A Model Study of the McPherson Moratorium Area in Groundwater Management District #2

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Executive Summary

The area of central Kansas known as the "Equus Beds" provides groundwater supplies for the cities of Wichita, Newton, McPherson, and several other smaller towns in the area. The "Equus Beds" also supplies water for many irrigation and industrial wells in the area. Since the 1940s the water levels in this area have been monitored to keep track of water-table changes.

In 1976 a major part of the Equus Beds area was organized into a groundwater management district in order to better manage and conserve the region's groundwater resources. By 1978 it had become obvious that a part of the Equus Beds around McPherson was experiencing a consistent water-level decline due to the large number of municipal, industrial, and irrigation wells located there.

In March 1978 the Board of Directors of the Equus Beds Groundwater Management District #2 requested that the Chief Engineer of the Kansas Department of Agriculture's Division of Water Resources declare a temporary moratorium on the drilling of new wells in an area of 56 square miles near McPherson until a thorough study of the causes and effects of the declining water levels could be completed. After discussion with the Chief Engineer and the Groundwater Management District, it was decided that a hydrogeologic study of the area, together with a computer simulation to predict future water-level declines, would be the best method of investigation. A computer model would give some idea of what the overall decline in the area would be under the present rate of withdrawal, and would also identify local trouble spots likely to crop up in the future.

A water-budget analysis for the moratorium area based on January 1978 water levels shows a deficit of about 6,400 acre-feet per year.

This would correspond to an average water-level decline over the moratorium area of about one foot per year. The Kansas Water Resources Board and the Groundwater Management District #2 have observation-well records for eight wells in the moratorium area. They show declines ranging from .66 to 2.98 feet during 1978. The average decline for these wells was 1.74 feet. An average decline over the whole area of about one foot per year seems compatible with these well measurements.

The model predicts a general slow decline of water levels in the moratorium area. 1973-77 average annual reported pumpage projected for 15 years cause drawdowns ranging from about 10 to 50 feet in the moratorium area. With 1973-77 pumpage, 675,000 acre-feet of the 1978 900,000 acre-feet of water remains in storage after 15 years. Two centers of noticeable water level decline appear: the area east of Conway containing industrial wells used for salt-jug washing and the area around the McPherson municipal well field.

Introduction

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Summary of Geologic Formations

The following discussion of the rock units found in the moratorium area has been generalized from Williams and Lohman (1949).

Permian System

Wellington Formation: The Wellington Formation is the oldest bedrock unit to occur in the moratorium area. It is composed primarily of calcareous gray and bluish-gray shale with some beds of maroon and green shale units near the top of the formation. Parts of the Wellington Formation contain beds of gypsum and thick beds of salt. The beds of salt are being dissolved in places and have formed sink holes and collapse features in overlying beds.

Ninnescah Shale: The Ninnescah Shale is found directly above the Wellington Formation and is composed mainly of red shale with some green shale and clayey limestone. Thin sandstone beds and gypsum also occur in the Ninnescah.

In this report the underlying shales of the Wellington Formation and Ninnescah Shale are considered as an impermeable lower boundary for the Quaternary aquifer. Gogel (1978), in his study of salt solution by groundwater in central Kansas, shows that parts of the Wellington Formation are in fact an aquifer containing salty water. The salt water is derived from solution of salt beds in the Wellington Formation by fresh water infiltrating from the overlying fresh-water aquifer. In most places the salty water zones are confined by a thick overlying shale unit. Gogel's field measurements and computer model indicate the head in the Wellington aquifer is lower than the head of the unconsolidated aquifer in the moratorium area. There is a possibility, however, that if water levels in the unconsolidated aquifer deline to the point where the head in the Wellington is higher, infiltration of salt water could take place. For example, Gogel (1978) shows a measured piezometric head in the Wellington of 1,288 feet above mean sea level (corrected to fresh water) about two miles southeast of Conway. The 1978 head in the unconsolidated aquifer at that location was approximately 1,430 feet above mean sea level, a difference of 142 feet. Water level declines after 15 years of pumping using the 1973-77 average pumpage (Plate 14) indicate a decline of about 20 feet in this area. This would not appear to be enough lowering of the head in the fresh-water aquifer to cause infiltration. Much of the potential for infiltration, however, depends on the thickness and permeability of the upper part of the Wellington Formation. This study did not investigate the hydraulic connection between the two aquifer systems; thus, only generalizations about future water quality can be made.

Quaternary System

Pleistocene Series

McPherson Formation: The McPherson Formation was deposited by Pleistocene streams that filled the pre-existing stream valleys in the McPherson area. The material is extremely variable, ranging from gravel zones several feet in thickness to thick clay lenses. Generally, the coarser material is found near the bottom of the formation and the sand and silt near the top.

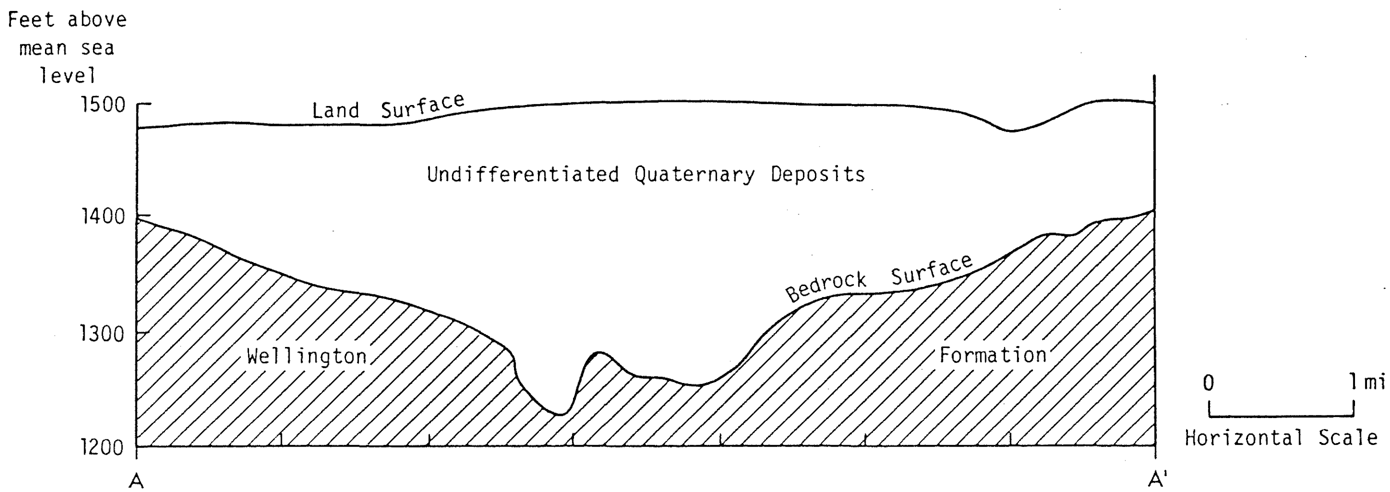
Geologic History of the Area

According to Williams and Lohman (1949), in late Tertiary or early Pleistocene time a major stream flowed south past Salina to Lindsborg, from there to McPherson, and then south toward Wichita. The ancestral Smoky Hill River was a tributary to that south-flowing stream and joined it northwest of McPherson. These streams eroded a large valley and a number of tributaries. Over a period of time the headwaters of this stream were captured, causing a drainage reversal near Salina; and the major southward-flowing stream was diverted eastward along the present Smoky Hill River valley. Along with and subsequent to the reversal process came a filling of the valley with the silt, sand, and gravel of the McPherson Formation. This sand and gravel was derived from rocks of nearby areas as well as from materials brought in by nearby streams. These processes filled the previously cut valley and left the "Equus Beds" as we see it today.

Bedrock Configuration

Plate 1 shows the configuration of the bedrock surface as determined from logs of wells and test holes. Data for this map were taken from Williams and Lohman (1949) and from drillers' logs of wells recently drilled in the area. As previously mentioned in the Geologic History, the trend of the buried bedrock channel is from north to south with the deepest parts bisecting the moratorium area (see Fig. 1 for cross section). The bedrock topography directly underlying the City of McPherson is relatively high, accounting for less saturated thickness being found there. A noticeable feature found at the southwest edge of the city in Sec. 1, T20S, R4W is a depression in the bedrock. This

Figure 1 -- Cross Section A-A' showing configuration of Permian Bedrock Surface.



Cross Section A-A' showing configuration of Permian Bedrock Surface (see plate 1)

Figure 1

depression is well defined by several drillers' logs. It appears to be one of the sink holes formed due to solution of salt in the Wellington Formation. Big Basin, just east of Conway, and Lake Inman, eight miles south of McPherson, are apparently surface expressions of other sinks.

