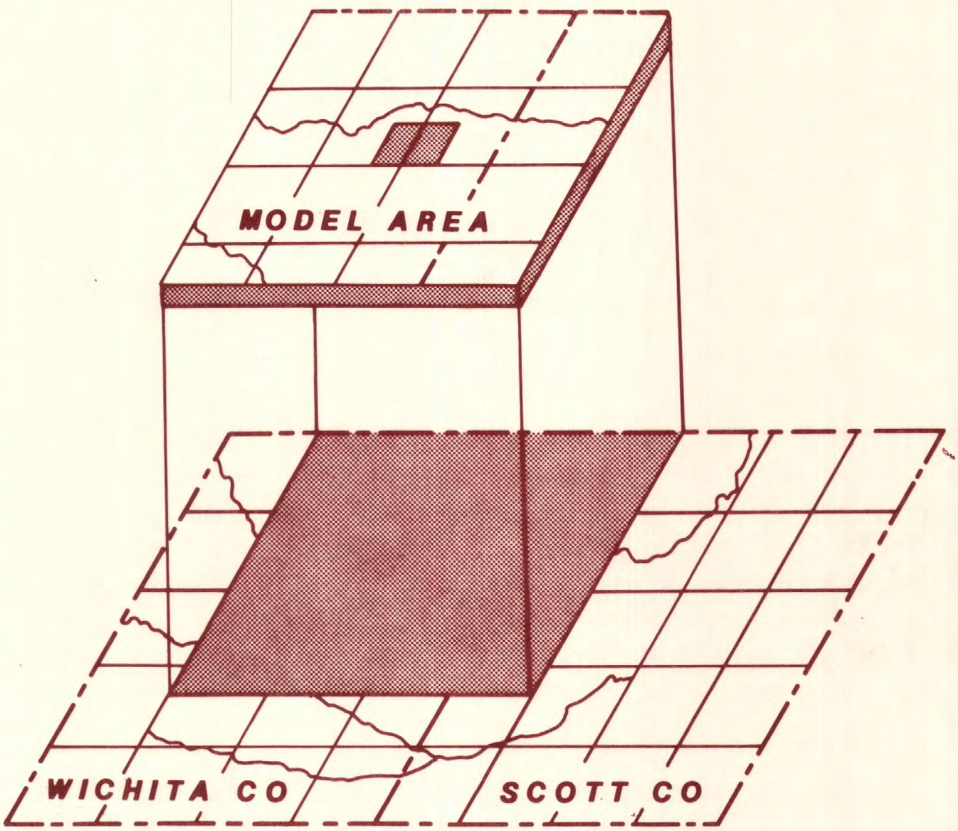
SIMULATED WATER-LEVEL DECLINES NEAR MARIENTHAL, WEST-CENTRAL KANSAS

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 80-39



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Intensive study in an area of 12-square miles near Marienthal, Kansas, has shown a decrease of 30 to 50 percent in saturated thickness of the Ogallala Formation since the development of irrigation. Projections from a digital model indicated the additional water-level declines that might occur from 1978 to 1989 if the pumpage in the model area was assumed to be one-half, equal to, or double the 1977 rate. The additional declines would range from 5 to 15 feet, 15 to 30 feet, and 25 to 40 feet, respectively. If pumpage only in the intensive-study area were assumed to be one-half or double the 1977 rate, water-level declines would range from 10 to 20 feet and from 20 to 25 feet, respectively. Reducing pumpage only in the intensive-study area could reduce the water-level declines locally. However, declines would be greatest near the edge of the area as a result of continued pumpage by wells outside the area boundary.

The digital model was more sensitive to changes in pumpage than to changes in hydraulic conductivity, specific yield, and recharge.

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By Lloyd E. Dunlap

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Lawrence, Kansas

April 1980

UNITED STATES DEPARTMENT OF THE INTERIOR

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GEOLOGICAL SURVEY

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SIMULATED WATER-LEVELS DECLINES NEAR MARIENTHAL, WEST-CENTRAL KANSAS

Lloyd E. Dunlap

ABSTRACT

Intensive study in an area of 12-square miles near Marienthal, Kansas, has shown a decrease of 30 to 50 percent in saturated thickness of the Ogallala Formation since the development of irrigation. Projections from a digital model indicated the additional water-level declines that might occur from 1978 to 1989 if the pumpage in the model area was assumed to be one-half, equal to, or double the 1977 rate. The additional declines would range from 5 to 15 feet, 15 to 30 feet, and 25 to 40 feet, respectively. If pumpage only in the intensive-study area were assumed to be one-half or double the 1977 rate, water-level declines would range from 10 to 20 feet and from 20 to 25 feet, respectively. Reducing pumpage only in the intensive-study area could reduce the water-level declines locally. However, declines would be greatest near the edge of the area as a result of continued pumpage by wells outside the area boundary.

The digital model was more sensitive to changes in pumpage than to changes in hydraulic conductivity, specific yield, and recharge.

GLOSSARY OF HYDROLOGIC TERMS

Aquifer - a formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Head - water-level altitude in a well.

Hydraulic conductivity - the rate of flow of water through a cross section of one square foot under a unit hydraulic gradient.

Saturated thickness - the amount (thickness) of material in an aquifer that is saturated.

Specific yield - the ratio of (1) the volume of water which the rock or soil, after being saturated, will yield by gravity to (2) the volume of the rock or soil.

Water table - that surface in a ground-water body at which the water pressure is atmospheric.

CONVERSION FACTORS

For readers preferring to use metric units, the factors for converting inch-pound units used in this report to International System (SI) of units are given as follows:

Multiply inch-pound units	by	To obtain SI units
inch (in)	25.4	millimeter (mm)
foot (ft)	.3048	meter (m)
square mile (mi^2)	2.509	square kilometer (km^2)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
gallons per minute (gal/min)	.06309	liter per second (L/s)

Note: Datum used in this report is National Geodetic Vertical Datum (NGVD) of 1929, formerly called mean sea level.

