WIS. GEOL. & NAT. HIST. SURVEY

Information Circular
Number 1

UNIVERSITY OF WISCONSIN

WISCONSIN GEOLOGICAL SURVEY

George F. Hanson, State Geologist

SOME EFFECTS OF PRECIPITATION ON GROUND WATER IN WISCONSIN

By
William J. Drescher

Prepared in cooperation with the
U. S. Geological Survey

Madison, 1955

Information Circular
Number 1

UNIVERSITY OF WISCONSIN

WISCONSIN GEOLOGICAL SURVEY

George F. Hanson, State Geologist

SOME EFFECTS OF PRECIPITATION ON GROUND WATER IN WISCONSIN

By
William J. Drescher

Prepared in cooperation with the
U. S. Geological Survey

Madison, 1955

SOME EFFECTS OF PRECIPITATION ON GROUND WATER IN WISCONSIN [1/]

By

William J. Drescher [2/]

INTRODUCTION

The importance of our water supplies has become increasingly apparent to most of us in recent years. The importance of water was forcefully dramatized by the water shortage in New York City in 1950. In nearly every State in the Union, one or more communities now has or has had a water problem whose effect on the citizens has been no less to them as was the one in New York City to New Yorkers. The increasing numbers of these problems have led to widespread speculation as to the adequacy of the Nation's water supplies.

By far the largest part (perhaps more than four-fifths) of our water supplies are derived from surface sources and many developments of surface water are still being planned. Nevertheless, it is believed that much of the readily available surface water of good quality is already allocated for various uses. Thus it would appear that more extensive use will have to be made of ground water and of ground-water reservoirs. Although we do not know how much ground water is available or the exact boundaries of our major ground-water reservoirs, or aquifers, rough calculations indicate that the amount of water in ground-water reservoirs may be several times the amount of surface water that can be stored, even including the Great Lakes, the water of which would cover the entire United States to a depth of about 10 feet. The annual rate of replenishment is believed to be considerably greater than the present

---

1/ Publication authorized by the Director, U. S. Geological Survey
2/ District Engineer, Ground Water Branch, U. S. Geological Survey

use (Sayre, 1950).[3/] Therefore it is of utmost importance to the Nation that the ground-water resources be located, evaluated, and utilized to the fullest possible extent. In the early part of the century many ground-water developments proved unreliable because the principles of ground-water occurrence were not recognized. Thus ground water came to have a bad reputation among engineers. In the twenties, however, the use of ground water began to increase and by 1935 it is estimated to have been 10 billion gallons a day. By 1945 the total use had doubled (Guyton, 1949) and by 1953 it is estimated to have been considerably in excess of 30 billion gallons a day - perhaps as much as 48 billion gallons a day (Picton, 1954).

Throughout the period of record the available water resources, except for local and temporary variations due to droughts, have remained essentially constant. There is some evidence that precipitation in some parts of the United States has decreased in the past 50 years. There is reason to believe that such dry periods will be followed by wet periods in the future as they have in the past (McGuinness, 1951). During the past 40 to 65 years, stream runoff in many places, as shown by carefully selected records of the U. S. Geological Survey, showed a downward trend which reached its lowest point in the decade of 1930 to 1940, but most records show an upward trend since 1940 (Sayre, 1950). Records of water levels in nearly 15,000 observation wells maintained by the Geological Survey and its cooperating agencies show no overall trend toward decline. However, water levels have declined in many areas because of pumping or other activities of man and, of course, water levels have declined temporarily as a result of severe droughts. Even the great drought of the thirties was subsequently offset by above-average precipitation which fully restored streamflow and ground-water levels to predrought stages.

3/ See references at end of paper

Although water levels have declined substantially in areas of heavy pumping, this fact does not mean that water levels are dropping throughout the country. In many cases it means that water is being taken out faster than it is being replenished, but in many others it merely means that the ground-water reservoir is adjusting itself to the hydraulics of ground-water movement under pumping conditions. On the other hand, fluctuations of water levels may mean that the ground-water reservoir is adjusting to changes in storage due to variations in natural recharge and discharge. Ground-water problems are due to maldistribution - both geographically and in time.

OCCURRENCE OF GROUND WATER

Hydrologic cycle

Ground water represents one phase of the hydrologic cycle. The hydrologic cycle, nature's perpetual-motion machine, is that system in which water moves from the atmosphere to the earth, over and through the earth, and back to the atmosphere. When rain falls some of the water is immediately evaporated and returned to the air. That which falls on the ground either soaks into the ground or runs off across the surface to lakes and streams and eventually to the ocean, some being evaporated along the way. The water that soaks into the ground replenishes soil moisture and is later used by plants or evaporated directly, or it continues to move downward until it reaches the zone of saturation. It is this last part - that which reaches the zone of saturation - that recharges the ground-water reservoir.

