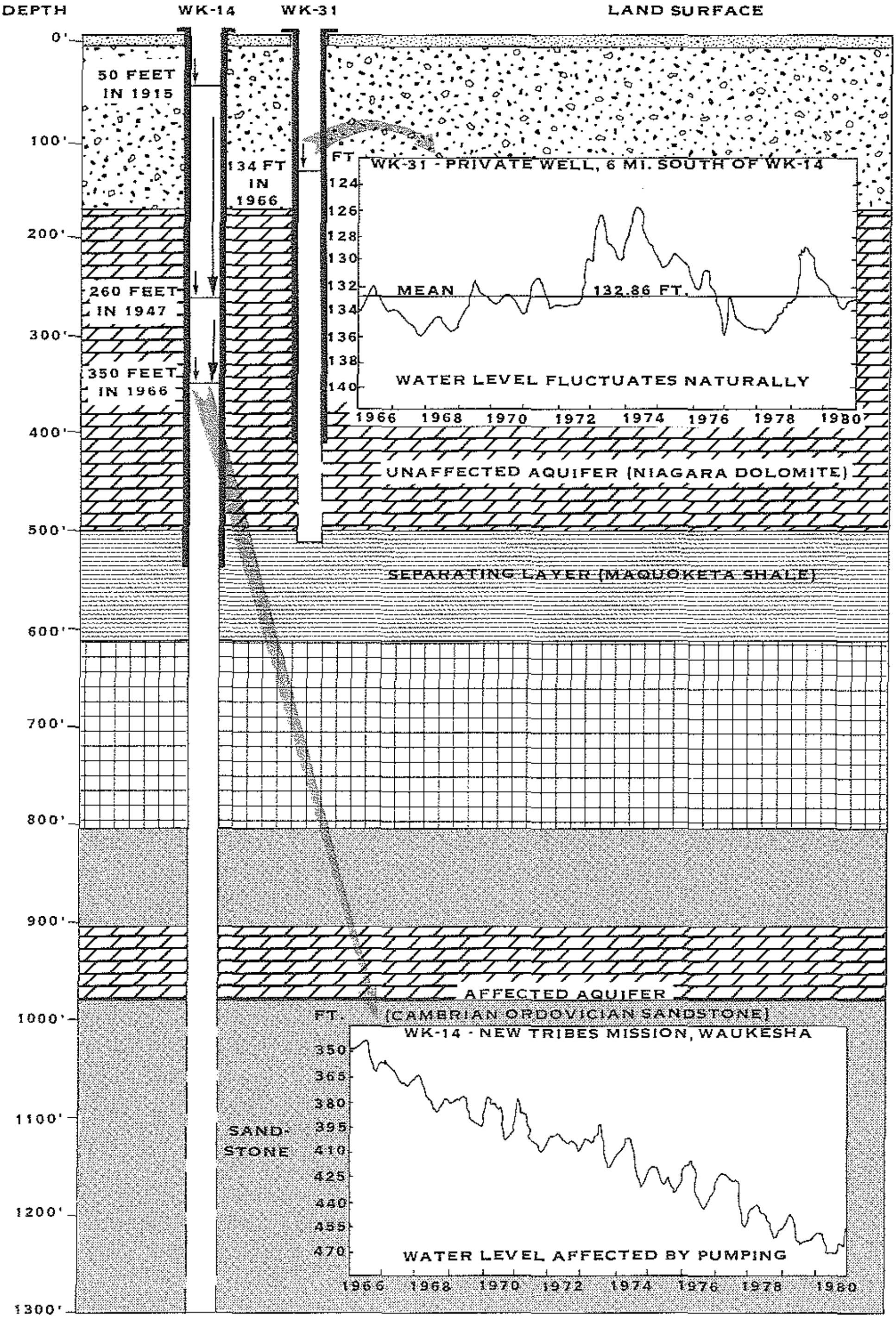

Figure 5. Relation of shallow and deep water levels in Milwaukee-Waukesha area of Wisconsin.

level in March and April. The water table rises immediately during periods of water surplus in the spring when evapotranspiration is low and the soil is adequately saturated. During summer, the water level goes through several cycles of decline and rise. The water level falls during the growing season, when evapotranspiration is high and light rains mainly replenish depleted soil moisture. Immediate peaks in water level are produced only by heavy rains (over 1.5 in.). Smaller rains are followed by a rise in water level after 1 or 2 days. After the end of the growing season, when evapotranspiration is low again, the autumn rains replenish ground water. During winter the ground is frozen, reducing or preventing direct recharge, and the water level declines because of discharge to streams and wells.