As the buried bedrock channel is traced southward, it rises slightly to a very shallow divide several miles south of McPherson. This shallow bedrock divide is partly the cause of a northward flow of groundwater through the moratorium area. Since this divide is slightly higher than bedrock on the north side of the moratorium area, groundwater flows generally from south to north across the moratorium area in the areas of greatest saturated thickness. Along the east and west sides of the moratorium area we do have westerly and easterly flow.

Water Table Configuration and Saturated Thickness

Fourteen water-level measurements (eight are shown) of January 1978 were used to compile the initial water-table map (Plate 2) and to compile the saturated thickness map (Plate 3). The saturated thickness map is compiled from the difference between the water-level elevations and the bedrock elevations. Groundwater generally flows at right angles to the contour lines on Plate 2; therefore, flow is into the moratorium area from the east, west, and south sides and out the north side.

The closely spaced contours on the east side of the moratorium area (Plate 2) indicate a relatively high gradient of 20-30 feet per mile. Both bedrock and water table slope to the west in this area. Another factor contributing to the steep gradient could be a relatively lower permeability of the sediments found there (although we have no direct evidence of this), causing the water to be impeded as it flows in from the east.

The water-table contours on the west side also indicate a high gradient relative to the center of the area. The water table was difficult to define in this area, however, due to lack of water-level data in the areas north and south of Conway. Therefore, the contours have been estimated relative to bedrock elevations on Plate 1. The slope of the water table in the central part of the area is very low, about 1-3 feet per mile to the north. The bedrock gradient is sloping gently north here and the sediments are probably more permeable, causing a flatter slope.

The saturated thickness or water-bearing part of the unconsolidated material is consistently greatest along the north-south trend of the channel (Plate 3). Saturated thickness ranges from a few feet along the western edge of the moratorium area to 188 feet at the southwest edge of McPherson (Plate 3).

The depth to water in the moratorium area ranges from about 45-102 feet and is generally below depths at which evaporation or transpiration discharge a significant amount of groundwater.

Groundwater Budget

A groundwater budget is simply an estimate of the flow of water into and out of storage in the groundwater reservoir. Before man changed the situation, the budget was generally balanced. That is, the amount of water in the aquifer (reflected by the water levels) was relatively constant. Water levels fluctuated up and down slightly, but remained within certain limits. The water levels would rise if there was more recharge to the aquifer than discharge from the aquifer and would fall if there was more discharge than recharge.

Recharge to an aquifer can come from several sources: precipitation, irrigation water infiltration, streams, recharge wells, etc. Discharge can take place from seeps, springs, or streams that receive water from the aquifer; from evaporation and transpiration if the water table is very close to the land surface; or from pumping wells. Not all of the above means of recharge and discharge take place in any one aquifer. The water table in the moratorium area is relatively deep and there are no streams that receive water from the aquifer. An examination of the moratorium area shows the following recharge and discharge mechanisms taking place.

Recharge

1. Local precipitation and local irrigation water infiltration
2. Inflow of groundwater from the east, west, and south sides

Discharge

1. Wells (irrigation, industrial, municipal, and domestic)
2. Outflow of groundwater from the north side

The following discussion will cover the recharge and discharge mechanisms in greater detail.

Recharge

Precipitation and Irrigation Return Flow

In order for recharge to take place, the soil and rock from the land surface to the water table must be both porous and permeable; that is, there must be continuous openings through which the water can move. According to Harold Dickey (personal communication, 1979) of the U.S. Department of Agriculture - Soil Conservation Service, the soils of the McPherson area contain a relatively high proportion of clay. This inhibits recharge and promotes a higher runoff rate than if the soils were sandy. Williams and Lohman (1949) point out that there is an area that extends several miles north, south, and west of McPherson that is underlain by silt deposits ranging from 4-75 feet thick. This silt is more permeable than clay, but less permeable than the underlying sand and gravel. This combination of silt deposits and clay soils tends to inhibit recharge in the moratorium area.

Evaporation should also be taken into account. The Kansas Water Resources Board (1967) estimates the average annual lake evaporation to be approximately 55 inches of water for this area. This means that open bodies of water would average 55 inches of water loss from their surface over a period of a year. This is not the same as evaporation from the soil surface, which would be less, but it does give an indication that precipitation that falls on the land surface is rapidly evaporated.

Irrigation return flow is a source of recharge. Some percentage of the groundwater pumped from the reservoir of the moratorium area returns to the water table, although a greater percentage is probably evaporated and used by plants (evapotranspiration) than returns to the aquifer. We have no direct way of calculating how much irrigation return flow contributes to recharge in the moratorium area. The amount of infiltration from excess irrigation water is probably small and, therefore, is estimated as if it were part of the annual precipitation. Considering all the climate, soil, and irrigation factors, it is probable that, of the 29 inches of precipitation that falls in the McPherson area, only 1-3 inches are returned to the water table in an average year. The total water accumulation for the moratorium area from precipitation would be 56 square miles (35,840 acres) times the 29 inches or 2.41 feet. This yields approximately 86,700 acre-feet of water per year. That amount would provide the following:

1 inch recharge $\cong$ 3,000 acre-feet per year

2 inches recharge $\cong$ 6,000 acre-feet per year

3 inches recharge $\cong$ 9,000 acre-feet per year

Inflow of Groundwater

Groundwater inflow is calculated by using water-level contour maps. Two maps were available: 1940-44 map from KGS Bulletin 79, and January 1978 map from recently measured wells. A water-budget calculation from the 1940-44 map was unsuccessful due to a lack of data existing in the moratorium area at that time. It was decided that the most recent bedrock and water-table maps (1978) had more data and, therefore, would be used for the water-budget calculations. As shown by the January 1978 water-table contour map (Plate 2), the model area receives inflow of groundwater from the east, west, and south sides. The amount of this flow can be estimated by calculating the cross-sectional area through which the water is flowing and multiplying this by the water-table slope and the hydraulic conductivity of the material through which the water is flowing. Cross-sectional areas can be calculated by measuring the average saturated thickness at the point where the flow is to be computed and multiplying this by the appropriate horizontal distance. The water-table slope or gradient is estimated from Plate 2. For example, 10 feet per mile would give a slope of .0019.

The hydraulic conductivity of the sediments can be estimated in several ways. Pumping tests of wells, drillers' and test hole logs, and laboratory measurements are three of the more common ways of estimates. For this study, previous work by Richards and Dunaway (1972) and estimates developed by us were used in conjunction with data from recently drilled wells. The first set of inflow calculations made used 750 gallons per day per square foot (100 feet/day) as an estimate of hydraulic conductivity. After some discussion, it was decided that, since conductivity may be considered dependent on saturated thickness, the conductivity should vary with the saturated thickness instead of remaining constant. Comparing the two sets of values, constant K (750 gpd/ft^2) and variable K (0-930), the results with variable K seemed more reasonable; so a variable K was used. The formula for calculation of water flow is Q = KIA where:

Q = amount of groundwater inflow or outflow

K = permeability or hydraulic conductivity of the water-bearing material (K varied directly with saturated thickness -- if saturated thickness = 30 feet, K = 30 ft/day)

I = slope of the water table (this generally ranged from 1 to 60 feet per mile)

A = cross-sectional area (ft^2)

To calculate the inflow across the moratorium boundary, each side was divided into half-mile sections of 2,640 feet. A sample calculation shows how this is done. Assuming a saturated thickness of 75 feet and a slope of 10 feet per mile, then

$$75' \times 2640' = 198{,}000 \text{ ft}^2 = A$$

$$10 \text{ feet per mile} = .0019 = I$$

$$0\text{-}930 \text{ gpd/ft}^2 = K \quad \text{(variable K)}$$

$$Q = 198{,}000 \text{ ft}^2 \times .0019 \times 750 \text{ gpd/ft}^2$$

$$= 282150 \text{ gpd}$$

$$= .87 \text{ AcFt/day or } 316 \text{ AcFt/yr}$$

Based on the previous discussions, the estimate for inflow from adjacent areas is:

East Side	=	2,300 AcFt/yr
South Side	=	765 AcFt/yr
West Side	=	1,100 AcFt/yr
		4,165 AcFt/yr

Summary of All Recharge

6,000 AcFt/yr	---	Natural Recharge (based on 2 inches per year)
4,165 AcFt/yr	---	Lateral Inflow
10,165 AcFt/yr	---	Total Recharge

Approximately 10,000 AcFt/yr total recharge.