INTRODUCTION

Withdrawals for irrigation in west-central Kansas are gradually depleting the amount of ground water stored in the Ogallala Formation. Because the economy of the area is largely dependent on the continued production of food and fiber through irrigation, the availability of adequate ground water is of immediate concern to state and local water-planning agencies and to farmers. Ground-water management is becoming increasingly important as the resource decreases in west-central Kansas.

As the development of irrigation increased in the 1950's, the net discharge of ground water from the aquifer began to exceed the natural recharge. This continuing depletion caused dramatic water-level declines. Hydrographs of water levels in wells located in the model area indicate that declines have been as much as 4 to 6 feet per year.

A detailed geohydrologic study was made, in cooperation with the Western Kansas Groundwater Management District No. 1, in part of the area where large water-level declines have occurred. The intensive-study area, which covers 12-square miles, is located near Marienthal in northeastern Wichita County (fig. 1). A mathematical model was used to simulate the aquifer system in the area and to evaluate the effects of selected management alternatives on ground water in storage.

GEOHYDROLOGIC FRAMEWORK

The principal source of water for irrigation is the Ogallala Formation of late Tertiary age, which extends over most of west-central Kansas. The Ogallala consists of interbedded clay, silt, sand and gravel with caliche, and layers of sand cemented by calcium carbonate (mortar beds). In the model area, these unconsolidated deposits range in thickness from 50 to 200 feet, and depth to the water table ranges from 100 to 200 feet. Discharge from wells ranges from 50 to 1,200 gallons per minute.

The underlying Niobrara Formation of Cretaceous age, which consists of shale and chalk, is not known to yield significant amounts of water to wells.

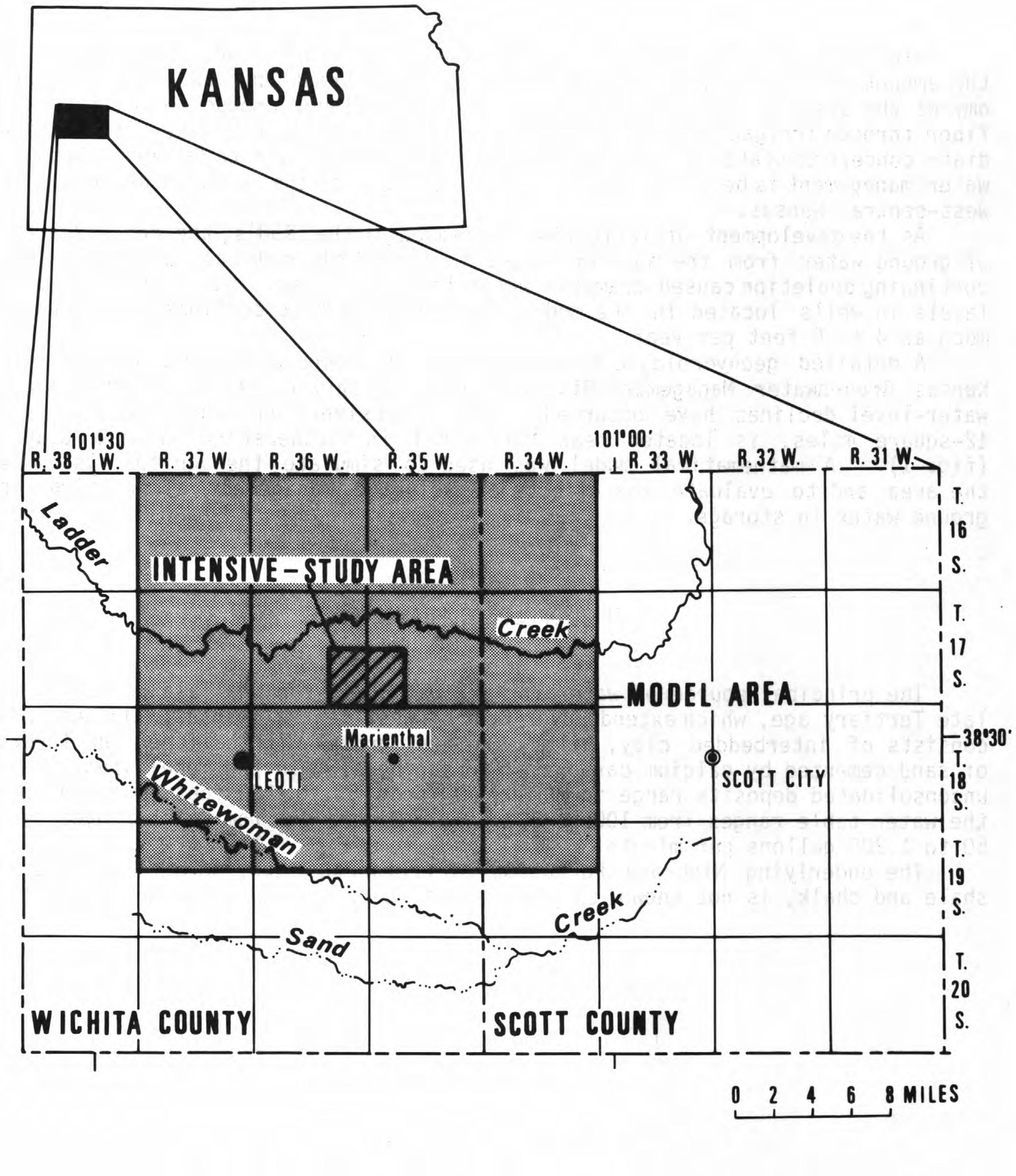


Figure 1.--Location of model area and intensive-study area in Scott and Wichita Counties, west-central Kansas.