Delayed Effect

Water levels in wells respond to recharge by precipitation after certain periods of time which can be estimated from detailed hydrographs. The hydrograph of well Mt-7 (fig. 9), finished in Pleistocene sand-and-gravel aquifer at Pembine, Marinette County, demonstrates these time lags.

To express the effects of preceding-year precipitation on water levels, annual precipitation was calculated for the calendar year and annual water level for the water year (October to September), and the precipitation time scale was shifted 1 year ahead. The water year is designated by the year in which it ends so the months of October through December overlap on the graphs.

The precipitation peaks are generally followed by peaks in water levels in the following water

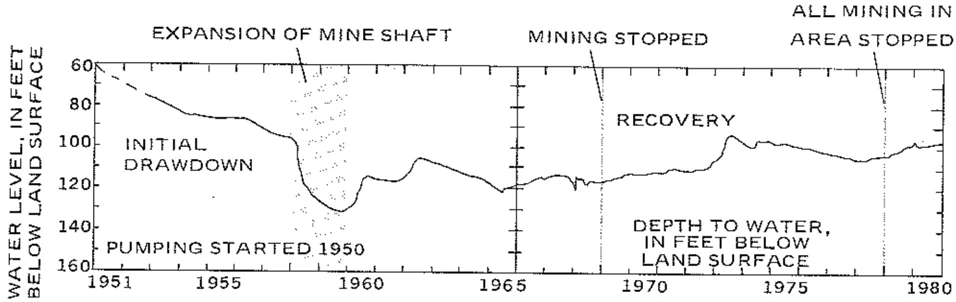

Figure 6. Water-level hydrograph for well Lf-57, 1953-80.

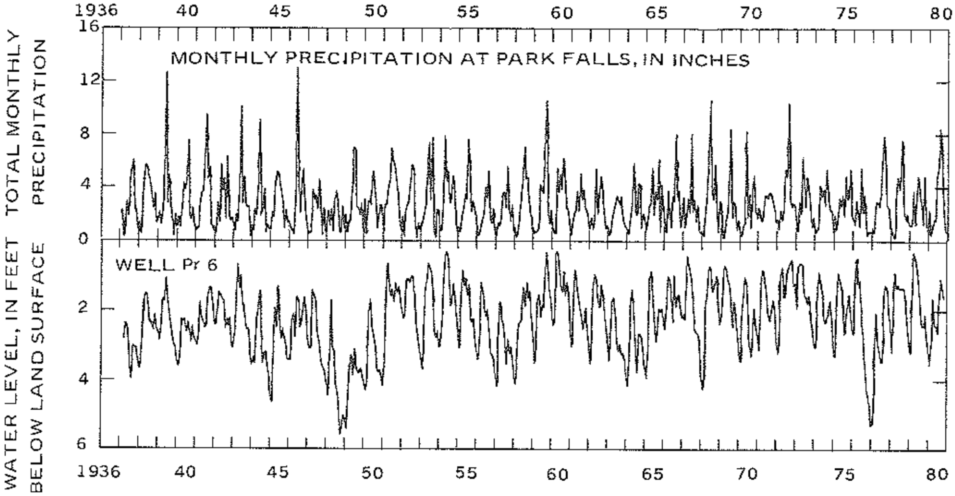

Figure 7. Relation of water level in well Pr-6 to monthly precipitation at Park Falls, Price County, Wisconsin.

year, with the exception of 1942 when both peaks occurred in the same year. The low levels follow the below-normal precipitation after a longer period of time because the discharge of the aquifer occurs much more evenly than the recharge. This is caused by the regulating effect of storage in the

