Correlation of Water-Level Fluctuations with Climatic Cycles in the Oklahoma Panhandle

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By I. WENDELL MARINE

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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CORRELATION OF WATER-LEVEL FLUCTUATIONS WITH CLIMATIC CYCLES IN THE OKLAHOMA PANHANDLE

By I. Wendell Marine

ABSTRACT

The most important aquifer in the Oklahoma Panhandle is comprised of unconsolidated and semiconsolidated mixtures of gravel, sand, slit, clay, and caliche of Pliocene and Pleistocene age, and it covers an area of about 5,200 square miles. Water pumped from these deposits for irigation, municipal, domestic, stock, and industrial use in 1959 was estimated to be about 127,000 acre-feet. Precipitation is the only significant source of recharge for these deposits, and springs and seeps are the principal forms of natural discharge.

Hydrographs of the water levels in these deposits correlate best with graphs of the 5-year moving average of precipitation. When the 5-year moving average of precipitation increased abruptly in 1941 the water levels in some wells began to rise that year whereas water levels in other wells did not begin to rise significantly until about 7 years later. The water levels in other wells show intermediate time lags in their correlation with precipitation. The time lag is determined by (a) the depth to the water table, (b) the vertical permeability of the intervening sediments, and (c) the topographic position of the well. The water levels in Pliocene and Pleistocene deposits of the Oklahoma Panhandle have not yet shown the effect of the most recent dry period (1952–60) but are still rising in response to the previous wet period.

The ground-water reservoir is not recharged until water is added to it at the water table; however, recharge at the water table is determined by the amount of recharge water that passed through the soil zone at some previous time. Although the rate of recharge may vary, periods of larger amounts of recharge should still be correlated with periods of heavier precipitation.

Discharge from the aquifer is controlled by the ground-water gradient, which varies with the height of the water table. The gradient does not increase in the same year that recharge increases. The effect of a dry climatic period is less pronounced than the effect of a wet period because periods of high water table and increased discharge lag behind the wet period that caused them. The effects of a dry cycle are spread over a much longer period than those of a wet cycle because the lateral ground-water movement is slow and the distances of travel are great.

Recharge does not equal discharge in any particular year, and the two cannot be equated except over a period of time that includes both a wet and a dry cycle.

INTRODUCTION

The most important aquifer in the Oklahoma Panhandle (consisting of Cimarron, Texas, and Beaver Counties) is formed by unconsolidated and semiconsolidated deposits of Pliocene and Pleistocene age. These deposits consist principally of gravel, sand, silt, clay, and caliche. The economy and agriculture of the Panhandle are directly related to the availability of ground water from these deposits, as nearly all domestic, stock, irrigation, municipal, and industrial water supplies are obtained from them. The amount of ground water in storage depends on the relation of recharge to discharge, and changes in the amount are indicated by fluctuations of the water levels in wells. An analysis of the causes and significance of water-level fluctuations in the Pliocene and Pleistocene deposits of the Panhandle is therefore of great importance to the economy of the area.

The purpose of this paper is to analyze fluctuations in water levels that have occurred in the principal aquifer of the Oklahoma Panhandle and to correlate them with past climatic cycles. Water-level fluctuations are the result of the imbalance of recharge and discharge which in turn is affected by precipitation cycles.

The area with which this paper deals is shown in the index map on plate 1. Most of this area is in the High Plains, the flat surface of which in some places has a covering of dune sand (pl. 1). The High Plains surface is dotted in many places with shallow circular depressions that are as much as 160 acres in extent. These depressions prevent overland runoff from reaching the streams, and during wet periods they contain temporary lakes or ponds. The major drainage entrenches the area throughout, but much of the land is otherwise undissected. In eastern Beaver County, however, tributary drainage is well developed, and the area of high flat plains is small. The total area of the Oklahoma Panhandle is 5,708 square miles of which about 5,200 square miles are underlain by Pliocene and Pleistocene deposits.