Ground water, like the water in other parts of the hydrologic cycle, is rarely at rest. It moves through the openings within the ground following the same fundamental laws that apply to all fluid motion. Water will move from a point of high potential energy toward a point of lower potential energy, provided, of course, that there are connected openings between the two points. Stated more simply, water will move down a hydraulic gradient along the path of least resistance. In order to have continued movement there must be a change in storage in or discharge from the aquifer. Recharge adds water to storage; if no ground water were discharged the reservoir would soon become full. This situation is avoided by natural discharge and by withdrawal of water by wells and drainage ditches. Natural discharge is by evaporation, by transpiration, and by flow to springs, streams, lakes, and oceans.

It may be said, then, that the ground-water phase of the hydrologic cycle consists of recharge, storage, movement, and discharge. Many factors influence each of these stages. Let us briefly consider a few of these factors before moving on to the prime consideration of the source of ground water.

Geology

The geology of an area is of importance to each stage of ground-water occurrence. Its influence on topography affects the rate, and therefore the proportion, of runoff and "soak in". The runoff will be greater in an area of steep hills and well-defined valleys than in a level area or one of gently rolling hills. The permeability of the rocks as well as their storage capacities are determined by the geology. A well-sorted sand may have much more available storage space than a sand or sandstone that contains silt and clay. A well-cemented sandstone or a sandstone containing much silt and clay is less permeable than a clean, well-sorted sand. The permeability is usually greater along bedding planes than across the bedding. In limestone aquifers, the permeability usually is controlled by the alinement of fractures, and the available storage usually depends upon the amount of solution of the rock that has taken place along the fractures. The discharge of ground water may be largely controlled by the outcrops of geologic horizons at relatively low elevations.

Thus it can be appreciated that a detailed knowledge of the geology is essential to a study of ground water in any area.

Surface conditions

The surface of the ground may be thought of with regard to its shape, its vegetation, its composition, or its exposure. It is tied intimately to the subjects of topography, biology, soils, and climate. We already have considered topography because of its close association with geology. The soil might well be considered as a part of geology but is considered separately here because of its pronounced effect on the rate at which water can soak into the ground. For instance, a tight clay soil will absorb water at a much slower rate than will a light sandy soil. Recharge will be decreased by the vegetation in an area because some of the precipitation will be transpired. On the other hand, vegetation will shade, and inhibit direct evaporation from, the soil surface. Humic material from decayed vegetation may inhibit runoff and encourage soak in. Geology, topography, and vegetation play an important part in the exposure of the surface to the prevailing climate.

So far we have limited this discussion to a few of the fundamentals of ground-water occurrence and some of those factors affecting recharge, movement, and discharge. Let us now consider that all-important, and principal, source of ground water - precipitation.

RESPONSE OF GROUND WATER TO VARIATIONS IN PRECIPITATION

As stated previously, our water-supply problems are problems of maldistribution in time and place. This statement applies equally well to precipitation. In fact, distribution of precipitation is the prime factor in many of our water-supply problems.

The geographic distribution of precipitation leaves much to be desired. Except for the high mountain areas and the Pacific Northwest, the average precipitation in the western third of the country is only about 15 inches per year. The Great Plains receive 15 to 40 inches, the average increasing to the east. The average in the eastern part of the country increases toward the southeast from about 35 inches near the Great Lakes to 60 inches in southern Florida.

The Nation as a whole is abundantly supplied with water. Precipitation averages nearly 30 inches per year. The average is well maintained and, for 5-year periods, varies from the long-time average by only a few percent. In some parts of the country, however, departures from normal have been of sufficient duration to cause acute distress.

Ground water is affected by the variations in precipitation. The response of ground water to changes in precipitation can be shown by several examples taken from Wisconsin where the average precipitation is very nearly the same as the national average. It should be kept in mind that different parts of the country have different annual precipitation patterns and that in some places, such as the arid to semiarid Southwest, evaporation is so great that minor amounts of precipitation are not effective in recharging the ground-water reservoirs.