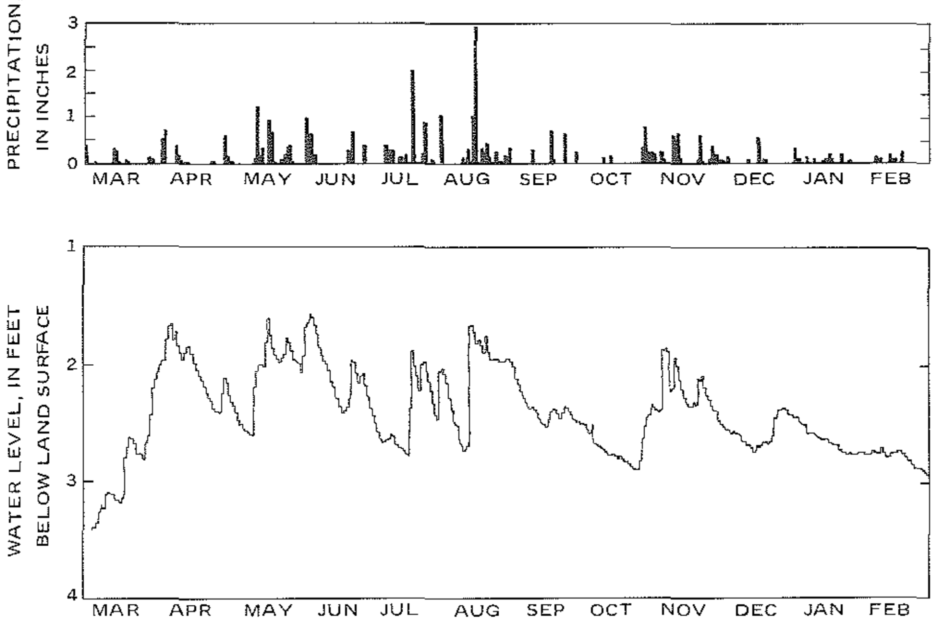

Figure 8. Variation in daily water level in well Pr-6 and in daily rainfall at Park Falls, Price County, Wisconsin.

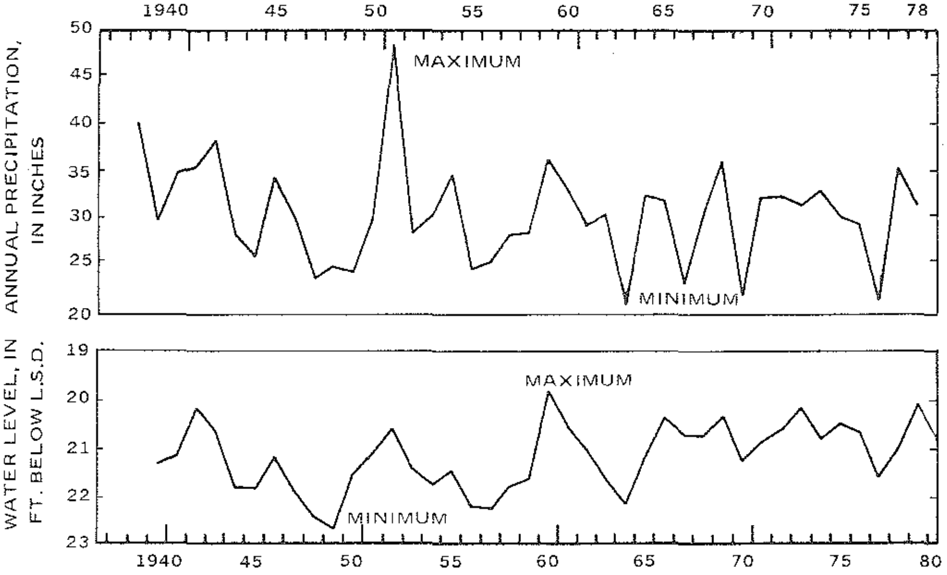

Figure 9. Relation of annual water level in well Mt-7 to annual precipitation, 1939-80, at Iron Mountain, Michigan.

aquifer which spreads the ground-water discharge over time, while ground-water recharge is more concentrated.

Most of the wells discussed in this report (Br-46, Dn-4, Mo-17, and Wk- 31) have delayed effects and fluctuate much like Mt-7. High levels occur most frequently in May or June, and low levels from January to March.

Cumulative Effect

Water levels in some wells, such as Lf-57 and Bt-2, fluctuate little and gradually change over long periods of time resulting from the cumulative effect of precipitation over several years.