GEOLOGY

Underlying the Pliocene and Pleistocene deposits in the eastern half of the area are red shale, siltstone, and sandstone of Permian age (pl. 1). In the western half of the area the Pliocene and Pleistocene deposits are immediately underlain by sandstone and shale of Triassic, Jurassic, and Cretaceous age. These Permian and Mesozoic units, commonly called bedrock in this area, yield small to moderate quantities of water to wells in some places, but they are never used as a source of water if a sufficiently thick saturated section of Pliocene and Pleistocene deposits overlies them. The Pliocene and Pleistocene deposits consist of the Ogallala Formation of Pliocene age in Cimarron and Texas Counties and in the western part of Beaver County; in eastern Beaver County the deposits are composed partly of Ogallala Formation and partly of formations of Pleistocene age. All the formations that make up the Pliocene and Pleistocene deposits generally have similar lithologic and hydrologic properties, thus they are shown as one unit on plate 1. These deposits are ancient flood-plain and channel sediments that consist of a variety of mixtures of gravel, sand, silt, and clay which contains much interspersed and, in places, bedded caliche. In part of the Panhandle, dune sand overlies the Pliocene and Pleistocent deposits (pl. 1). Although the dune sand is commonly not staturated with water, it serves a vital hydrologic function by absorbing precipitation for transmittal to the underlying deposits. Near the major streams, alluvium is generally channeled into and overlies the Pliocene and Pleistocene deposits, and in some places where these deposits have been completely removed by erosion, the alluvium lies directly on the Permian or Mesozoic bedrock. The alluvium is not shown on plate 1.

WATER USE

Nearly all domestic water supplies in the Oklahoma Panhandle are obtained from wells that derive their water from the Pliocene and Pleistocene deposits. Many of these wells are drilled only a few feet below the water table and may go dry if the water table declines sufficiently. Most irrigation wells also obtain water from the Pliocene and Pleistocene deposits. Yields of the irrigation wells average about 700 gpm (gallons per minute), but some wells yield as much as 2,000 gpm. Most irrigation wells penetrate the full thickness of the deposits and reach the top of the underlying bedrock. Most of the industrial and municipal wells in the Panhandle also obtain water from the Pliocene and Pleistocene deposits, but these are few compared with the number of irrigation wells.

The total pumpage from these deposits in the Panhandle in 1959 was estimated to be about 127,000 acre-feet. Of this total about 103,000 acre-feet was pumped for irrigation, 17,000 acre-feet for municipal use, and the remainder for domestic, stock, and industrial use.

SOURCE, MOVEMENT, AND NATURAL DISCHARGE OF GROUND WATER

The source of the water in the Pliocene and Pleistocene deposits in the Panhandle is rainfall within the Panhandle or adjacent areas. The ground-water gradient is generally eastward except where it is modified by the entrenched streams. Locally the gradient is toward streams sustained by ground water. Because of the eastward gradient, no large quantities of water enter or leave the area from either Kansas on the north or Texas on the south. The Pliocene and Pleistocene deposits are not present to the west where underlying Mesozoic rocks crop out, therefore water does not enter the deposits from that direction. Water does not enter the Pliocene and Pleistocene deposits from the underlying bedrock because the head of the water in the overlying rock is generally greater than in the bedrock.

Water is discharged from springs and seeps where stream channels have cut into the saturated zone. Many of these springs and seeps are localized near the exposed contact between these deposits and the underlying bedrock.

WATER-LEVEL FLUCTUATIONS

Hydrographs of wells are shown for each of the three counties in the Oklahoma Panhandle in figures 1, 2, and 3. At the top of each figure is a graph of the 5-year moving average of precipitation for a weather station near the center of the county.

In Beaver County the hydrographs of the first several wells (fig. 1) follow the 5-year moving average fairly closely, whereas hydrographs of the last wells rise throughout the period of low precipitation during the late 1950's. All the hydrographs of wells in Texas and Cimarron Counties (figs. 2 and 3) are similar to the last hydrographs in Beaver County in that they rise throughout the dry period.