Short-term variations

Figure 1 is composed of three graphs representing rainfall, water stage in a controlled drainage ditch, and water level in a well (Pt-255) about 230 feet from the ditch. The location is in central Wisconsin about 10 miles south of Stevens Point. The area is a very flat plain formed by glacial outwash sands overlain by 1 to 2 feet of peat and sandy soil. Soil moisture

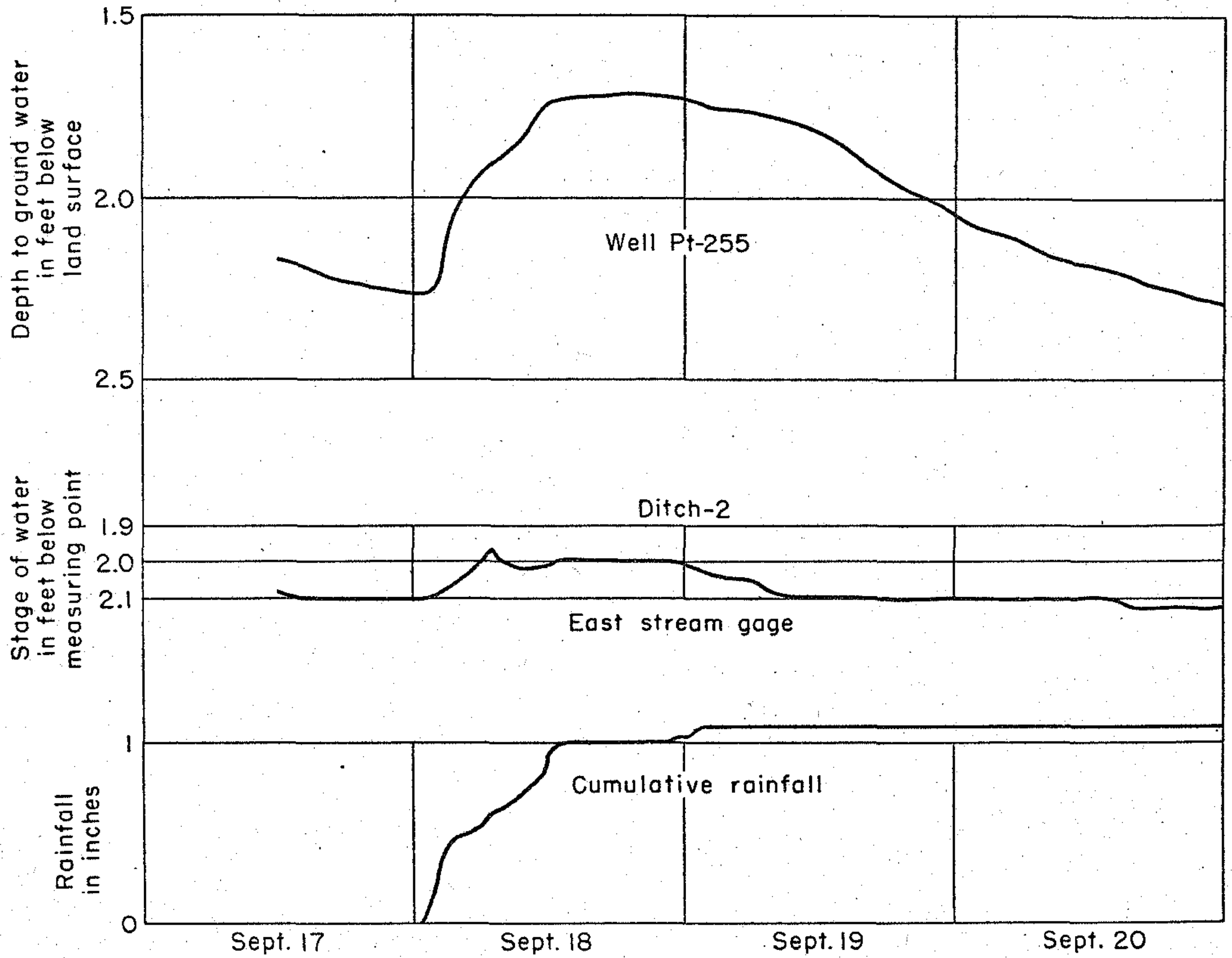

Figure 1.--Water levels in well Pt-255 and in drainage ditch, and rainfall south of Stevens Point, Wis., September 17-20, 1954.

was near a maximum, owing to recent rains. The only vegetation is grass.

Rainfall began at 12:30 a. m. on September 18, 1954, and continued until 1:00 p. m. the same day, totaling 1.00 inch and averaging about 0.08 inch per hour. Another 0.08 inch fell between 10:30 p. m. on September 18 and 1:00 a. m. the next day.

The water level in the well began to rise, from about 2 feet below the surface, within half an hour after the beginning of the rain. The water level rose rapidly during the rain until about noon, continued to rise until about 6:00 p. m., reaching a point about 0.6 foot above its origin, and then began to decline. By about 8:00 p. m. on September 20 the water level in the well had reached its original level and had resumed the same rate of decline as before the rain.