In contrast to other wells previously described, the water level in well Bt-2 (fig. 10) located at Webster, Burnett County, and finished in Pleistocene sand (the sand-and-gravel aquifer), is relatively stable (average annual amplitude is 0.6 ft). It has few seasonal variations, caused only by exceptionally heavy rains, but fluctuates in response to the long-term changes in precipitation. The hydrograph of this well closely correlates with the 3-year running mean of monthly precipitation. Water-level changes are delayed several months to more than a year because water must percolate about 34 ft to reach the water table.

Definition: 3-YEAR RUNNING MEAN: A mean value calculated by averaging the value of the current month and the values of the preceeding 35 months.

The hydrograph of well Bt-2 indicates that over extended time natural changes are in balance. Following a prolonged drought in the 1930s, the ground-water level declined to a record low in 1938 and continued at low levels until 1941. Other less severe droughts caused similar declines of ground-water level in 1949-52, 1963-66, and 1978. These declines did not seriously deplete the ground water. The maximum range in fluctuation was less than 7 ft, and the declines were followed by significant rises in 1946-47, 1954-58, and 1973-76.

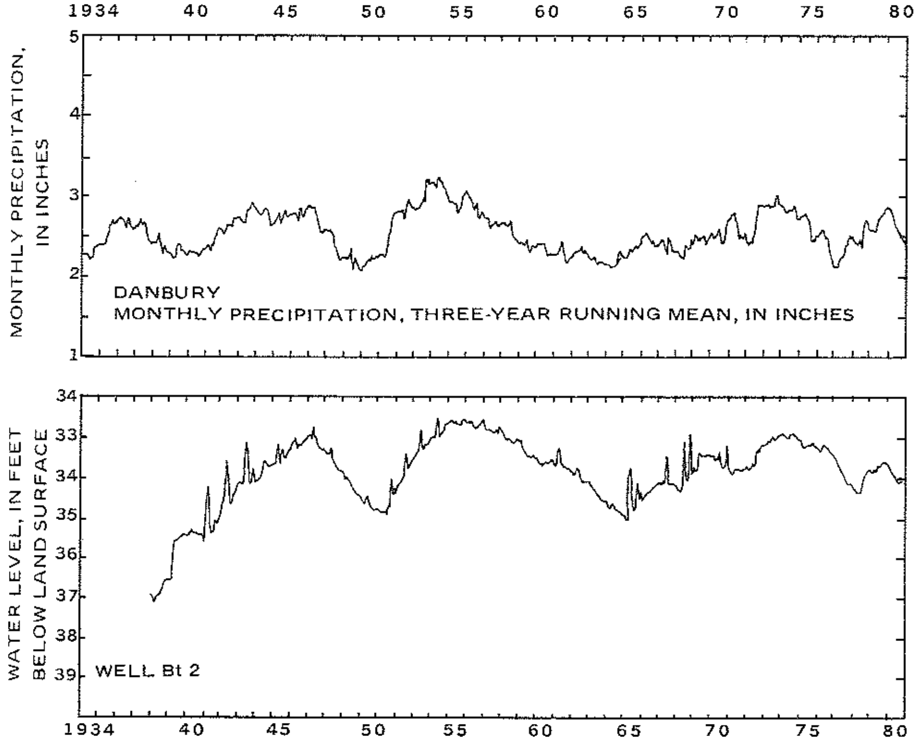

Figure 10. Relation of water level in well Bt-2 to the 3-year running mean of monthly precipitation at Danbury, Burnett County, Wisconsin.

Long-Term Fluctuations

Hydrographs such as the one for Bt-2 (fig. 10) reveal somewhat regular fluctuations several years in length that can be used to estimate long-term trends of water levels. The long-term water-level fluctuations result from long-term climatic fluctuations as shown by correlation of the hydrograph of well Mr-28 with the cumulative departure from normal precipitation (fig. 11). By establishing the correlation of the water-level curve with the cumulative-departure curve, it is possible to estimate the trends in water levels on Mr- 28 for periods without observations, such as prior to 1945. The cumulative-departure curve at Eau Pleine Reservoir indicates that a substantial peak in water levels also occurred in 1944.