As water moves from the surface of the ground downward to the water table, individual pulses of recharge are smoothed and averaged so that the water level fluctuates smoothly. Factors that determine the extent of smoothing are the depth to the water table, the vertical permeability of the material between the surface and the water table, and the position of the well relative to areas of discharge and recharge. Probably none of the water-level fluctuations in wells in the Pliocene and Pleistocene deposits would correlate with recharge from individual storms because the depth to the water table is too great and the vertical permeability of the material is too low. Seasonal fluctuations in precipitation might correlate with water-level fluctuations in some wells in which the water level is near the surface. Changes in annual precipitation correlate better still, but the best method of presenting the precipitation for purposes of correlation with the level of the water table in these deposits appears to be a 5-year moving average. Each annual point plotted on this graph, shown at the top of figures 1, 2, and 3, is the average of the precipitation for the previous 5 years.

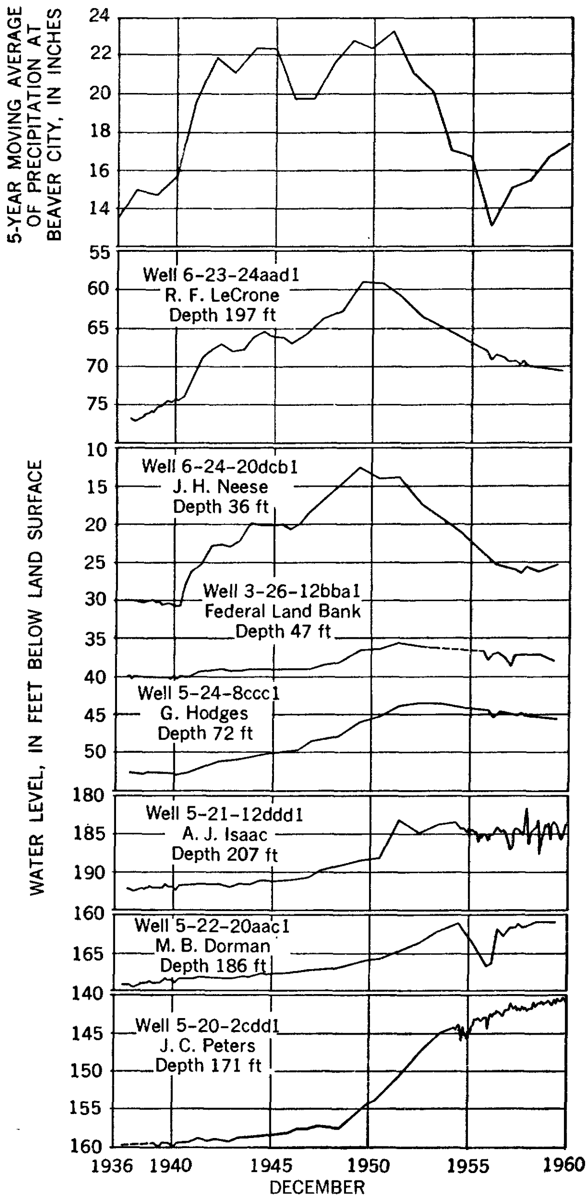

Figure 1.—Fluctuations of water levels in the Pliocene and Pleistocene deposits of Beaver County, Okla.