MODEL CONSTRUCTION

Pumpage

Crop water demand and the the amount of irrigated acreage were used to estimate annual pumpage in the model area. A soil-zone model used by Lappala (1978, p. 94) in Nebraska estimates the amount of water, in addition to precipitation, needed to grow an irrigated crop. The model tabulates soil moisture and crop water demand for various crops and totals the irrigation needed to maintain the available soil moisture at 50 percent. Input parameters to the soil-zone model include precipitation, temperature, potential evapotranspiration, and soil characteristics. Crop irrigation demand was calculated for corn, wheat, grain sorghum, and alfalfa. The annual pumpage from 1951 through 1977 was calculated based on annual changes in crop acreage and crop irrigation demand.

A uniform value of recharge was used in the model. This recharge was the amount of water from precipitation that went into the aquifer via nonirrigated farmland, tailwater pits, road ditches, and ephemeral streams. Recharge in Wichita County is about 1 percent of the precipitation (18 to 19 inches) on nonirrigated land (Slagle and Weakly, 1976, p. 8).

Precipitation during some months exceeds crop water demand. Crop water demand in the soil-zone model is calucated monthly and summed over each year as annual pumpage. The soil-zone model calculates the amount of water that goes to surface-water runoff and to ground-water recharge on irrigated land. When this recharge occurs, it is considered to reach the aquifer instantaneously. This annual volume of recharge from irrigated land was subtracted from the annual volume of pumpage, which resulted in the net annual water withdrawn from the aquifer.

A check was made to test the accuracy of pumpage data in the model. Using crop water demand and irrigated acreage, the net amount of ground water withdrawn from the intensive-study area in 1977 was calculated to be 7,019 acre-feet. Using totalizing flow meters and hour meters installed in the irrigation systems, the actual amount of ground water withdrawn from the intensive-study area in 1977 was 6,800 acre-feet. Irrigation-return flow from irrigated fields in the intensive-study area is very small according to soil-moisture measurements taken in 1977-78 (Kume and others, 1979, p. 38). Thus, the pumpage calculated for the intensive-study area by crop water demand during 1977 was very close to actual field measurements.

Constant-Gradient Boundaries

In modeling of large aquifers, model boundaries should be extended to the physical boundaries of the aquifer, if possible. The Ogallala Formation in west-central Kansas contains a long, narrow aquifer trending east and west. The north and south model boundaries were located at the aquifer's physical boundaries. But extending the model boundaries to the east and west physical boundaries was not feasible due to the enormous amount of data collection that would be required. However, a boundary condition was used in which the aquifer inflow and outflow decreased at the east and west boundaries as the saturated thickness decreased. This condition, called the constant-gradient boundary, assumes that the gradient across the boundary remains relatively constant through time.

MODEL CALIBRATION

A two-dimensional finite-difference model of ground-water flow, described by Trescott, Pinder, and Larson (1976), was used to simulate the aquifer system. This model was constructed to represent an area larger than the area of intensive study (fig. 1) so the effects of pumping from the surrounding irrigation wells also could be simulated. The model area was increased in size to a distance where simulated pumping of wells in the intensive-study area caused negligible change in head (water level) at the boundary of the model.

Values for the hydraulic parameters required for the model were estimated based on the best data available. Then the model was calibrated by adjusting certain parameter values until established historic conditions could be simulated. Hydraulic conductivity and recharge were adjusted in the steady-state model. Specific yield was adjusted in the transient model.

The model was calibrated first to simulate steady-state or equilibrium conditions that existed in 1950, prior to appreciable development of ground-water irrigation. The dimensions of the aquifer system in the model area, such as the altitude of the water surface (1950) and the base of the aquifer, were determined mostly from data in previous studies.

Recharge to the aquifer was calibrated to be a uniform value of 0.3 inches per year.

Hydraulic conductivity in the model area was initially estimated at 75 feet per day. This value was derived from lithologic logs of test holes drilled in the intensive-study area. The hydraulic conductivity was lowered during the calibration in two areas outside the intensive-study area. The hydraulic conductivity in the two areas was reduced from 20 to 60 percent to match 1950 water-table contours. This reduction was within the range of values obtained from studying lithology from drillers' logs in the area. The resulting water-level contours simulated by the steady-state model reasonably matched the 1950 observed water-level contours (fig. 2).

After steady-state calibration, the model subsequently was calibrated to simulate increases in pumpage that existed as irrigation development increased. The transient calibration requires values of pumpage and specific yield. Initial estimates of specific yield were based on well logs and aquifer tests. Calibration of the model under transient conditions indicated that a uniform specific yield of 0.17 best fit the observed water-level conditions.

Simulated water levels in January 1978 were compared with water levels generated by the transient-state model based on January 1978 data, as in figure 3. Hydrographs of water levels in two wells located in the model area are compared with hydrographs of simulated water levels in figure 4.