Discharge

Wells

Annual pumpage of groundwater by wells in the moratorium area is difficult to calculate. Irrigators, and industrial and municipal water users in the moratorium area are required by the Division of Water Resources and Groundwater Management District #2 to submit annual water-use reports. Since only a few of the 139 wells in the moratorium area are metered, the reports are estimates by the well owners and are subject to errors. The groundwater budget calculations were based on water-use reports submitted by the Groundwater Management District and the Division of Water Resources. These are listed in Table 1. These water-use reports were used in the water budget and in the computer model itself. In some years the water use reports showed less than 10,000 acre-feet per year being withdrawn. In 1977 and 1978, however, 10,000-15,000 acre-feet per year were reported as pumped. An estimate of 15,000 acre-feet per year was used for the water-budget calculations. A figure of 16,263 acre-feet per year of groundwater withdrawal was used as the average for the projections in the computer model. This figure is higher than that used in the water budget because the water budget uses water actually pumped in 1977. The model projection was based on applications approved and pending prior to the moratorium and, in some cases, the wells had not been pumped yet. In fact, some had not yet been drilled.

Outflow of Groundwater

Outflow was estimated by the same technique as inflow (Q=KIA). The northern side of the moratorium area is the only one out of which water is flowing. It is estimated that 1,400 acre-feet per year are flowing across this boundary.

Summary of All Discharges

15,000 AcFt/yr	-- Wells
1,400 AcFt/yr	-- Lateral Outflow
16,400 AcFt/yr	-- Total Discharge

If we then subtract total inflow from total outflow,

16,400 AcFt/yr	-- Total Discharge
10,000 AcFt/yr	-- Total Recharge
6,400 AcFt/yr	-- Deficit

The result is a deficit of about 6,400 acre-feet of water per year, which has to come from aquifer storage. In this case, water levels should be declining and this is what is being observed.

As a check on the water-budget computations, the loss of water from storage can be computed from the average water-level decline for the entire moratorium area. In order to make this calculation, some explanation is needed.

Water is stored in the void spaces between the particles of rock that make up the aquifer. Generally, the amount of interconnected void space is referred to as the storage coefficient or S_y and is a percent of the total volume of the aquifer. Water-table aquifers in Kansas generally have an S_y between .10 and .20. Based on experience and literature review, an S_y of .18 was chosen for this calculation. This storage coefficient is then multiplied by the decline in water levels to find the amount of water withdrawn.

The Kansas Water Resources Board and Groundwater Management District #2 have observation-well records for eight wells in the moratorium area. They show declines ranging from .66 to 2.98 feet during 1978. The average decline for these wells was 1.74 feet. Assuming the average decline over the moratorium area to be between 1 and 2 feet, the following calculations indicate the amount of water removed.

$$1 \text{ ft} \times 35{,}840 \text{ ac} \times .18 \cong 6{,}500 \text{ AcFt}$$

$$2 \text{ ft} \times 35{,}840 \text{ ac} \times .18 \cong 13{,}000 \text{ AcFt}$$

The above calculations would indicate that about 1 foot of water-level decline per year is probably an accurate average over the 35,840 acre moratorium area.

Summary

The recharge and discharge calculations of the water budget for the moratorium area based on January 1978 water-table data show a deficit of about 6,400 acre-feet per year removed from storage. Calculating this deficit by the water-level-decline method shows a removal of water from storage of approximately 6,500-13,000 acre-feet per year. The preceding results indicate that indeed water is being removed from storage in the moratorium area. In the next section, a digital computer model will be used to approximate future water-level declines in the area.

Basic Modeling Parameters

The water budget analysis performed in the preceding pages shows that in the moratorium area the average annual rate of groundwater-level decline is about 1-2 feet. The purpose of this section is to project the future areal distribution of water-level decline. This may be achieved by the use of a mathematical groundwater model.

The purpose of a groundwater model is to predict the water flow and, therefore, the water levels as a function of time, provided the rate of withdrawal is given. In order to do this, we must know what physical aquifer parameters affect the groundwater flow. There are three basic physical parameters: hydraulic head, hydraulic conductivity, and specific yield. We now turn our attention to a short discussion of each of these.

It is commonly known that water moves from areas of high pressure to areas of low pressure, everything else being constant. Similarly, water flows from high elevations to low elevations, everything else being constant. Pressure and elevation may interact, so it is important to look at their sum instead of at each individually. The hydraulic head (h) is defined as

$$h = z + \frac{p}{\gamma} \qquad (1)$$

where z is the elevation, p is the fluid pressure and γ is the specific weight (weight per unit volume) of water. The hydraulic head has units of length (e.g., feet) and can be measured with respect to an arbitrary datum. Sea level is a very common datum and will be used in this work. In an assumed unconfined aquifer (no confining layer between the top of the aquifer and the atmosphere), such as the Equus Beds aquifer, the only pressure on the water table is atmospheric pressure. It is common to take this pressure as zero for simplicity. However, adding a constant atmospheric pressure to equation (1) would not change any later results. With this simplification, we see that the hydraulic head is just the elevation of the top of the water table. Therefore, field measurements of hydraulic head, h, can easily be made.

Hydraulic conductivity (K) is a measure of how easily a fluid may flow from one point to another. With a little thought, it can be understood that hydraulic conductivity depends both on the fluid flowing and the material through which it flows. Obviously, water will flow more easily than molasses through an aquifer. The grain size of the aquifer material affects the hydraulic conductivity. In general, the larger the grain size, the higher the conductivity. However, the conductivity also depends on things such as the pore interconnectivity and the degree of material sorting. For example, if we have a mixture of fine and coarse material, the conductivity will be reduced due to the fine particles filling the larger pore spaces. We will say more about field determination of hydraulic conductivity later.

Specific yield (S_y) measures the ultimate yield of a unit volume of aquifer material. Porosity is the total amount of void volume per unit volume of aquifer. If the aquifer is totally saturated, the pore space is completely filled with water. Specific yield is a measure of how much of this water can be drained by gravity. Obviously not all can be drained because some is held very tightly to aquifer material by molecular, capillary, and other forces. As the aquifer granules and the pore spaces become larger, more of the water can be drained and the specific yield approaches the porosity. Fine-grained material such as clay may have 40-50% porosity and practically no specific yield. For average sand and gravel aquifers, the specific yield is usually in the range of 10-30%.

Model Equations and Grid System

Having some insight on the physical parameters of an aquifer, we now need to know how these parameters regulate the flow of water. In 1856, a French engineer named Darcy established a relationship between water velocity (v), hydraulic conductivity (K), and hydraulic head (h). The following relation is now called Darcy's Law (Fig. 2).

$$v = K\frac{h_1-h_2}{\Delta x} = -K\frac{\Delta h}{\Delta x} = -K\frac{\partial h}{\partial x} \qquad (2)$$

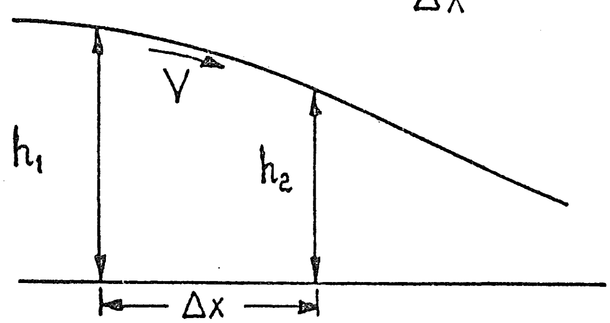
Darcy's Law simply says that water flows from areas of high head to areas of low head with a velocity that depends on the hydraulic conductivity. Where $h_2-h_1 = \Delta h$ is the head difference between two measurement points and Δx is the distance between these two points (shown in Figure 2). As Δx becomes smaller and smaller, $\Delta h/\Delta x$ is represented by $\frac{\partial h}{\partial x}$, which is called the derivative of h with respect to x. It is simply the slope of the water table.

We know that water is not being created or destroyed within an aquifer, so there are only a limited number of possibilities that would make the water table fluctuate. If more water flows into an area than out, the water table will rise, other factors being held constant. Similarly, if more water flows out of an area than in, the water table will decline. This water-table fluctuation is caused by the water velocity that is given by Darcy's Law (equation (2)). Additionally, the water table may be made to rise or decline by recharge or discharge of

DARCY'S LAW

$$h = \frac{P}{\gamma} + Z = \text{HYDRAULIC HEAD}$$

$$V = K\,\frac{h_1 - h_2}{\Delta X} = \text{WATER VELOCITY}$$



IF h_1 IS BIGGER THAN h_2 WATER FLOWS FROM h_1 TO h_2.

K IS THE HYDRAULIC CONDUCTIVITY AND DEPENDS ON THE FLUID AND THE MATERIAL THROUGH WHICH FLOW OCCURS.