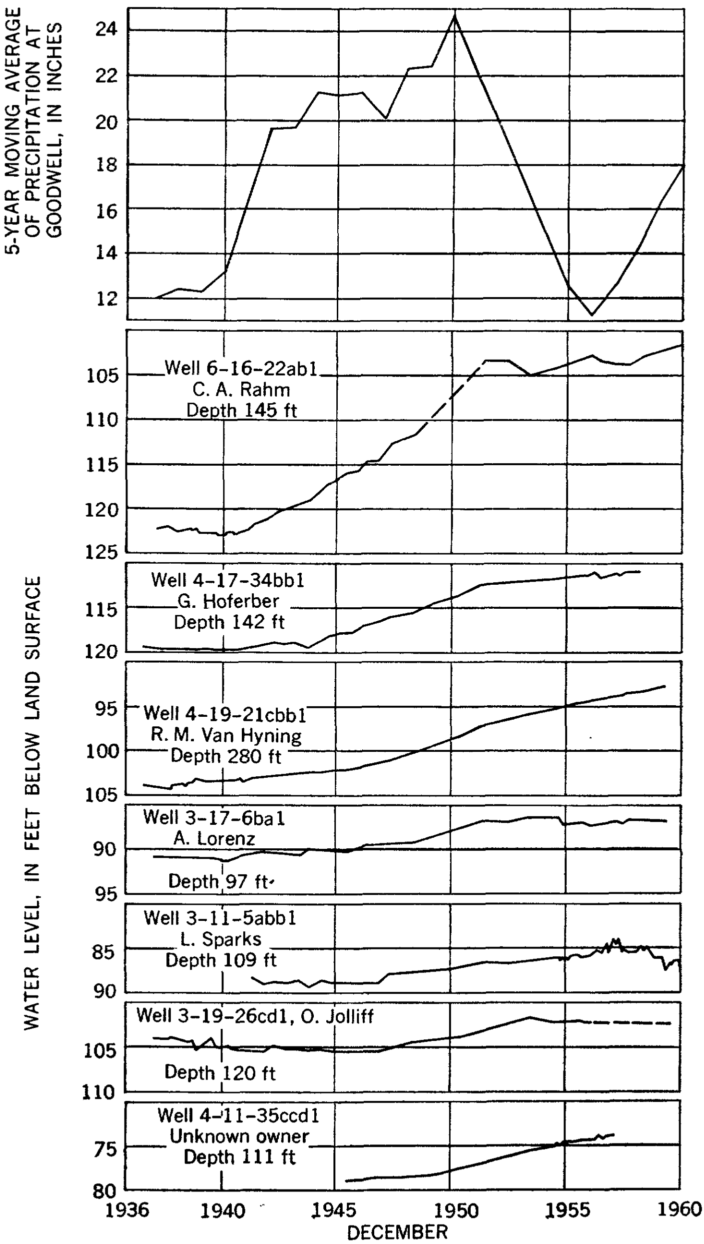

Figure 2.—Fluctuations of water levels in the Pliocene and Pleistocene deposits of Texas County, Okla.