The water level in the drainage ditch began to rise as soon as the rain began and reached a peak, about 0.13 foot higher, at 7:00 a. m. The water level then declined slightly and maintained an elevation about 0.10 foot above its origin until about 11:00 p. m. By noon on September 19 the stage in the ditch had declined to its original level, and by the end of September 20 it had declined another 0.03 foot. There was no direct runoff to the ditch during the storm, except from the ditch banks.

From an analysis of the graphs it is evident that in this area ground water is rapidly recharged even by small amounts of precipitation. It is estimated that 80 to 90 percent of the rain reached the water table. That means that in each cubic foot of sand about 0.12 cubic foot of water can be stored. The permeability of the sand is high, as evidenced by the rapid decline in the well as the water was discharged by the drainage ditch.

Seasonal variations

Precipitation is greater during some seasons of the year than during other seasons at any one place. Similarly we have what may be called yearly cycles of water levels, in the sense that periods of low water level are followed by periods of higher water level. In figure 2, graphs are shown representing daily precipitation, cumulative monthly departures from normal precipitation, and daily water levels in a well (Ws-9) near Hancock, Wis. The area is a glacial outwash plain having a slight slope to the southeast. The soil is light and sandy and is underlain by about 18 feet of fine to coarse sand. Beneath the sand is a coarse gravel in which the well screen is placed. The vegetation immediately around the well is grass and about 100 feet west is a north-south windrow of 35-foot pine trees.

Precipitation was below normal during the fall of 1953 and during the first three months of 1954. The precipitation in January, February, and the first half of March was snow which was largely lost by evaporation. Rainfall was generally above normal from April through October, with the exception of dry spells during parts of May and July.

The graph of water levels in the well shows a steady decline from January until the latter part of April and then a nearly continuous rise through October. No response to individual rains is apparent under the conditions here. The correlation between the water-level graph and the daily-precipitation graph must be made in a general way. The cumulative-departure curve, however, makes the correlation of rainfall and water levels apparent at once.

Several conclusions can be drawn from the graphs: Small amounts of precipitation cause little, if any, recharge to ground water. Larger amounts of rainfall contribute to recharge but there is a lag of 15 to 20 days from time of rain to rise in water level. During periods of 20 days or more of little