FIGURE 2. DIAGRAM ILLUSTRATING DARCY'S LAW

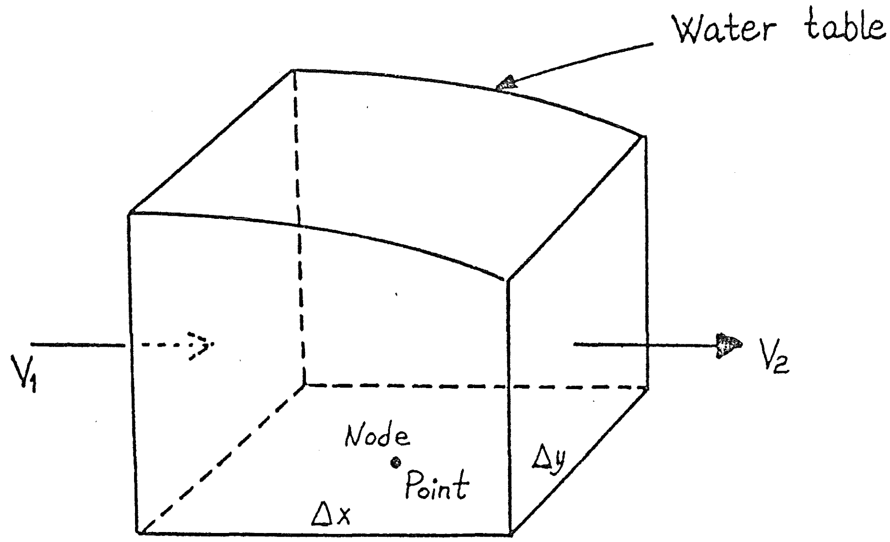
water. Recharge can include such things as infiltration from rainfall, infiltration from perennial or ephemeral streams, or man-made recharge. Discharge can include such things as evaporation and transpiration from the water table, discharge to streams, or man-made discharge (pumping).

Since water is not created or destroyed, these effects (water velocity, recharge-discharge, and water-table fluctuation) must exactly balance each other. The equation describing this balance is called the continuity equation.

$$\frac{\partial}{\partial x}\left(Kb\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(Kb\frac{\partial h}{\partial y}\right) + Q = S_y\frac{\partial h}{\partial t} \qquad (3)$$

The first two terms in equation (3) are due to the water velocity. The third term, Q includes all recharge-discharge effects, and $\frac{\partial h}{\partial t}$ is the change in the height of the water table with time. S_y is the specific yield, which indicates how much water is available for each cubic foot of aquifer dewatered; b is the saturated thickness and is the difference between water level elevation and bedrock elevation.

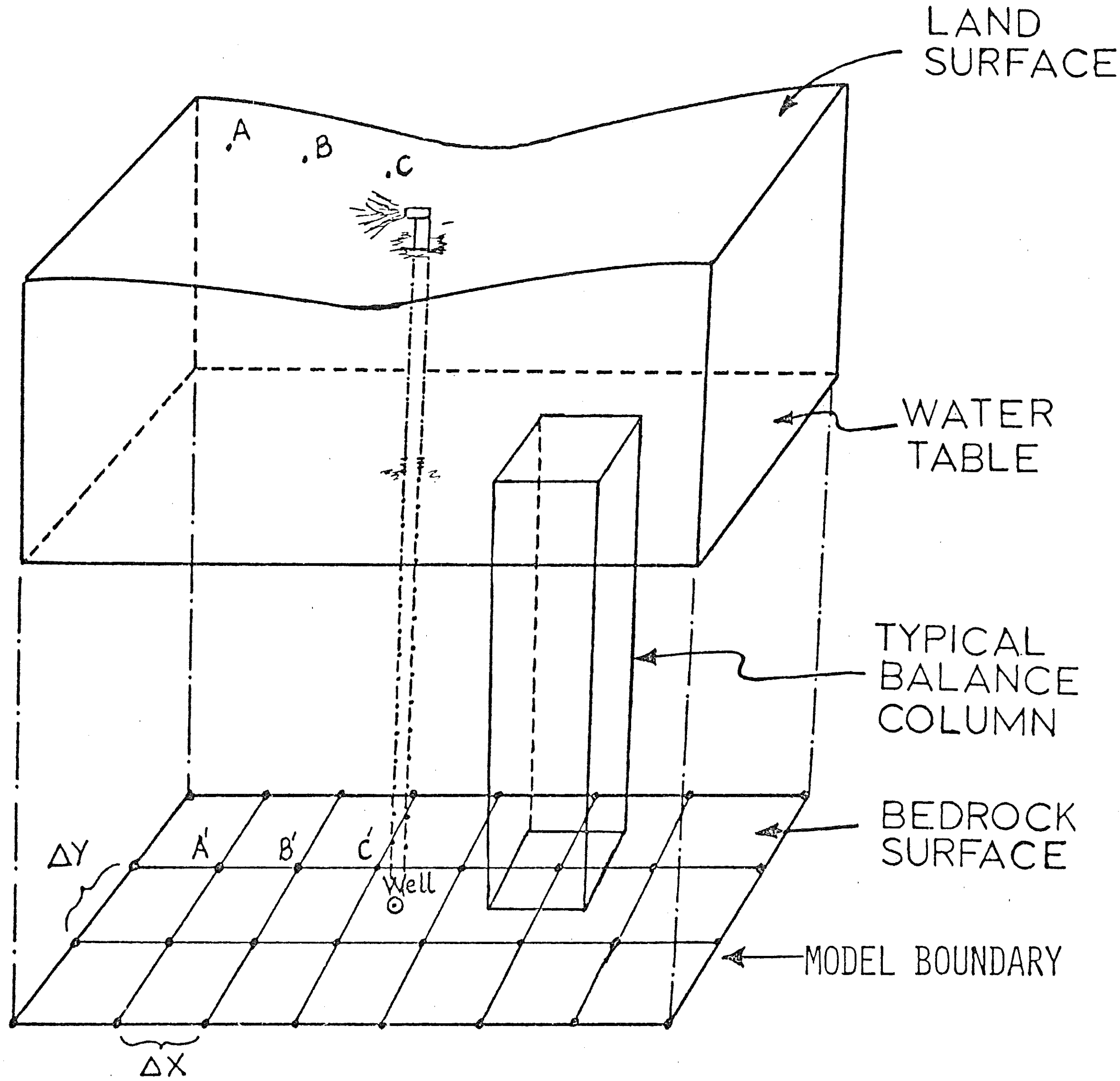
Although equation (3) may look rather complex, it actually simply states that we must have water balance at every point in an aquifer. To implement this equation in a digital computer, we do not consider water balance at a point, but instead consider a square or rectangular column whose height is that of the water table, as shown in Figure 3. The base of the column has dimensions Δx and Δy, which is called the grid spacing in the x and y directions respectively. A numerical model is made up of many of these columns, each centered at a node point. All node points taken together define a square or rectangular grid system crossing the entire surface of the aquifer to be modeled. This arrangement is shown schematically in Figure 4. Equation (3) is written for each node point;



IF THE WATER FLOW INTO THE COLUMN IS NOT EQUAL TO THE WATER FLOW OUT, THE WATER TABLE CHANGES ELEVATION.

ADDITION CHANGES IN THE WATER TABLE CAN BE CAUSED BY PUMPAGE FROM THE COLUMN.

FIGURE 3. ILLUSTRATION OF WATER BALANCE IN A NUMERICAL MODEL



A MODEL CONSISTS OF MANY VERTICAL COLUMNS EACH CENTERED ABOUT A "GRID POINT" SUCH AS A', B', OR C'.

FIGURE 4. SCHEMATIC ARRANGEMENT OF A NUMERICAL MODEL

and we may have hundreds of node points. Therefore, it is easy to see why a computer is needed to solve these many equations simultaneously.

Model Boundaries

Any aquifer or numerical model is limited in areal extent. Therefore, to completely describe the aquifer or to set up the numerical model, one must know what is happening at the outer boundaries. For small withdrawals and/or large aquifers or models, it is possible that the boundary effects are not too important. This should be verified before boundaries are ignored. In general, there are two common types of boundary conditions. First, the hydraulic head may be specified on a boundary. If the head does not change with time, we have a constant head boundary. An example of this might be a lake or river whose average annual height does not vary much. Secondly, the flux of water across the boundary may be specified. If the flux is zero, no water flows and we have a barrier boundary. An example of this would be where impermeable bedrock is at or near the ground surface. Some type of boundary must be specified at every point on the boundary of the aquifer or model.

Calibration of Model

One is always faced with the question of how good is the model? In other words, how accurately does it represent the real world aquifer? The process by which one changes the model parameters (K and S_y) to make them simulate the aquifer more closely is called calibration. The calibration process usually proceeds in three steps. First, the aquifer characteristics (K, S_y, and boundaries) are determined as accurately as possible from available data. Second, the water levels for some base year are assumed to be stable and the natural recharge-discharge is calculated. Third, if water levels and man-made discharge are known over some time period, the values of K and S_y are changed within limits to get the "best fit" of the model output to the historical water levels. The "best fit" is usually obtained by trial and error and tends to be somewhat subjective. If the calibration process is done with reasonable care, the model should be a fairly good simulator of the aquifer. Hard numbers for the model accuracy are difficult to impossible to obtain. Generally speaking, the model projections become less accurate as one projects farther into the future.