Long-term declines in water level resulted from long periods of below-normal precipitation (1946-50, 1955-58, and 1973-77). Long-term rises resulted from periods of above-normal precipitation (1959-61 and 1968-72). These same long-term fluctuations can be seen in hydrographs for wells throughout the State.

Definition: CUMULATIVE DEPARTURE: Difference between measured rainfall and average value for a selected period of time, summed (or accumulated) for the entire period of record.

The records indicate that since 1934, when water-level measurements in Wisconsin began, there have been five distinct periods of below-average water levels: 1935-38, 1948-50, 1957-59, 1963-65, and 1977-78. The periods of above-average water levels include: 1942-44, 1960-62, 1971-76, and the recent period 1979-81. The occurrence and extent of these periods differ, of course, dependent on local precipitation. The intervals between dry or wet years range from 5 to 13 years.

Effects of Earthquakes on Water Levels

Observations in different parts of the world have revealed that shock waves generated by earthquakes can induce water-level fluctuations in dis-

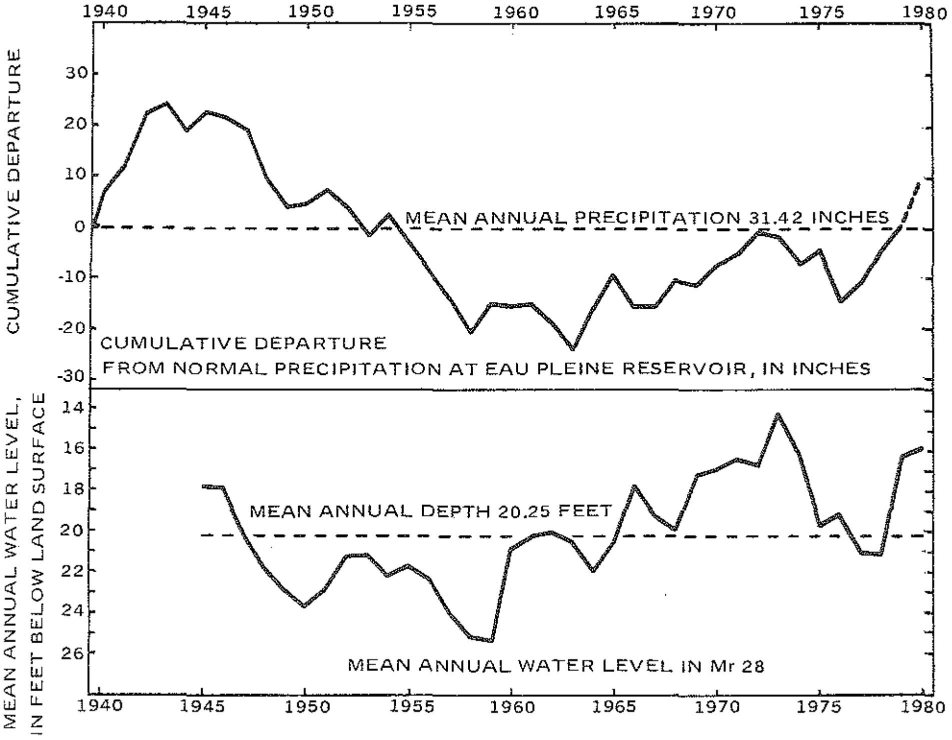

Figure 11. Relation of ground-water levels in well Mr-28 to cumulative departure from normal precipitation at Eau Pleine Reservoir, Marathon County, Wisconsin.

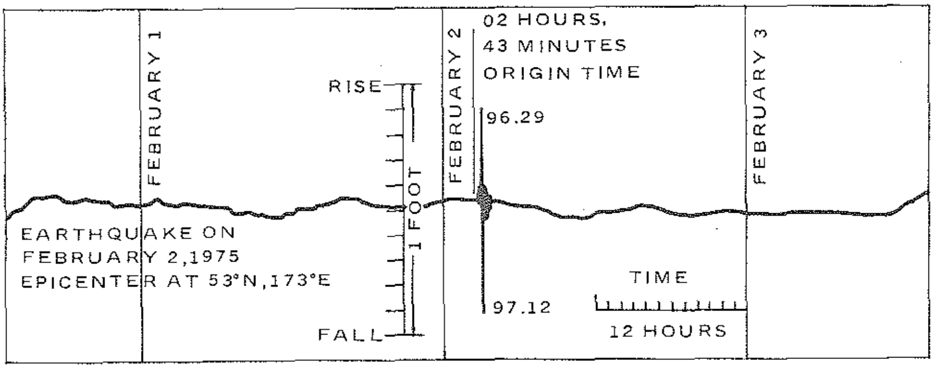

Figure 12. Water level fluctuation in well Lf-57 near Shullsburg, Wisconsin, resulting from an earthquake centered near the Aleutian Islands, northern Pacific Ocean.