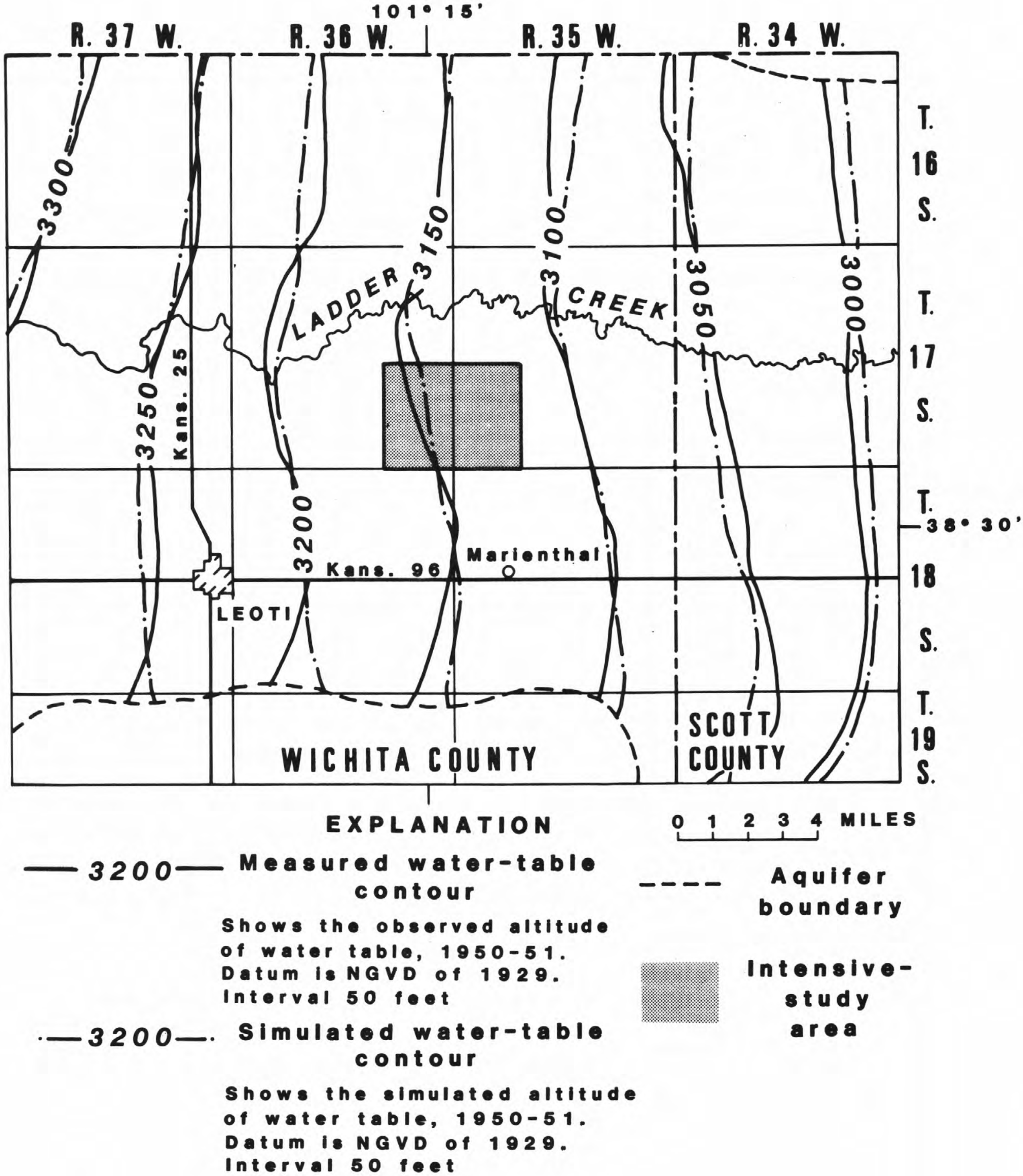
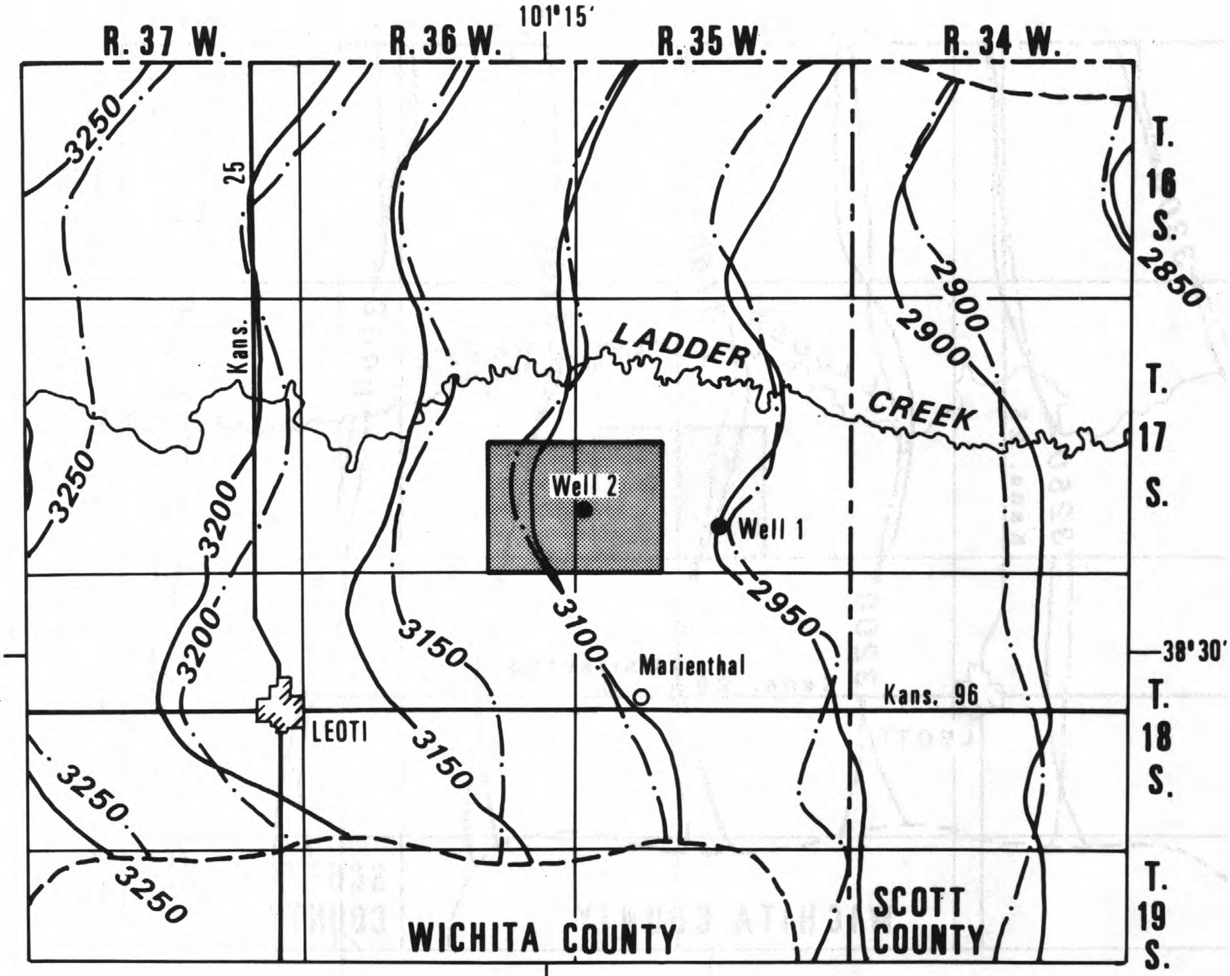