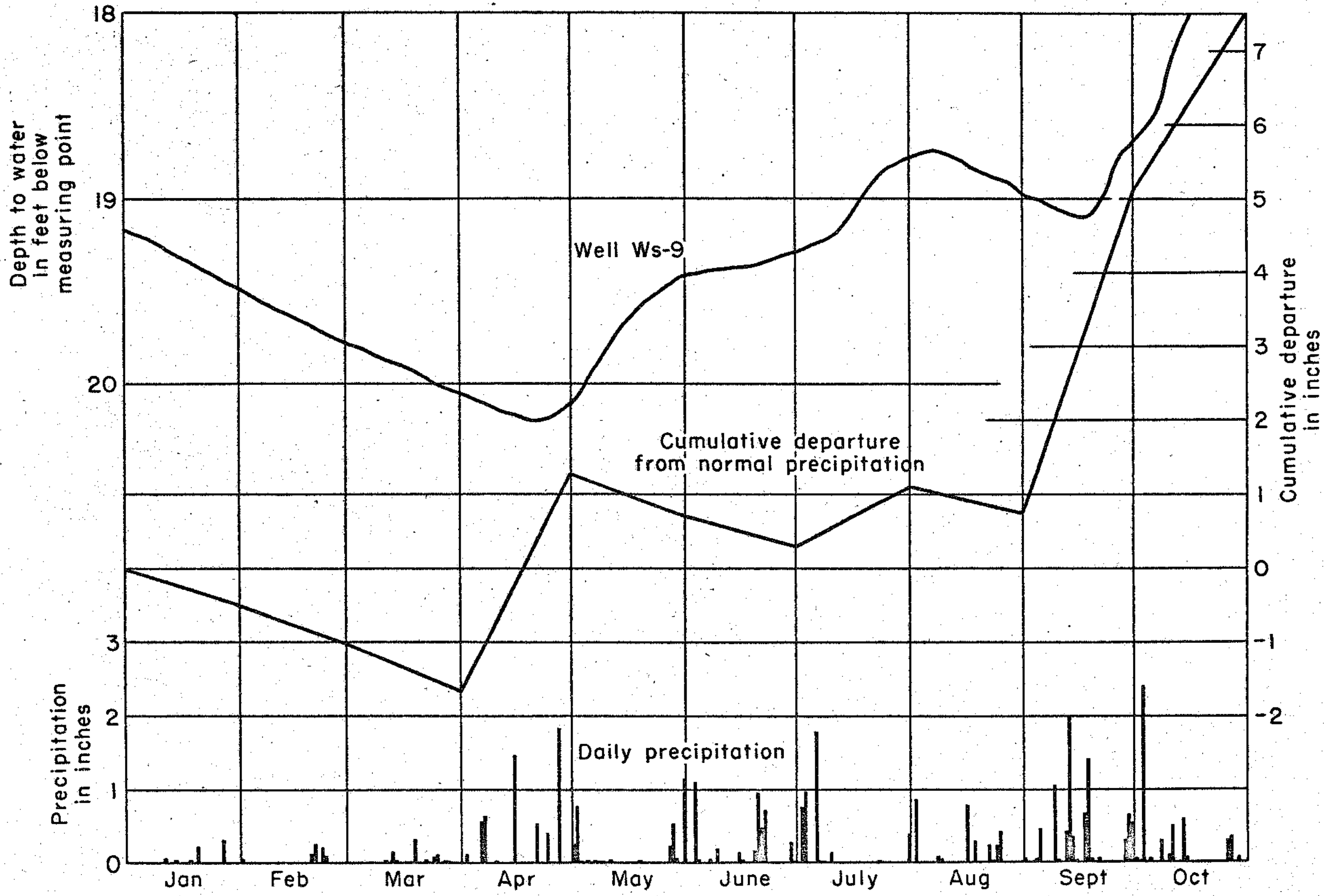

Figure 2.--Water levels in well Ws-9 and precipitation near Hancock, Wis., 1954.

or no rainfall, water levels decline, indicating that there is continuous discharge from the ground-water reservoir.

A significant part of the precipitation in Wisconsin, and in the northern part of the country as a whole, occurs as snow. Snow usually falls on frozen ground and remains for some time on the surface. As air temperatures increase in the spring, the snow melts, the ground thaws, and part of the snow melt usually recharges the ground-water reservoir. The amount of moisture in the ground, the depth of freezing, and the rate of melting will influence the amount of snow melt that soaks into the ground.

Figure 3 consists of graphs of daily precipitation, snow on the ground, daily mean temperatures, and water levels in a well near Hancock, Wis. The conditions at this area are similar to those for figure 2 except that the well is located among large trees, both deciduous and coniferous, and the water level is only 7 to 9 feet below the surface.

No influence of daily precipitation on the water level is apparent. Each time that the mean temperature rises above the freezing point there is a decrease in the snow on the ground and a response, in some cases only slight, in the water level. The water level declined during the period of below-freezing temperatures. At the end of March, the mean temperature rose and remained almost continuously above 30°F. At the same time the snow melted and the water level rose rapidly about $1\frac{1}{2}$ feet.

It is apparent that discharge of ground water takes place throughout the year but that precipitation does not recharge the ground water during periods of freezing temperature. It is apparent also that, under the conditions in 1952, a large amount of the snow melt became recharge.