tant wells. Some of these waves travel at speeds of approximately 120 mi/min so that fluctuations may appear after little more than 1 hour, even from the most distant earthquake centers. Water levels in some artesian aquifers are very sensitive and react to the passage of shock waves even though the waves may not be detectable on the land surface. Because the water level in well Lf-57 usually fluctuates gradually without rapid short-term variations, it clearly exhibits the phenomenon of shock-wave fluctuations. A good example is furnished by the water-level record from February 2, 1975 (fig. 12), when an earthquake centered near the Aleutian Islands, some 4,000 mi from the well, produced an abrupt fluctuation of 0.83 ft as the waves passed through the area. The effect of the shock lasted more than 1 hour, with the maximum disturbance to the water level lasting about 17 minutes. Similar fluctuations in well Lf-57 and other Wisconsin wells have been produced by other large earthquakes.

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Table 1. General information and statistical data for analyzed wells.

	County name and well number	Aquifer name and type	Well depth (feet below land surface)	General topography	First year of measurement	Average water levels (feet below land surface)				
						For period of record	Lowest annual and year of occurrence	Highest annual and year of occurrence	Lowest monthly and month of occurrence	Highest monthly and month of occurrence
Wells unaffected by pumping	Barron Br-46	Sandstone (water table)	65	Flat	1957	31.37	35.15 1959	22.25 1980	35.45 May 1959	26.44 Aug. 1979
	Burnett Bt-2	Sand and gravel (water table)	46	Flat	1938	33.86	36.85 1938	32.60 1955	37.13 Mar. 1938	32.51 May 1954
	Dane Dn-4	Sandstone (water table)	70	Hillside	1947	44.05	51.57 1964	36.60 1979	53.14 Feb. 1965	29.24 May 1974
	Marathon Mr-28	Sand and gravel (water table)	27	Flat	1945	20.15	25.40 1959	14.38 1973	26.04 Mar. 1959	12.77 July 1973
	Marinette Mt-7	Sand and gravel (water table)	33	Flat	1940	21.17	22.58 1948	19.72 1960	23.19 Oct. 1948	18.43 June 1960
	Monroe Mo-17	Sandstone (water table)	192	Flat	1951	4.38	6.39 1977	2.64 1973	7.61 Feb. 1977	.91 May 1973
	Price Pr-6	Sand and gravel (water table)	12.5	Flat	1938	2.27	3.95 1949	1.30 1960	5.55 Oct. 1948	.29 Apr. 1960
	Waukesha Wk-31	Niagara dolomite (artesian)	2/ 434 508	Hilltop	1948	132.86	137.25 1958	128.23 1974	137.99 Feb. 1959	126.57 May 1974
Wells affected by pumping	Brown Bn-76	Sandstone (artesian)	2/ 150 500	Flat	1951	103.20	230.53 1955	45.13 1961	248.97 Aug. 1955	41.24 May 1961
	Lafayette Lf-57	Galena-Platteville (water table)	2/ 16 265	Undulating	1953	105.18	129.36 1959	78.99 1953	130.81 Oct. 1959	75.76 Jan. 1953
	Waukesha Wk-14	Sandstone (artesian)	2/ 480 1,300	Hilltop	1947	358.48	455.15 1980	264.92 1947	467.06 July 1980	254.45 May 1947

Table 1. General information and statistical data for analyzed wells--Continued.