Figure 2.--Measured and simulated water-table configuration, 1950.



EXPLANATION

——3150—— **Measured water-table contour**
Shows altitude of water table, January 1978. Datum is NGVD of 1929. Interval 50 feet

—·—3150—·— **Simulated water-table contour**
Shows altitude of simulated water table, 1978. Datum is NGVD of 1929. Interval 50 feet

— — — — **Aquifer boundary**

Intensive-study area

Figure 3.--Measured and simulated water-table configuration, January 1978.

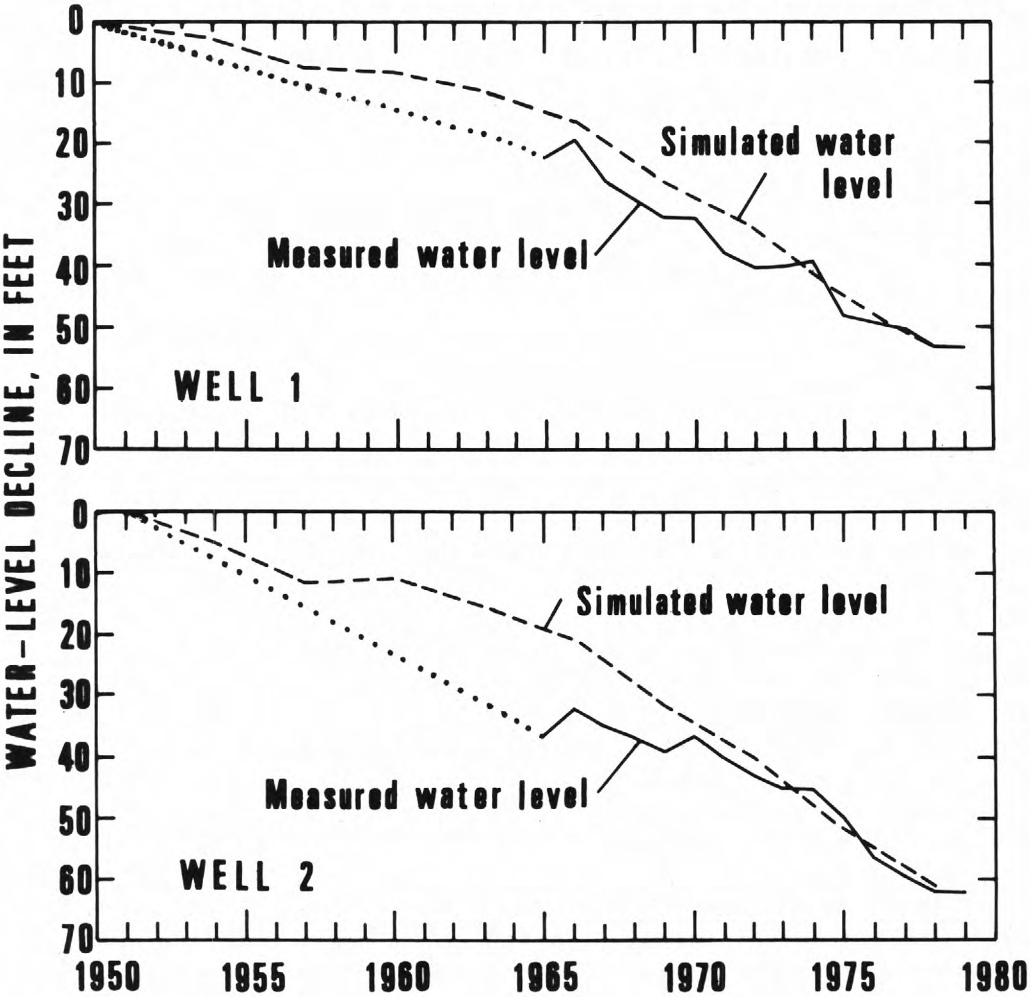


Figure 4.--Measured and simulated water levels in observation wells 1 and 2.

SENSITIVITY

When calibrating a model, there is always some degree of uncertainty about the accuracy of data in the model. Sensitivity of the model to this uncertainty was examined by individually changing aquifer parameters and pumpage within their expected ranges and observing the head changes. This analysis showed that a 25-percent change in pumpage caused an average 10-foot change in simulated head; whereas, a 50-percent change in recharge, hydraulic conductivity, and specific yield caused an average of 2- to 3-foot change in head.

MODEL PROJECTIONS

After a mathematical model of a ground-water system is calibrated to adequately simulate historical ground-water levels, different management alternatives can be tested to forecast future water-level trends with changes in simulated pumpage and recharge.