Basic Data for a Numerical Model

We have already briefly mentioned all the data that must be put into a numerical model. In this section we will elaborate on each kind of input data. The bedrock data has been discussed in an earlier section of this report (Plate 1). It is obtained from test-hole and well logs in the Kansas Geological Survey and U.S. Geological Survey files. The water levels in the major aquifers of the State are measured annually by a joint program of the KGS, USGS, DWR (Division of Water Resources), KWRB (Kansas Water Resources Board), and the groundwater management districts. The January 1978 measurements have been used to create the water-level map shown on Plate 2. We have a certain number of data points for the bedrock and water level. Generally speaking, these data points do not fall at node points of our model. To overcome this difficulty, generalized contour maps, such as Plates 1 and 2, are constructed from the available data. Our model grid is now superimposed over these maps, and values of bedrock or water level are read for each model node point. These values are then keypunched into a format that can be read into a computer and used in the numerical model.

The values of hydraulic conductivity (K) and specific yield (S_y) can be determined or estimated by pumping tests, detailed evaluation of test-hole and well logs, or laboratory methods. The pumping test is generally preferred since it samples a large portion of the aquifer in place. However, the number of pumping tests is usually very limited so the data are very sparse. The conductivity and specific yield depend upon the type of material (silt, clay, sand, gravel) present and the size of the material grains, so a qualitative estimate can be made by a detailed examination of test-hole and well logs or, preferably, representative samples from test holes and wells. Unfortunately, a quantitative examination of samples is a very time-consuming process. The conductivity and specific yield can also be determined through laboratory methods. The drawbacks to laboratory methods include at least three items: investment in laboratory equipment is large; only a very small part of the aquifer is sampled at a time; and the drilling and sampling process may have disturbed the sample such that it is no longer representative of the aquifer.

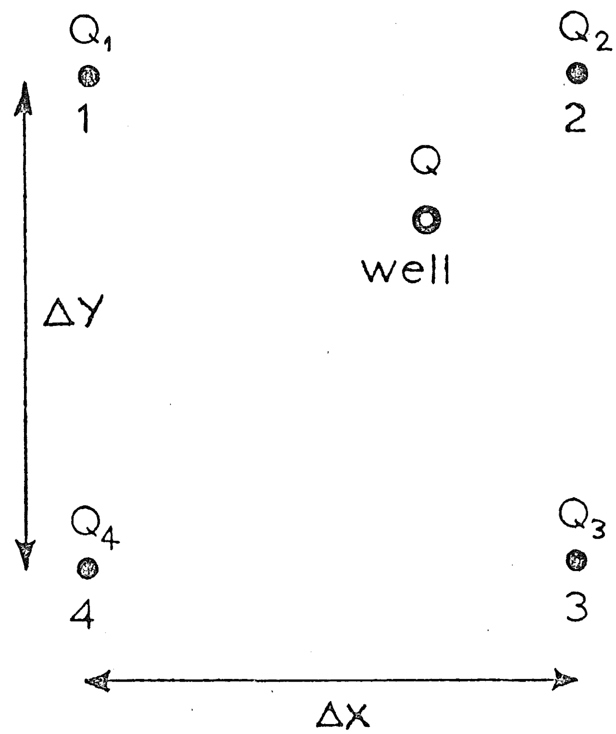
The man-induced withdrawal (pumpage) is, generally speaking, the least accurately known of the basic data input to a numerical model. First of all, the known wells must be inventoried and located on a map according to their legal description. A report of measured annual pumpage is not required in Kansas (only the user's best estimate), so one must estimate the pumpage from either the acre-feet approved by the KSDA-DWR or the reported pumpage of unknown accuracy. There is an additional problem with pumpage. Except by accident, the wells do not coincide with the model nodes as shown in Figure 4. We can only put data into the numerical model at a node point. Therefore, the pumpage must be distributed to the model nodes according to some scheme. No matter where the well is located, we can always find four node points surrounding it, as shown in Figure 5. Logically, the pumpage should be distributed to these four node points, with the closest one receiving the most pumpage. If Q_1, Q_2, Q_3, and Q_4 are the pumpages assigned to the four nodes and Q is the well pumpage, then

$$Q = Q_1 + Q_2 + Q_3 + Q_4 \qquad (4)$$

In the example shown in Figure 5, Q_2 is the largest and Q_4 is the smallest. If this distribution scheme is followed for each known well, we may obtain a total pumpage figure for each model node, which can be used as input data to the numerical model.

The McPherson Moratorium Area Model

The moratorium area has been shown on previous maps, in particular the bedrock map and the January 1978 water-level map (Plates 1 and 2). A model grid with half-mile spacing between node points was chosen to cover the area. This means that each vertical column for which we consider water balance (equation 3) has an area of 160 acres (quarter section) and a height equal to that of the water table. The grid system extends one or two miles outside the moratorium area. The grid system is 21 nodes by 21 nodes; so 441 node points or vertical columns must be considered for simultaneous water balance. The bedrock and water-level input data have been obtained by superimposing this grid over the



$$Q = Q_1 + Q_2 + Q_3 + Q_4$$

FIGURE 5. Distribution of well pumpage to surrounding node points.

appropriate map and reading a value for each node point. The following is a summary of the procedure used in estimating other parameters and constants for the model.

a) Specific Yield: The specific yield for the majority of the unconsolidated aquifers in Kansas ranges from 10-20%. Stramel (1956) in KGS Bulletin 119, Part 1 suggests that 20% is appropriate in the Wichita well-field area. We have used 18% in our modeling efforts. This is probably a good average value, but it may be a little conservative. However, the effect of specific yield is only to change the time scale. For example, if the specific yield is increased to 20%, we only need to multiply the time scale by .2/.18 = 1.11. This means that maps showing 5-year declines for a specific yield of .18 would be the same as a 5.55-year decline map if .2 were used for the specific yield. The specific yield undoubtedly varies from point to point due to changes in aquifer composition. However, our knowledge of these changes is so limited that we have used a constant average value of 18% in the model.

b) Hydraulic Conductivity: The hydraulic conductivity has been determined at various locations through the years in the Equus Beds by pumping tests. The total number of pumping tests is not large and they are usually confined to high production areas such as the Wichita well field. In KGS Bulletin 79 by Williams and Lohman, page 103, the results of 25 pumping tests done in the Wichita well field are presented. These tests yield values of hydraulic conductivity varying from 30 ft/day to 162 ft/day. Some recent work by Layne-Western southwest of McPherson indicates the hydraulic conductivity should be in the range of 133-167 ft/day; this is a rather good aquifer area and its conductivity is probably somewhat higher than the average for the moratorium area. With the lack of more detailed knowledge of the hydraulic conductivity, we have chosen a constant average value of 100 ft/day for our numerical model.

c) Pumpage: As mentioned earlier, the pumpage for the moratorium area is poorly known. Groundwater Management District #2 supplied us with a well inventory for the moratorium area. The inventory included the legal description and the amount of water approved by the KSDA-DWR or the amount being requested in a pending application. Generally speaking, the amount approved is usually greater than the average estimated usage. We reviewed all the approved or pending water rights in the DWR records to see if water use reports were available for previous years. Table 1 summarizes the pumpage data available to us. The table shows the water-right application number, the legal description of the well, the allocated pumpage approved by DWR or the requested pumpage pending before the KSDA-DWR (both in acre-feet), the reported pumpage for the period 1973-1977 in acre-feet, the average reported pumpage, and finally the type of well (IR-irrigation, M-municipal, and ID-industrial).

As pumpage data for the model, we used the average reported pumpage if it was available. If the average was not available, we used the amount approved by DWR or the amount requested in a pending application. As described earlier, the pumpage was then allocated to the model nodes based on distance to the surrounding four nodes. This pumpage data was used in the model for predicting the water level declines and saturated thicknesses for future years. If the saturated thickness declined below 10 feet at any node, the pumpage was turned off at that node until the water level recovered such that there was again 10 feet of saturated thickness available.

As mentioned previously, a mass balance analysis of the 1940-44 water table was unsuccessful. So a calibration of the model based on these data was not justified. Therefore, we assumed that the 1978 water level was an equilibrium surface and the natural recharge-discharge relationship to hold that surface constant was calculated. This is equivalent to assuming the 1978 water level is a steady-state surface. This natural recharge-discharge was then assumed constant for all future years when projections were made. This means constant flux boundaries were assumed. This procedure is subject to scientific debate simply because one can argue that the 1978 water level is not really an equilibrium surface. This is a compromise decision whose consequences should be within the error bounds of this study. The error due to this procedure should be small except in those areas that have large amounts of pumpage and are experiencing significant water-level declines due to man-induced discharge. The effect of this procedure in these regions is to give somewhat greater projected water-level declines. We have made no attempt to match historical water levels by varying specific yield and hydraulic conductivity. To do so, we would need to know the pumpage as a function of time, and several additional water level maps would need to be prepared. This is something that could be done in the future, but would require a study of much greater effort than the present one.