	County name and well number	Aquifer name and type	Lowest recorded water level (feet below land surface) and date of occurrence	Highest recorded water level (feet below land surface) and date of occurrence	Average annual amplitude (feet) for period of record	Smallest annual amplitude (ft) and year of occurrence	Largest annual amplitude (ft) and year of occurrence	Month with lowest average water level	Month with highest average water level
Wells unaffected by pumping	Barron Br-46	Sandstone (water table)	34.45 May 15, 1959	26.44 Aug. 6,1979	1.29	0.18 1963	3.84 1966	March	June
	Burnett Bt-2	Sand and gravel (water table)	35.10 Mar. 26, 1965	30.33 June 28, 1968	.59	.16 1940, 1955, 1971, 1974	1.44 1968	February	May
	Dane Dn-4	Sandstone (water table)	53.36 Feb. 8, 1965	26.64 Mar. 19, 1952	6.36	1.67 1970	12.82 1973	February	July
	Marathon Mr-28	Sand and gravel (water table)	26.09 Mar. 30, 1959	12.77 July 21, 1973	1.91	.49 1953, 1954	4.08 1973	March	July
	Marinette Mt-7	Sand and gravel (water table)	23.26 Nov. 2, 1948	18.01 May 17, 1960	1.46	.52 1980	2.72 1965	February	May
	Monroe Mo-17	Sandstone (water table)	7.75 Mar. 2, 1977	.43 May 8, 1973	2.44	1.32 1958	4.31 1965	February	June
	Price Pr-6	Sand and gravel (water table)	5.67 Oct. 31, 1948	1/ -.41 June 29, 1946	2.51	1.38 1940	4.32 1976	February	April
	Waukesha Wk-31	Niagara dolomite (artesian)	138.14 Feb. 2, 1959	126.28 June 10, 1974	2.22	.53 1954	4.06 1972	January	May
Wells affected by pumping	Brown Bn-76	Sandstone (artesian)	248.97 Aug. 30, 1955	41.24 May 3, 1961	24.96	9.29 1978	108.48 1957	July	April
	Lafayette Lf-57	Galena-Platteville (water table)	130.99 Nov. 3, 1959	63.67 Apr. 29, 1952	5.14	.51 1955	28.79 1958	April	July
	Waukesha Wk-14	Sandstone (artesian)	469.40 July 23, 1980	249.86 July 6, 1947	14.86	4.65 1951	28.42 1977	September	March

1/ -0.41 water level above land surface.

2/ Interval of uncased or screened opening.

Table 2. Probability of exceedance of water levels for wells unaffected by pumping.

Well number	Data set used	Water level, in feet below land surface, having a probability of exceedance of			Years in which water levels having 10-, 5-, and 2-percent probabilities of exceedance have occurred		
		10 percent	5 percent	2 percent	10 percent	5 percent	2 percent
Br-46	Highs	27.4	26.4	25.3	1979, 1980	Has not occurred	Has not occurred
	Lows	35.5	36.3	37.1	Has not occurred	Has not occurred	Has not occurred
Bt-2	Highs	32.7	32.6	32.5	1954, 1955, 1956, 1957	1954, 1955, 1956	Has not occurred
	Lows	35.3	35.8	36.5	1938, 1939, 1940, 1941	1938, 1939	1938, 1939
Dn-4	Highs	34.5	32.0	29.5	1952, 1973, 1974, 1979, 1980	1973, 1979	1973
	Lows	51.0	52.0	53.2	1959, 1964, 1965	1964, 1965	Has not occurred
Mr-28	Highs	15.5	14.4	13.2	1973, 1974, 1979, 1980	1973	1973
	Lows	24.5	25.5	26.4	1951, 1957, 1958, 1959	1958, 1959	Has not occurred
Mt-7	Highs	19.3	19.0	18.7	1960, 1973, 1979	1960, 1979	1960
	Lows	22.7	22.9	23.1	1945, 1948, 1949	1948, 1949	1948
Mo-17	Highs	2.0	1.6	1.1	1965, 1966, 1973	1965, 1973	1973
	Lows	6.7	7.1	7.4	1976, 1977	1976, 1977	1977
Pr-6	Highs	.5	.4	.3	1954, 1959, 1960, 1967, 1976, 1979	1954, 1959, 1960, 1979	1960
	Lows	4.6	5.0	5.5	1945, 1948, 1949, 1976, 1977	1948, 1949, 1977	1948
Wk-31	Highs	128.8	128.0	126.9	1973, 1974	1973, 1974	1973, 1974
	Lows	136.5	137.3	138.0	1958, 1959	1958, 1959	Has not occurred