Effects of Alternative Pumpage Plans

Simulations were made to determine the water-level changes that would occur in the intensive-study area from January 1978 to January 1989 as a result of pumping at different rates. The pumpage calculated for 1977 was used in these projections because the annual rainfall during that year was near average and irrigation withdrawals were approximately equal to the average annual withdrawal during 1970-77.

Projections of the water-level declines in the intensive-study area are shown (figs. 5 and 6) for five different management plans. Plan A assumed that all of the pumpage in the model area continued at the 1977 rate; plan B assumed pumpage was reduced to one-half of the 1977 rate; plan C assumed pumpage was increased to double the 1977 rate. Plans D and E assumed that most of the pumpage in the model area continued at the 1977 rate while pumpage in the intensive-study area was reduced to one-half of the 1977 rate (plan D) or was increased to double the 1977 rate (plan E).

Plan A might be considered as a management scheme to maintain irrigation at the 1977 level of development. This plan assumes that all pumpage in the model area would be allowed to continue at the 1977 rate. The plan also assumes no new wells would be installed and irrigated acreage would remain unchanged. This projection (fig. 5) indicates that 15 to 30 feet of additional water-level decline would occur in the intensive-study area in 11 years.

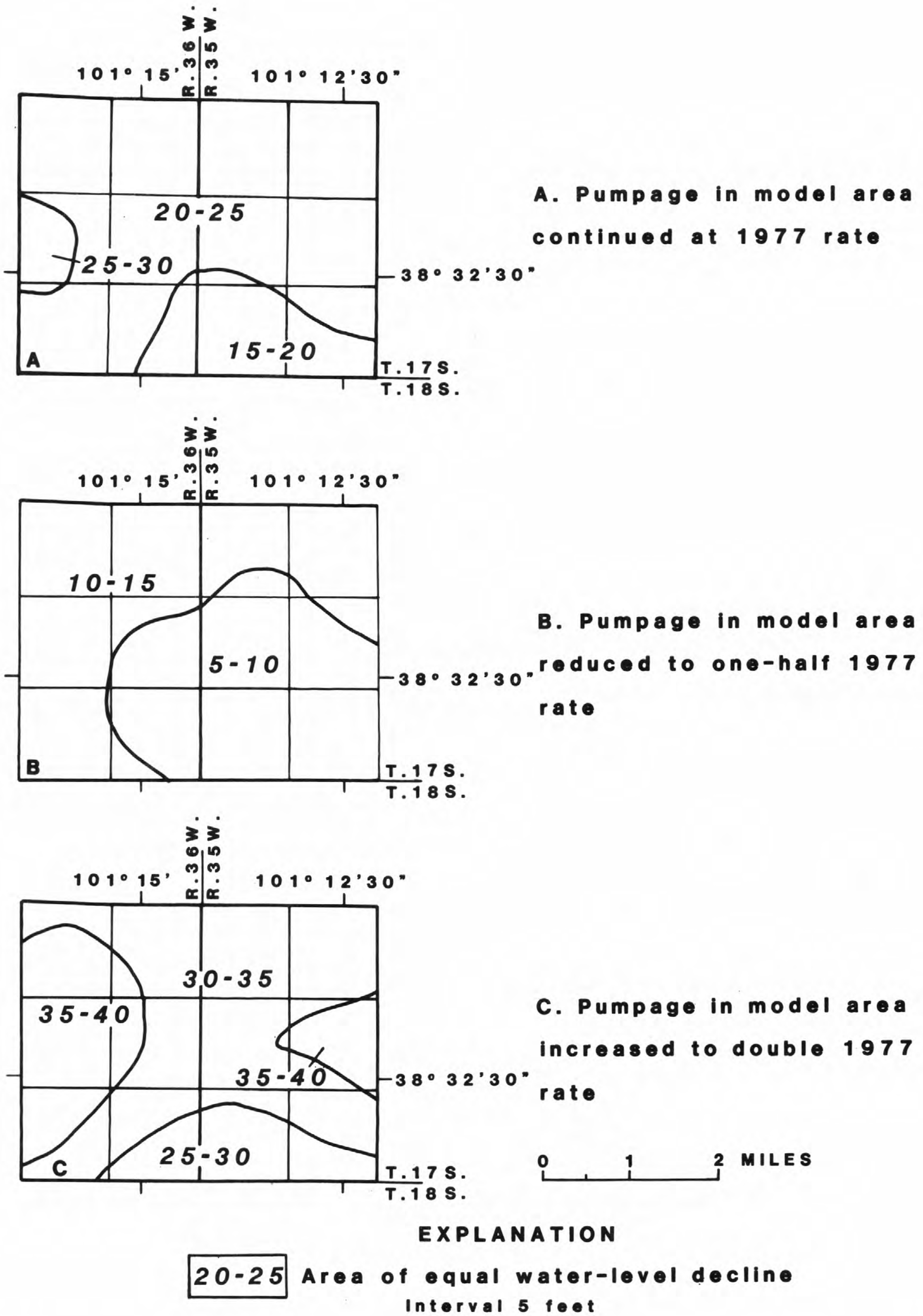


Figure 5.--Simulated water-level declines in the intensive-study area resulting from selected pumpage rates in the model area.