However, in order to evaluate the sensitivity of the modeled area to hydraulic conductivity, a computer run was made with the conductivity varying with saturated thickness; that is, if the saturated thickness was 150 feet, conductivity equaled 150 ft/day. If saturated thickness was 10 feet, conductivity was 10 ft/day. The 5-year drawdowns of the run with a variable hydraulic conductivity were compared with the 5-

year drawdowns of a run where the conductivity was held constant at 100 ft/day. Pumpage was 16,263 AcFt/yr in both cases. The results of this comparison are shown in Figure 6. Even though the hydraulic conductivity in some areas varies by a factor of two or more, the final results are strikingly similar. This indicates that the model is not too sensitive to variations in hydraulic conductivity, and values on the order of 100 ft/day will produce similar results.

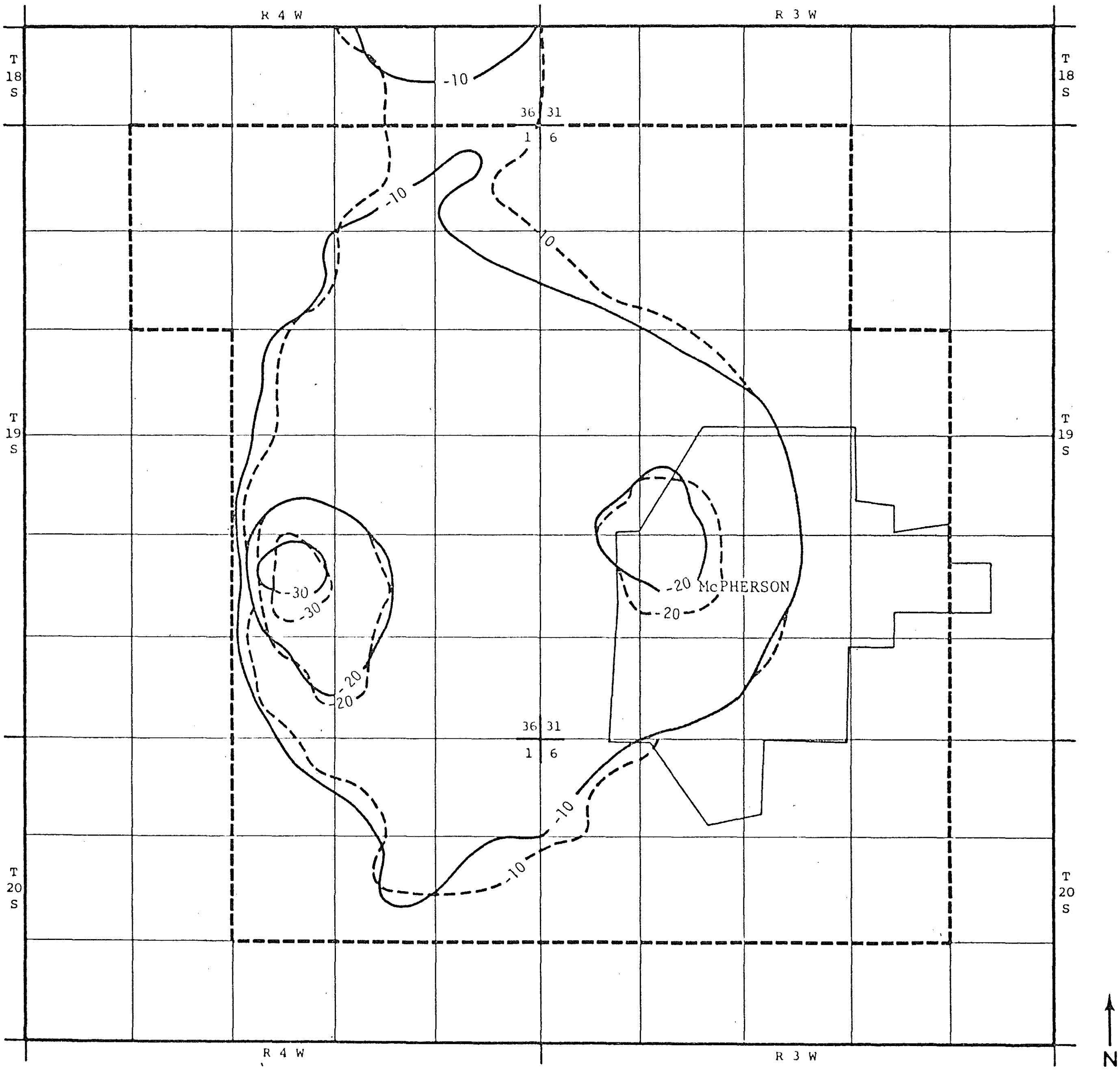
Model Output

As originally conceived, the model output consisted of projections of water-level declines for the next 15 years with pumpage based on a 1973-77 average. After consideration, however, it was decided to present not only projections based on the most possible accurate estimate of present pumpage, but also projections for amounts above and below this estimate. The higher and lower figures would then give the Groundwater Management District and the Chief Engineer estimates of how rapidly various pumping options would remove water from storage. Each pumping option was calculated at five-year intervals for a total of 15 years. The amount of water-table decline as well as saturated thickness is shown at five year intervals. The following pumping options were used.

Option #1: Projections were made using total allocated or requested water rights for the moratorium area (see Table 1). This amounted to 25,672 acre-feet per year and is more than 1 1/2 times the estimated actual pumpage. Drawdown and saturated thickness maps are shown in Plates 4-9.

As shown in Plate 4, two centers of decline appear rapidly where the majority of the water is being removed - at the west edge of McPherson

Figure 6 -- Comparison of water level declines using fixed and variable K.



0 1
Scale in miles

Figure 6

around the municipal well field and west of McPherson near Conway where a combination of withdrawals for salt-jug washing activity and irrigation account for a large amount of drawdown. By the end of 15 years (Plate 8), projected declines average 70 feet in the Conway area and greater than 60 feet near McPherson.

Option #2: Projections were made using the 1973-77 average annual reported pumpage (Table 1). This was a reasonable estimate of the actual amount of water removed (16,263 acre-feet per year). The results are shown in Plates 10-15.

Declines after five years (Plate 10) are about 25 feet near McPherson and greater than 30 feet near Conway. Declines are not as great as those in Option #1 because less water is being removed. However, the same two areas of decline are evident. The 15-year projections (Plate 14) show approximate maximum declines of 50 feet near McPherson and Conway. Saturated thickness remaining after 15 years is shown in Plate 15.

Option #3: Projections for this option were made using 90% of the 1973-77 average annual reported pumpage. This amounted to 14,637 acre-feet per year and the results are shown in Plates 16-21.

This option was calculated in order to see how the life of the aquifer would be prolonged by limiting the present pumpage. Plate 16 shows the projected declines after five years. As expected, they are not as severe as Option #1 or #2. However, the same centers of decline near McPherson and Conway are somewhat greater than 40 feet in both locations. Plate 21 shows the remaining saturated thickness.

Option #4: Projections were made using 80% of the 1973-77 average annual reported pumpage (16,263 AcFt/yr). This amounted to 13,010 acre-feet per year. The results are shown in Plates 22-27.

Five-year declines are the least of all previous options (Plate 22). Only two small areas of 30-foot decline are shown. In the majority of the moratorium area the declines are less than 20 feet. After 15 years, maximum declines are slightly more than 40 feet, with most of the area less than 30 feet. Plate 27 indicates the remaining saturated thickness after 15 years.