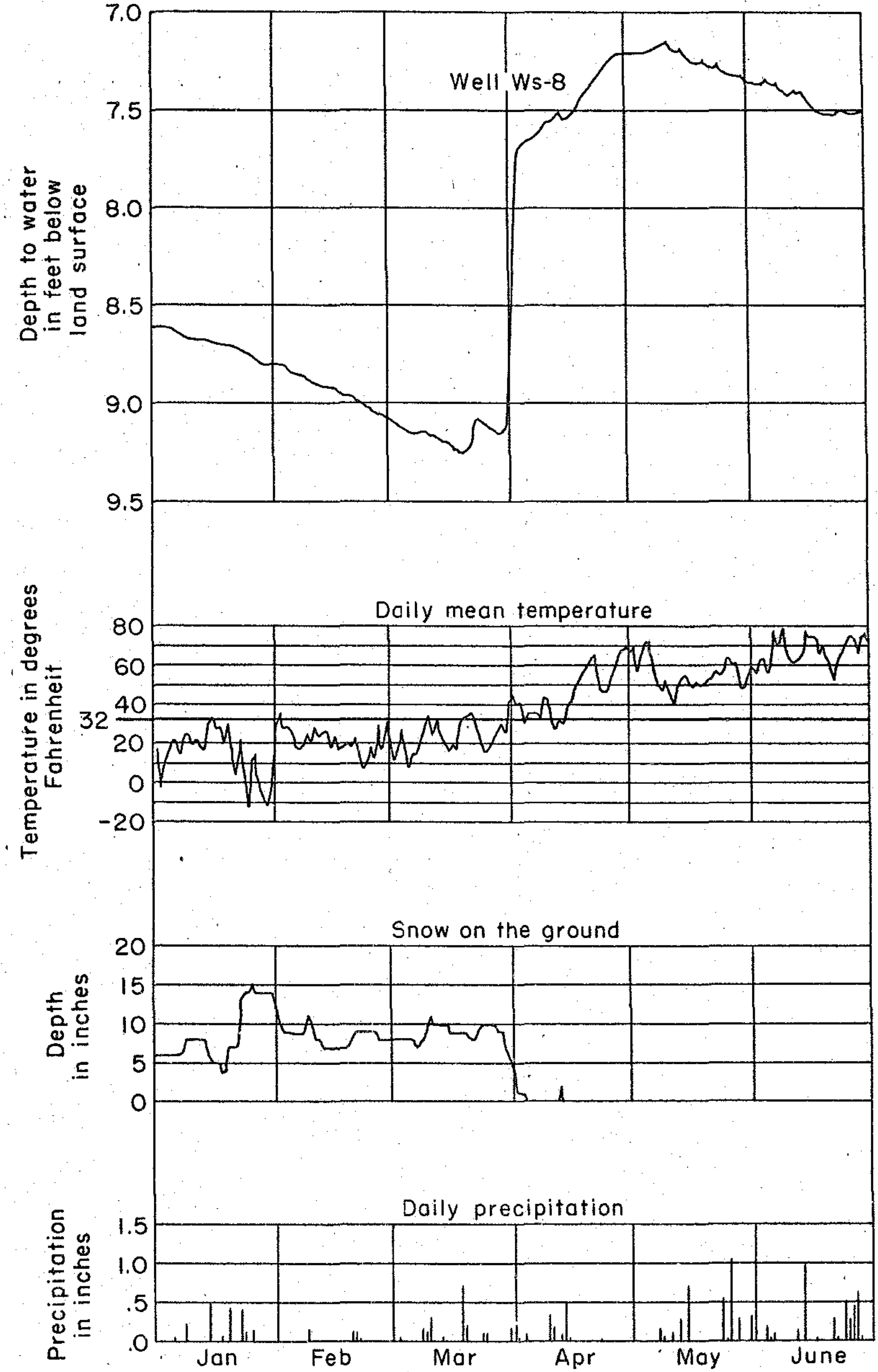

Figure 3.--Water levels in well Ws-8 and climatological data near Hancock, Wis., 1952.

Long-range variations

Variations in precipitation, other than short-term and seasonal, take place over periods ranging from a few years to tens and possibly hundreds or thousands of years. The principles involved in correlating ground-water storage and precipitation are believed to be the same for the longer periods as for the periods of a few years.

Figure 4 consists of graphs of 5-year average precipitation at Wausau, Wis., and water levels in a well about 12 miles southeast of Wausau. The area around the well is a plain formed by very fine to medium sand derived from glacial outwash. The vegetation immediately around the well is grass and woods and cultivated cropland lies beyond about 150 feet.

In trying to correlate the water levels with precipitation, plots were made of monthly precipitation, monthly and cumulative departures from normal precipitation, and running average departures from normal precipitation. Although each method gave a faintly discernible similarity to the water-level graph, the 5-year running average of precipitation gives a graph nearly parallel to the water-level graph.

This particular aquifer, as represented by this well, is not responsive to individual rains and only poorly responsive to seasonal variations in rainfall. On the other hand, recharge from precipitation is demonstrated by the response of water levels to long-term, 5-year, variations in precipitation.

Indirect response

The examples used above have all dealt with water in shallow, unconfined aquifers. When an aquifer is confined beneath relatively impermealbe material so that the water is under pressure, it is said to be an artesian aquifer. The pressure or "head" is derived from the elevation of the water in the recharge