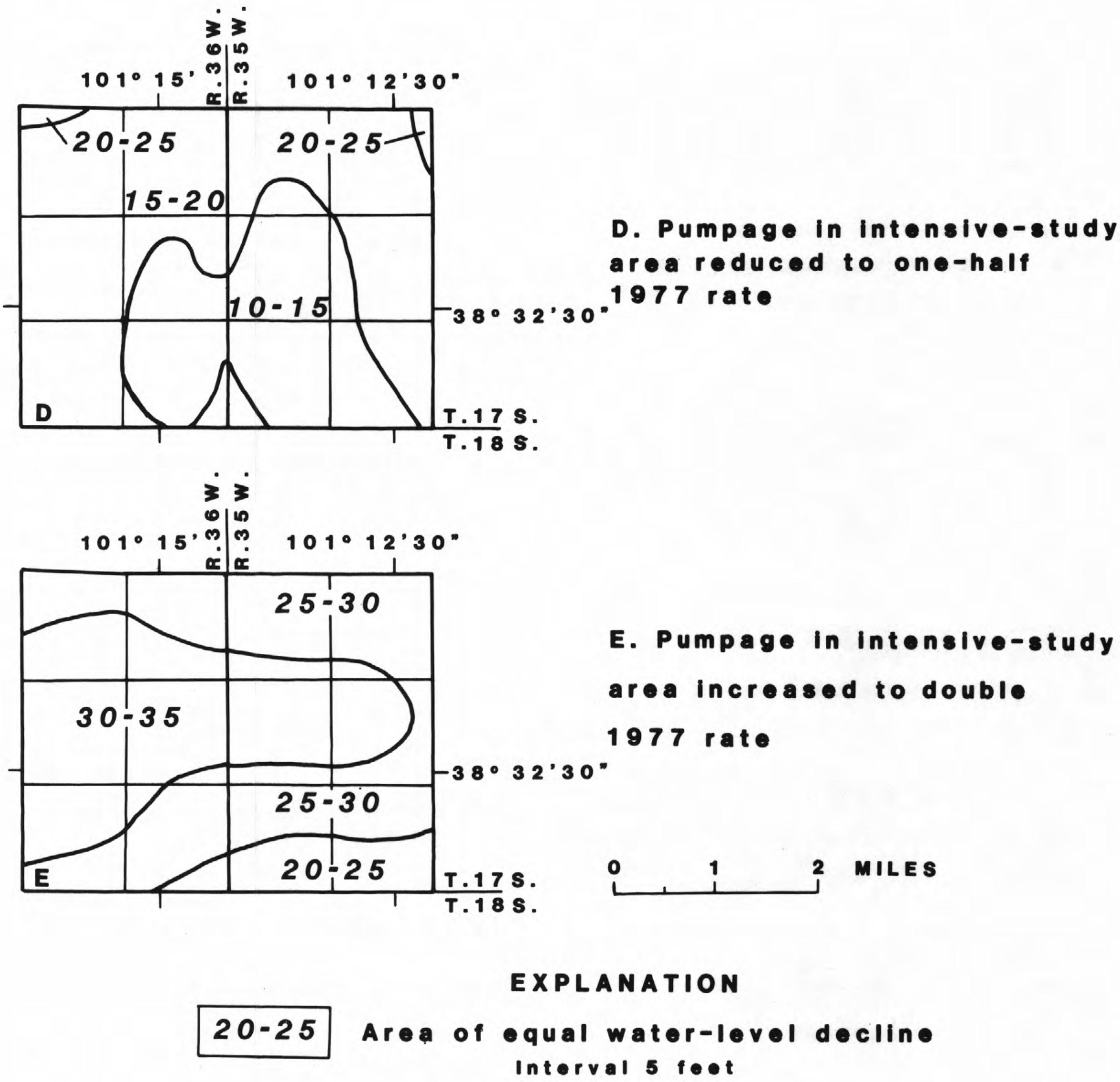


Figure 6.--Simulated water-level declines in the intensive-study area resulting from selected pumpage rates in the intensive-study area.

Alternative plan B might be considered as a possible scheme by management to reduce the amount of water applied without substantially reducing crop acreage. Studies by the Kansas State Experiment Station in Tribune, Kansas (Gwin and Gallagher, 1979, p. 39-43), showed that corn production was reduced 65 percent when the amount of water applied was 40-percent less than that applied to fully irrigated corn. Production of grain sorghum was reduced only 4 percent when the amount of water applied was 48-percent less than that applied to fully irrigated grain sorghum. Thus, a 50-percent reduction in ground-water withdrawal might be feasible if grain sorghum became the dominant crop in the modeled area.

Plan B assumes that all pumpage in the model area was reduced to one-half of the 1977 rate, and the number of wells and irrigated acreage would remain constant. This projection indicates that there would be only 5 to 15 feet of additional decline in the intensive-study area, which is one-half the decline in plan A.

Alternative plan C might be assumed to represent conditions that could occur if the management scheme permitted unrestricted development. This plan assumes that every irrigator in the model area increased pumpage to double the 1977 rate by installing twice the number of wells to irrigate additional land. This projection indicates that there would be 25 to 40 feet of additional water-level decline.

Alternative plan D might be construed as a management scheme to alleviate water-level declines by reducing the pumpage in a small "control area." In plan D, the intensive-study area was simulated as a control area by reducing pumpage to one-half of the 1977 rate while the number of wells and irrigated acreage remained constant. Plan D also assumes that wells outside the control area were pumped at the 1977 rate. The projection indicates there would be 10 to 25 feet of additional water-level decline in the intensive-study area. Results show the declines to be less than those in plan A and more than those in plan B. Continued pumpage at the 1977 rate of wells in the surrounding model area causes greater water-level declines in wells near the border of the control area and smaller declines in wells near the center.

Alternative plan E might be assumed to represent conditions that could occur if the management scheme permitted unrestricted development in a small area (the intensive-study area). In plan E, it was assumed that wells in the intensive-study area increased pumpage to double the 1977 pumpage rate and wells outside the intensive-study area continued to pump at the 1977 rate. This projection indicates that additional water-level decline from doubling the pumpage in only the intensive-study area would not be as great as it would be if all wells in the model area doubled their pumpage rate (plan C). Thus, increased pumpage in the unrestricted area would induce water movement from outside the intensive-study area. The result would be smaller water-level declines in wells near the border of the intensive-study area than in those wells near the center.