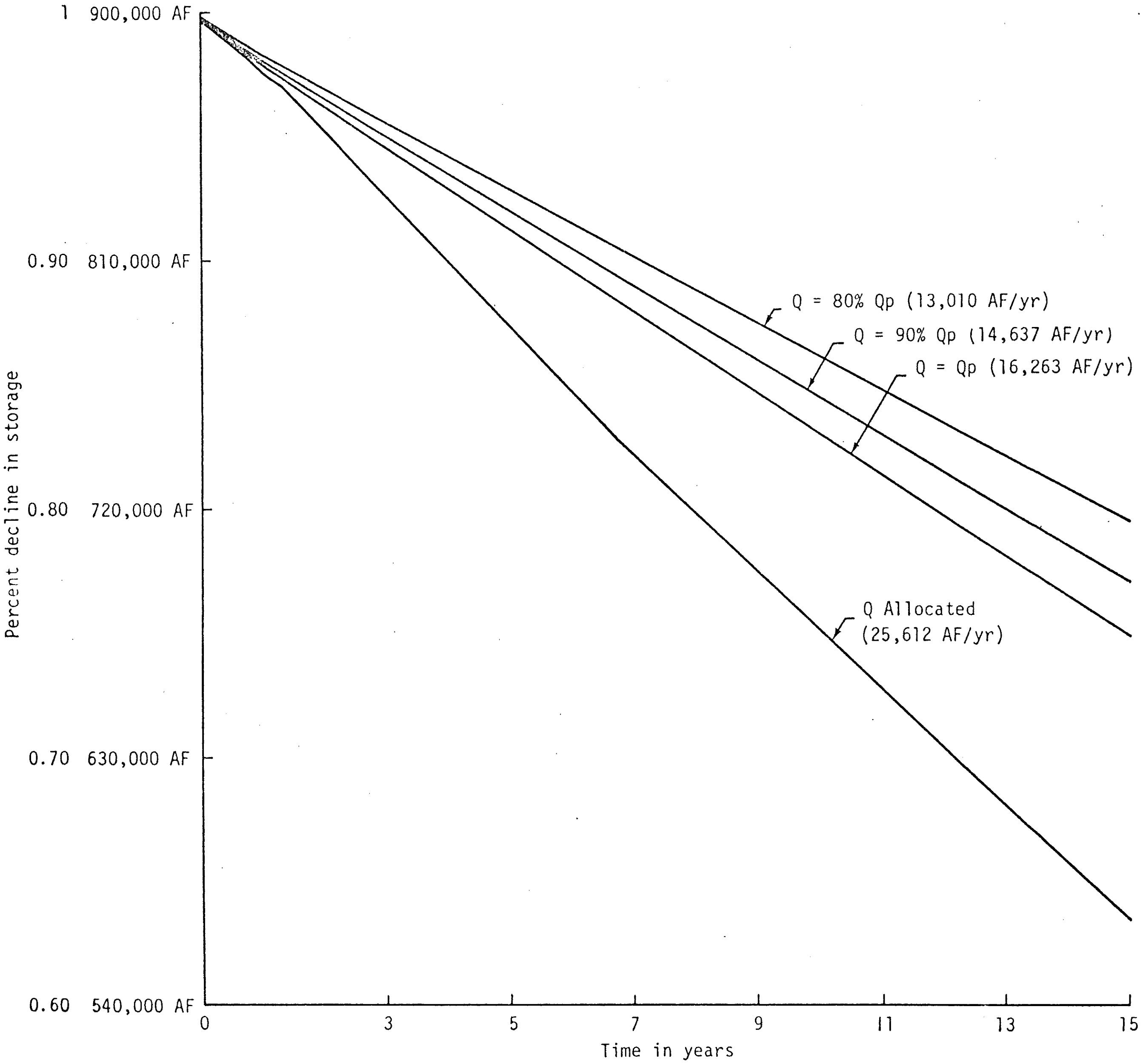
Conclusions

The model predicts a general slow decline of water levels in the moratorium area. 1973-77 average annual reported pumpage rates projected for 15 years cause drawdowns ranging from about 10 to 50 feet in the moratorium area. With 1973-77 pumpage, 675,000 acre-feet of the 1978 figure of 900,000 acre-feet of water in storage remains after 15 years. Figure 7 illustrates the storage declines for pumpage values above and below the 1973-77 values.

Two centers of noticeable water-level decline appear: the area east of Conway containing industrial wells used for salt-jug washing and the area around the McPherson municipal well field.

Several assumptions made in this modeling study should be kept in mind when using these projections. As was metnioned before, the wells are shut off when the saturated thickness falls below 10 feet. This is an arbitrary decision whose justification is based on the fact that at

Figure 7 -- Storage decline versus time for options 1-4 as calculated by numerical model.



1
900,000 AF
0.90
810,000 AF
0.80
720,000 AF
0.70
630,000 AF
0.60
540,000 AF
Percent decline in storage
0
3
5
7
9
11
13
15
Time in years
Q = 80% Qp (13,010 AF/yr)
Q = 90% Qp (14,637 AF/yr)
Q = Qp (16,263 AF/yr)
Q Allocated
(25,612 AF/yr)

Figure 7

some point in time the users will shut off their pumps, at least temporarily, simply because there may not be enough water. No provision is made in the model to add additional pumpage beyond what is listed in Table 1 (i.e., no new wells were added to the existing system). Therefore, the annual pumpage is never greater than that assumed for the first year, and decreases as the water table declines. Secondly, the value of the specific yield of 18% used in this model may be conservative; 20% might be more accurate. If 20% is used for the specific yield, the amount of water in storage at any time would be about 10% greater than that predicted here. Thirdly, the calibration technique used in this work will probably result in projected water-level declines somewhat greater than actual in areas of heavy development, such as near Conway and McPherson.

The monitoring of a depleting resource such as groundwater supplies in the moratorium area is the only way by which the future status of the resource may be predicted. In the case of groundwater supplies, two monitoring steps are of absolute importance: 1) water level measurements must be collected on a specified grid system and at a specified time; and 2) pumpage must be measured more accurately than is being done now. The only way that this can be accomplished is by the use of a meter on every irrigation, industrial, and municipal well. Without these data, any future prediction of the status of the depleting groundwater resource is subject to significant errors. This model study is not a definitive projection of detailed future water levels. It shows general regional trends in the water levels, and should be a useful tool for planning future withdrawals from the aquifer in the modeled area.

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TABLE 1

WATER RIGHTS AND PUMPAGE

Application No.	Location ¼	¼	¼	Sec.	Township	Range	Allocated or Requested Annual Pumpage (Ac.Ft.)	Reported Pumpage (Ac.Ft.) 1977	1976	1975	1974	1973	Average	Remarks
26912	NE	SE	SE	34	18	4W	234	234	133	--	--	--	184	IR
29259	CENTER		SW	35	18	4W	240	9.8	--	--	--	--	10	IR
29261	SW	SE	NE	35	18	4W	113	NONE	--	--	--	--		IR
24125	SE	SW	NW	36	18	4W	120	7	105.5	54.7	--	--	56	IR
12863		SE	NE	36	18	4W	207	106	93.9	70.9	--	--	90	IR
29362	NW	SE	NE	31	18	3W	60	NONE	--	--	--	--		IR
30451	SW	SW	NW	32	18	3W	195	NONE	--	--	--	--		IR
26451	SE	NW	SE	1	19	4W	210	36	139	--	--	--	88	IR
26859	NE	SE	NE	9	19	4W	180	7.4	212	--	--	--	110	IR
25478	SE	SE	SE	9	19	4W	135	141.4	212	--	--	--	177	IR
30070	CENTER		NW	11	19	4W	182	NONE	--	--	--	--		IR
24036	NE	SW	SW	11	19	4W	203	46	--	--	--	--	46	IR
24953	NE	NE	NE	14	19	4W	175	49.5	139.48	--	--	--	95	IR
26504	NE	SW	NW	13	19	4W	195	33.6	--	--	--	--	34	IR
26505	SE	NW	NW	17	19	3W	195	31.5	--	--	--	--	32	IR
22143	CENTER		SW	24	19	4W	240	46	83	--	--	--	65	IR
30465	SW	SE	SE	24	19	4W	337	31	--	--	--	--	31	IR
	(2 wells)													
29391	NE	SW	SE	20	19	3W	6	NONE	--	--	--	--		IR
27927	CENTER		NW	36	19	4W	228	NONE	--	--	--	--		IR
24338	CENTER		SE	36	19	4W	198	10.1	--	58	--	--	34	IR
23310	SE	SE	NE	31	19	3W	614	217	239	110.28	--	--	189	M
26697	NW	NW	SE	1	20	4W	230	69.6	386.6	--	--	--	228	IR
29904	SE	NW	NW	36	20	4W	240	74.24	--	--	--	--	74	IR
26522	SW	SE	SE	30	20	4W	120	21.7	82.85	--	--	--	52	IR
30391	CENTER		SW	6	20	3W	198	NONE	--	--	--	--		IR
31415	SE	SE	NW	21	18	4W	105		--	--	--	--		IR
23878	NW	NE	NW	35	18	4W	240	--	198.86	--	--	--	199	IR
29544	SW	SW	SW	33	18	3W	195	21.7	--	--	--	--	22	IR
30614	CENTER		SW	6	19	3W	195	NONE	--	--	--	--		IR
30783	CENTER		SW	13	19	4W	195	NONE	--	--	--	--		IR
31107	N½	S½	NW	18	19	3W	120	NONE	--	--	--	--		IR
31140	CENTER		SW	17	19	3W	300							IR
31456	SE	NW	NW	23	19	4W	105							IR
31534		SW	SW	20	19	3W	613							M