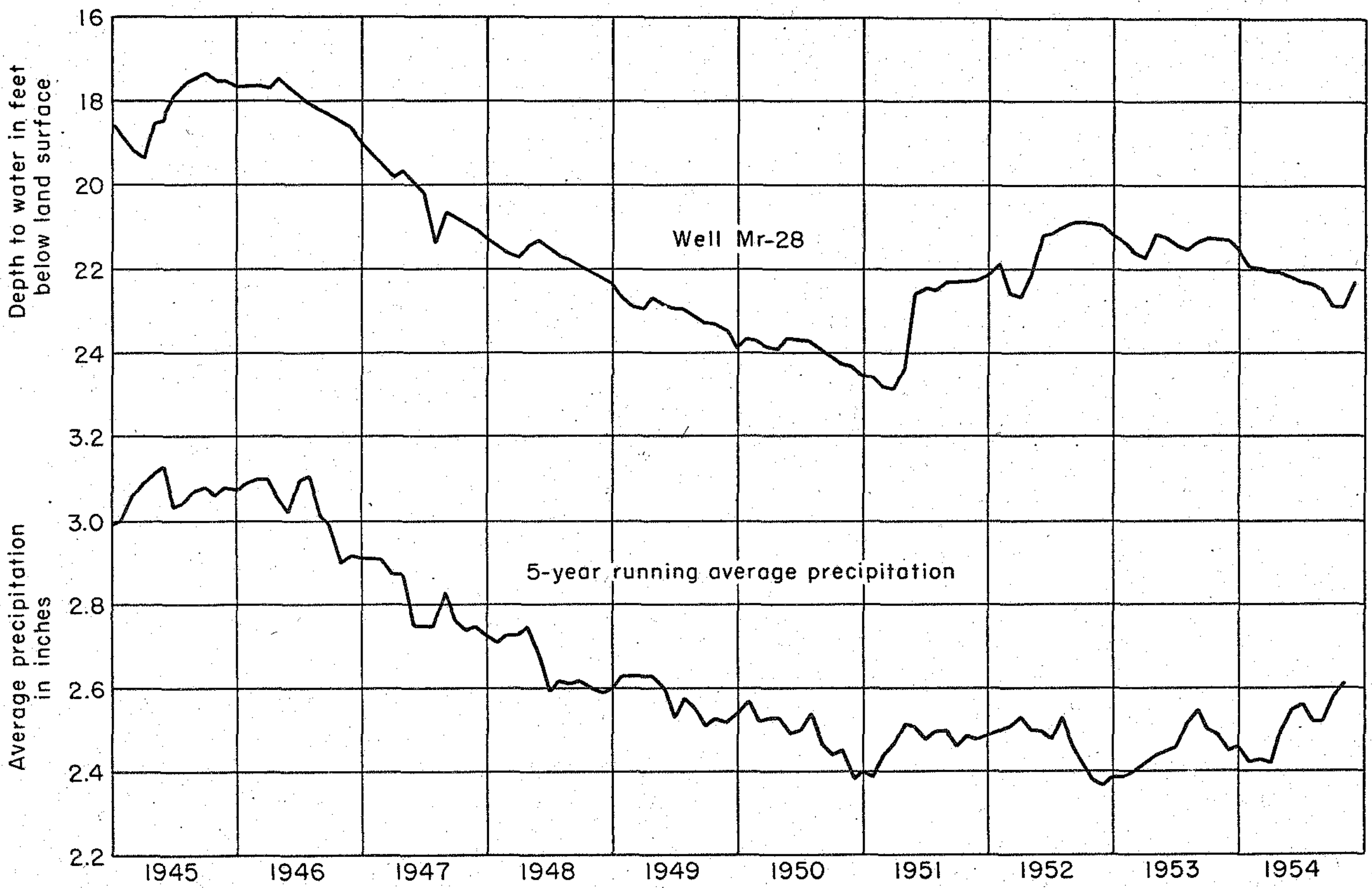

Figure 4.--Water levels in well Mr-28 and 5-year average precipitation at Wausau, Wis., 1945-54.

area and may or may not be sufficient to cause an artesian well to flow at the surface. The recharge area of an artesian aquifer may be many miles from any particular well in the aquifer.

Figure 5 shows the monthly water levels in an artesian well in Milwaukee, Wis., the annual departures from normal of precipitation and temperature, and the total areal pumpage from the aquifer. The recharge area for the aquifer is about 35 miles west (Foley, Walton, and Drescher, 1953), and any fluctuations in the water level due to recharge are damped out by frictional resistance and elasticity of the aquifer.

The graphs indicate that pumpage in the area generally decreases in periods of low temperature and, to some extent, during periods of high precipitation. The annual cycle of water levels is caused by a greater demand for water during the summer than during the winter for industrial and municipal use. The decrease in the overall rate of decline in 1950 is believed to have been caused by the lower-than-normal temperatures and the consequent smaller demand for industrial cooling water. In 1951 the water level assumed its former rate of decline even though the year was cooler and wetter than normal. This decline was caused by a greater-than-normal increase in industrial pumpage.

It can be concluded that, although short-term climatic changes have little direct effect on artesian-water reservoirs, the indirect effect may be quite significant.

In conclusion let me quote A. N. Sayre, chief of the Ground Water Branch, U. S. Geological Survey: "Adequate research on the hydrologic cycle should be programmed and carried out to determine the major factors that affect the net amount of water available for beneficial use." (Sayre, 1950). High on the list of such research should be a study of the causes and effects of precipitation cycles on ground water.