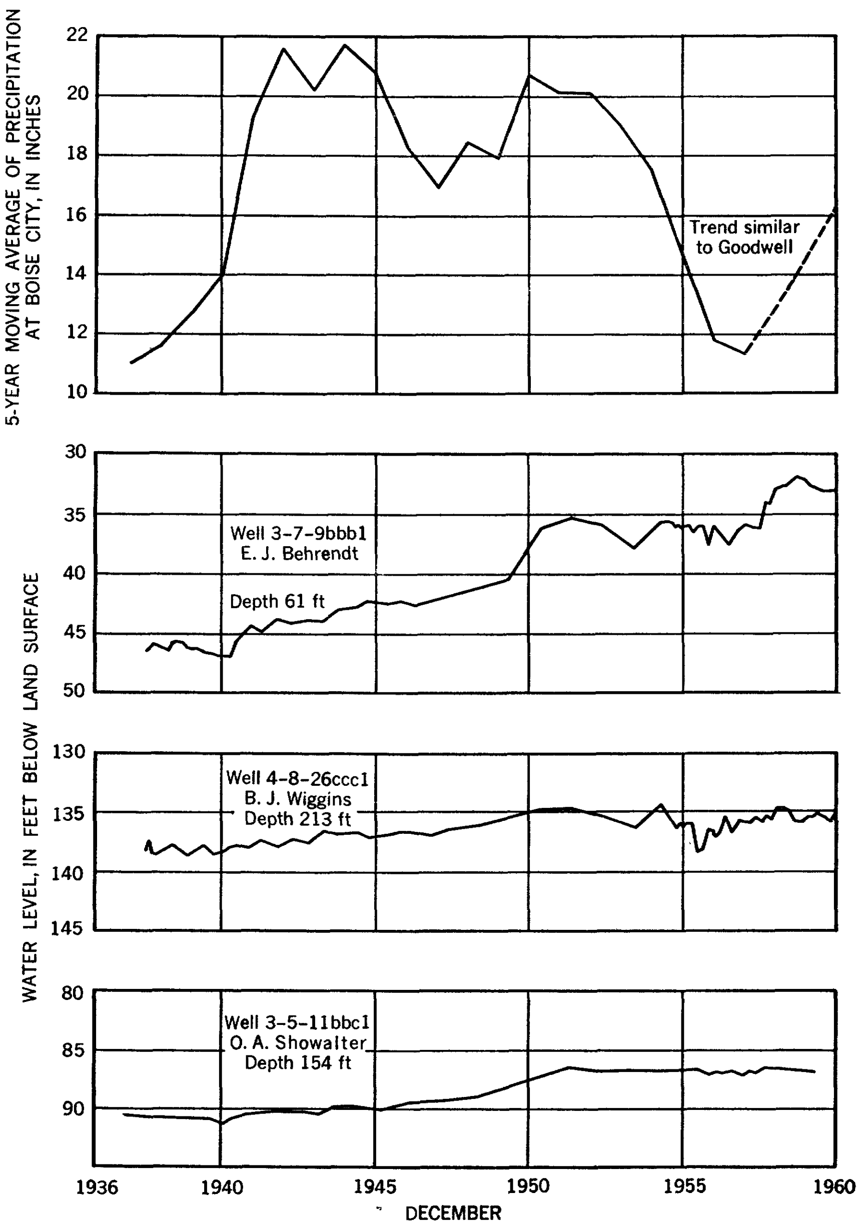

FIGURE 3.—Fluctuations of water levels in the Pliocene and Pleistocene deposits of Cimarron County, Okla.

The same factors responsible for the averaging effect in recharge also determine the time lag in correlation of water levels with precipitation. The hydrographs on figures 1, 2, and 3 are arranged with the one having the least lag at the top and the one having the greatest lag at the bottom; in between are hydrographs having intermediate lags. As would be expected, the hydrograph with the least lag (LeCrone well, fig. 1) correlates best with small fluctuations shown on the graph of the 5-year moving average of precipitation. The hydrographs with the greatest lag (Peters well, fig. 1; unknown owner well, fig. 2; and Showalter well, fig. 3) hardly correlate at all with any of the small fluctuations on the precipitation graph. For these wells only a general rise of water level in the later part of the period correlates with the general high in precipitation that occurred from 1941 through 1951. All fluctuations in precipitation of smaller magnitude than this do not show up as fluctuations of the water table.

The period 1933–40 was one of drought in the Oklahoma Panhandle as it was in most of the Great Plains. The water table near the end of this period was the lowest during the period of record. The 5-year moving average of precipitation for the period 1937–40 had a mean of about 15 inches in Beaver County and about 12.5 inches in both Texas and Cimarron Counties (figs. 1, 2, and 3). The precipitation increased, starting in 1941, and for the next 11 years the 5-year moving average had a mean of 21.5 inches in Beaver County, 21 inches in Texas County, and 20 inches in Cimarron County. Water levels did not rise abruptly in response to precipitation but rose gradually as increments of recharge in excess of discharge were added to the ground-water body. In some wells the rise in water level began the same year as the increased precipitation (LeCrone, and Neese wells, fig. 1; Rahm well, fig. 2; Behrendt well, fig. 3), but in most, the effect of increased precipitation was not reflected by a sharp rise in water level until some time later.

From 1951 through 1956, the 5-year moving average of precipitation decreased steadily. In hydrographs that show the closest correlation, the water levels declined steadily also, indicating an excess of discharge over recharge. During the same period, the water levels of wells showing a large time lag were still rising slightly owing to the high precipitation of 1941–51. These water levels are believed to be near their peak and probably will start a gradual decline soon. Water levels showing intermediate lag times are declining but probably are not as low as they will go, even if precipitation increases in the next several years.