Figure 7 shows the additional water-level decline and saturated thickness of three hypothetical wells in the intensive-study area from January 1978 to January 1989. The five different hydrographs for each well represent the five alternative management plans. The hydrographs show the additional decline that would occur if all wells in the model area were pumped at the 1977 rate (plan A), one-half the 1977 rate (plan B), or double the 1977 rate (plan C). The hydrographs also show the additional decline that would occur if wells in the model area were pumped at the 1977 rate and wells in the intensive-study area were pumped at one-half the 1977 rate (plan D) or double the 1977 rate (plan E).

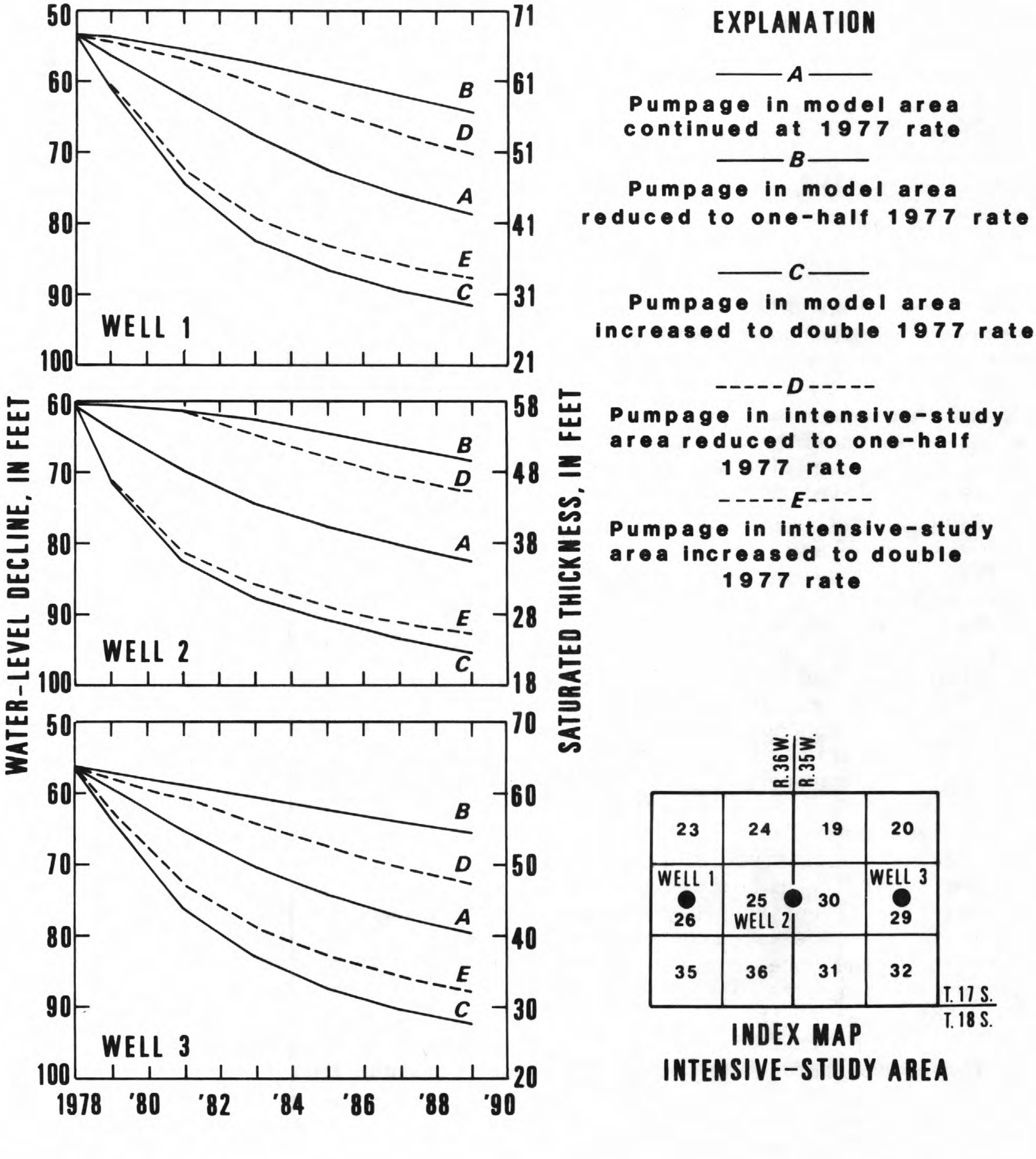


Figure 7.--Simulated water-level declines in three hypothetical wells in the intensive-study area resulting from different pumpage projections.

SUMMARY AND CONCLUSIONS

The gradual depletion of ground-water reserves has resulted in concern for the agricultural economy of west-central Kansas. With the use of a digital computer model, water levels are projected for different management schemes designed to prolong the life of the aquifer. Projection under a management policy that allows pumpage to continue at 1977 rates indicates that 15 to 30 feet of additional water-level decline would occur in the intensive-study area in the next 11 years. A management policy that reduces all pumpage in the model area to one-half of the 1977 rate is projected to result in water-level declines of 5 to 15 feet in the intensive-study area in the next 11 years. Control areas might be designed to alleviate water-level declines by reducing the quantity of water pumped in a small area. If pumpage from wells in the model area were continued at the 1977 rate and the control area was reduced to one-half the 1977 rate, a decline of 10 to 25 feet probably would occur. However, declines near the edge of a control area would be greater than those near the center as a result of heavy pumpage from wells outside the area boundary.

The digital model was more sensitive to changes in pumpage than to changes in hydraulic conductivity, specific yield, and recharge.

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