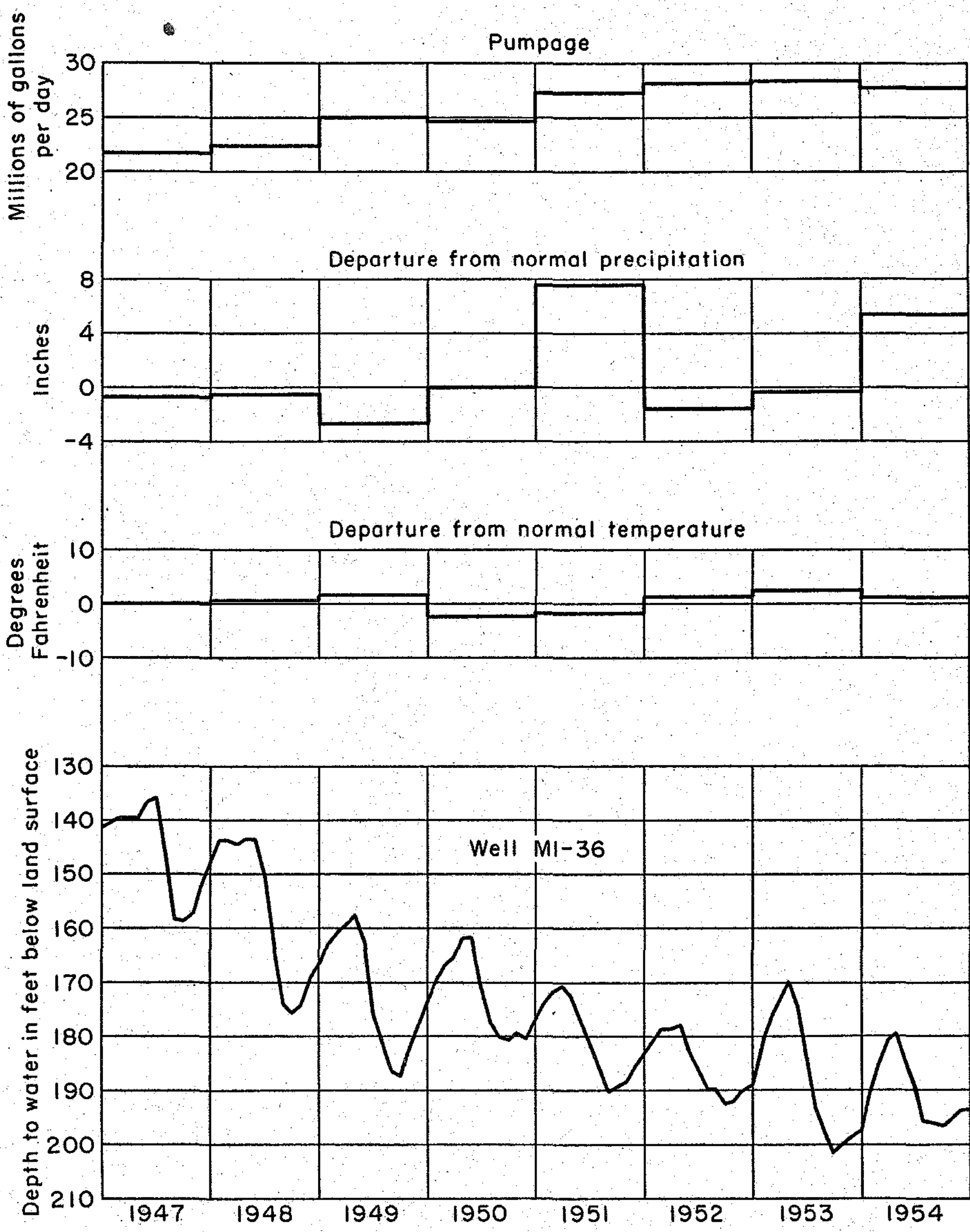

Figure 5.--Water levels in well Ml-36 and pumpage, precipitation, and temperature data at Milwaukee, Wis., 1946-54.

REFERENCES

1. Foley, F. C., Walton, W. C., and Drescher, W. J., 1953, Ground-water conditions in the Milwaukee-Waukesha area, Wisconsin: U. S. Geol. Survey Water-Supply Paper 1229.

2. Guyton, W. F., 1949, Estimated use of ground water in the United States, 1945: U. S. Geol. Survey duplicated report.

3. McGuinness, C. L., 1951, The water situation in the United States, with special reference to ground water: U. S. Geol. Survey Circ. 114.

4. Picton, W. L., 1954, Water well drilling, a big industry: Water Well Jour., November-December.

5. Sayre, A. N., 1950, Water resources of the United States. Paper presented to panel on water sponsored by Am. Soc. Civil Eng., New York, January 1950: U. S. Geol. Survey duplicated report.