Since 1956 there has been a slight increase in precipitation, but the Neese well (fig. 1) is the only one in which the water level has risen.

EFFECT OF RECHARGE ON WATER LEVELS

Because of the long period of time required for water to percolate from the land surface to the water table, the term "recharge" must be qualified. The ground-water body is not recharged until water is actually added to that body. This may be called recharge at the water table. However, in order to have recharge at the water table, water must have entered the ground at some previous time. The lapse of time between infiltration and recharge at the water table ranges from a fraction of a year to as much as 7 years on the hydrographs shown in figures 1, 2, and 3. The range in lapse time is shown by the time between the abrupt rise in precipitation in 1941 and the beginning of the steady rise in water level shown on the hydrographs.

Because precipitation is the only significant source of recharge, any changes in the amount of recharge over a period of time must be caused by a change in the amount of precipitation or in the rate at which that precipitation enters the ground or both. The rate of infiltration may vary depending on the frequency, distribution, and intensity of rainfall during the year and on the previous moisture conditions of the soil. The rate of recharge at the water table is determined by a former rate of infiltration into the soil, as once the water has passed below the root zone there is no appreciable change in the amount of water percolating toward the water table. It is not known whether the infiltration rate during wet periods is greater or less. However, it is highly unlikely that the rate of infiltration could be so much less in wet periods as to make the annual amount of water added to the ground less than in dry periods. Periods of rising water level, therefore, should be attributed to periods in increased rainfall.

The amount by which ground-water storage increased owing to the wet cycle of the 1940's may be computed by taking the maximum rise in water level and multiplying it by the specific yield of the material. The specific yield of the Pliocene and Pleistocene deposits probably is between 10 and 15 percent. The average rise of water level for all the wells shown in figures 1, 2, and 3 is more than 9 feet. This rise averages about 0.8 foot per year for the 11-year wet period. These wells are believed to be representative of the water-level rise throughout the Panhandle. If 10 percent is used for the specific yield of these deposits, about 1 inch or about 270,000 acre-feet of water per year was added to ground-water storage as a result of the wet cycle of 1941–51. Recharge at the water table had to include more water than this because ground water was being discharged continually during this period.

EFFECT OF NATURAL DISCHARGE ON WATER LEVELS

The natural discharge from a ground-water body is governed by Darcy's law which states that the rate of discharge is dependent on the coefficient of permeability, the ground-water gradient, and the cross-sectional area through which the water discharges. The gradient and cross-sectional area vary in time and are controlled by the height of the water table. Therefore, except for pumpage, the discharge is controlled by the height of the water table—the higher the water table, the greater the discharge.

Because the rate of natural ground-water discharge is dependent on the height of the water table, discharge does not increase in the same year that recharge increases. Discharge begins to increase only after much water has been added to storage and the height of the water table has increased. Discharge does not therefore equal recharge in any given year. Even after the water table has risen there is a long time lapse before water is discharged because of this rise. Lateral movement of water in the Pliocene and Pleistocene deposits is slow, and under most of the High Plains the distance is great to the place where water can emerge at the surface—for many areas 10 miles or more. This may explain why a decline in water level lags a dry cycle by more time than a rise in water level lags a wet one. For most wells shown in figures 1, 2, and 3 there has been no significant decline in water level during the 23-year period of record. Owing to the present higher water table in these deposits, more recharge must occur in order to balance the greater discharge if water levels are to remain stationary. If precipitation fluctuates in the future in the same manner and magnitude as in the past and the general rate of infiltration remains the same, a net decline in water level should occur.

From the foregoing discussion it may be seen that in the Pliocene and Pleistocene deposits of the Oklahoma Panhandle, recharge does not equal discharge on a year by year basis, and it would be incorrect to estimate recharge for any small period of time by measuring discharge and equating the two.

REFERENCE

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