Application No.	Location ¼	¼	¼	Sec.	Township	Range	Allocated or Requested Annual Pumpage (Ac.Ft.)	Reported Pumpage (Ac.Ft.) 1977	1976	1975	1974	1973	Average	Remarks
28152	SE	SE	NW	27	19	4W	692.67	27.84	--	--	--	--	28	M/ID
	NE	SE	NW	27	19	4W	692.67 Total=	34.8	--	--	--	--	35	M/ID
	NE	NE	NW	27	19	4W	692.67 2078	400.90	--	--	--	--	401	M/ID
30520	SW	SW	NW	26	19	4W	1326	NONE	--	--	--	--	315*	ID
29122	SE	SE	NE	26	19	4W	15	<½	--	--	--	--	1	IR
25366	SE	NW	SW	26	19	4W	807	613.7	528.49	--	--	--	571	ID
30116	NE	NE	SE	34	19	4W	552	New well	--	--	--	--		ID
27928	SE	NE	NW	35	19	4W	334	NONE	--	--	--	--		IR
30366	NE	NE	SE	2	20	4W	120	NONE	--	--	--	--		IR
29292	SE	SE	SW	10	20	4W	233	Not Yet Drilled						IR
29405	CENTER		SW	27	18	4W	195	49.9	--	--	--	--	50	IR
23069	NE	SW	SE	26	18	4W	173	91.15	--	--	--	--	92	IR
29260	NW	NE	NW	35	18	4W	234	44.19	--	--	--	--	44	IR
27540	NW	NW	NE	30	18	3W	95	36.27	59.65	--	--	--	48	IR
27656	CENTER E		SE	10	20	4W	120	37.12	110.47	--	--	--	74	IR
28439	SW	NE	SW	11	20	4W	223.5 Total=	--	--	--	--	--		IR
	SW	NE	SE	11	20	4W	223.5 447	--	--	--	--	--		IR
30367	CENTER		NE	11	20	4W	240	--	103.57	--	--	--	104	IR
23644	NW	SW	SE	12	20	4W	224	35.35	--	--	--	--	36	IR
24644	CENTER		NW	18	20	3W	180	43.45	133.75	--	--	--	89	IR
27876	CENTER		NE	32	20	3W	180	--	--	--	--	--		IR
29724	SE	NW	NW	32	20	3W	111	Not Yet Drilled						IR
27922	SE	SW	SW	31	20	3W	200	NONE	--	--	--	--		IR
27900	CENTER		NW	31	20	3W	234	36.82	--	--	--	--	37	IR
18833	SW	NE	NE	35	20	4W	240	88.38	228.32	154.67	185.99	--	165	IR
29402	SW	NE	SW	26	20	4W	230	60.76	--	--	--	--	61	IR
29317	NW	SE	NE	22	20	4W	230	NONE	--	--	--	--		IR
27655	SW	NE	SE	22	20	4W	120	6.6	--	--	--	--	7	IR
24809	CENTER		SW	23	20	4W	225	47.69	--	--	--	--	48	IR
29315	SE	NE	SE	23	20	4W	100	NONE	--	--	--	--		IR
26705	NW	SE	NW	24	20	4W	300	56.71	198.79	--	--	--	128	IR
30547	SW	SW	SW	22	20	3W	210	Not Yet Drilled						IR
17867	SE	NE	SE	29	18	4W	120	106.06	152.46	129.26	--	--	130	IR
11008	W½ of SW			36	18	4W	210	44.19	131.28	87.83	--	--	88	IR
6666		SE	SE	36	18	4W	45	4.2	8.50	6.27	--	--	7	IR
22019	CENTER		NW	31	18	3W	225	32.55	48.72	90.74	--	--	58	IR

Application No.	Location ¼	¼	¼	Sec.	Township	Range	Allocated or Requested Annual Pumpage (Ac.Ft.)	Reported Pumpage (Ac.Ft.) 1977	1976	1975	1974	1973	Average	Remarks
24391	CENTER		SE	3	19	4W	198	38.00	187.81	--	--	--	113	IR
17712	SE	SW	NW	1	19	4W	225	43.75	189.78	132.87	--	--	122	IR
12751	NE	SW	NE	1	19	4W	120	69.97	--	--	101.86	81.31	85	IR
											(1970)	(1969)		
7308	NE	SW	SW	1	19	4W	160	22.09	73.65	95.74	64.44	81.01	68	IR
												(1970)		
14745	SE	SE	SE	10	19	4W	180	87	142.51	129.26	--	109.37	127	IR
17259	SW	NW	NW	7	19	3W	100	13.25		9.29	--	128.89	51	IR
12751A		NW	NE	35	18	4W	105	79.17	105.52	83.96	76.45	--	86	IR
									(1970)	(1969)	(1968)			
25863	SW	SW	NE	7	19	3W	180	17.67	70.70	--	--	--	44	IR
6441			SE	7	19	3W	228	37	165.71	110.66	--	--	105	IR
17913	SW	NE	NE	15	19	4W	231	64.36	--	96.66	66.28	--	76	IR
16697	NW	NW	SE	15	19	4W	360	16.57	182.29	155.04	--	--	118	IR
21618	SW	NW	SW	14	19	4W	236	0.5	110.20	89.21	--	--	67	IR
19588	NE	NE	SE	23	19	4W	222	110.47	--	193.33	--	198.86	168	IR
3050		SE	NW	21	19	3W	60	<0.5	21.21	22.09	30.93	--	25	IR
									(1966)	(1965)	(1964)			
8431		SW	NE	27	19	4W	640	698	--	603.22	851.93	--	718	ID
21719	SE	SW	SE	26	19	4W	240	57.44	132.57	198.86	--	--	130	IR
30099	SW	NE	NE	36	19	4W	233	1.47	--	--	--	--	2	IR
21102	SE	NW	SW	36	19	4W	240	125.2	125.2	--	--	--	126	IR
24602	CENTER		SW	31	19	3W	210	--	159.09	--	--	--	159	IR
1311 #1	NE	NW	SE	29	19	3W		--	--	--	--	35.44	36	M
												(1969)		
#2	NE	NW	SE	29	19	3W		400.61	411.35	216.72	136.44	639.31	361	M
#3	SE	NW	SE	29	19	3W		69.25	233.81	197.48	208.54	307.63	204	M
#4	SE	SW	SE	29	19	3W	Total =	22.62	26.40	40.54	167.16	292.56	110	M
#5	NE	SW	NE	29	19	3W	3990	164.83	290.12	174.42	165.71	325.63	224	M
#7	NE	NE	NE	31	19	3W		258.7	1745.39	227.01	368.84	98.44	540	M
#8	NW	NE	SW	20	19	3W		586.68	546.14	707.84	585.31	987.15	683	M
#9	SE	SW	SW	20	19	3W		1375.62	1547.64	1358.98	1584.84	140.87	1202	M
26698	NE	NW	NW	11	20	4W	240	38.9	276.19	--	--	--	158	IR
12781	CENTER		NE	12	20	4W	240	126.49	276.19	100.16	151.17	115.08	154	IR
29316	NW	SE	NE	15	20	4W	152	0.25	--	--	--	--	1	IR
17264	NW	NE	NE	23	20	4W	237	124.84	289.01	202.1	209.02	--	207	IR

Application No.	Location ¼	¼	¼	Sec.	Township	Range	Allocated or Requested Annual Pumpage (Ac.Ft.)	Reported Pumpage (Ac.Ft.) 1977	1976	1975	1974	1973	Average	Remarks
28802	NE	SW	NW	19	20	3W	225	48.47	--	--	--	--	49	IR
17020	SW	NE	SW	27	20	4W	195	41.42	--	--	--	--	42	IR
6088	N½ of NE			27	20	4W	120	53.03	--	--	88.93	63.63	69	IR
											(1972)	(1971)		
13008	SW	SE	NE	27	20	4W	179	86.91	--	--	310.22	188.14	195	IR
											(1969)	(1968)		
17801	SE	SW	SE	27	20	4W	135	64.44	209.17	154.67	140		142	IR
15671	SW	NE	SE	27	20	4W	86	38.66	--	75	--	106.06	73	IR
												(1972)		
17021	NE	SE	NW	26	20	4W	153	90.74	--	--	--	--	91	IR
17982	NW	SE	NW	25	20	4W	233	35.35	233.29	--	--	229.68	166	IR
4751	N½ of SE			35	20	4W	240	36.82	149.14	51.55	--	--	79	IR
23003	SW	SW	NE	36	20	4W	180	43.30	177.09	29.46	--	--	84	IR
25036	N CO			36	20	4W	225	88.38	220.95	--	--	--	157	IR
	E SIDE SE NE													
28581	NW	SE	SE	31	20	3W	150	15.02	--	--	--	--	15	IR
11397		SE	NE	32	20	3W	48	15.39	48.32	34.8	18.13	--	30	IR
17250	NE	SE	SW	34	20	3W	126	32.22	226.20	126.40	101.31	44.19	114	IR
												(1971)		
4954	SW corner		SW	21	18	4W	195	116.00	--	--	--	--	116	IR
4536	SW	SW	SW	30	18	3W	237	51.37	144.94	94.2	97.97	--	98	IR
3195		SW	SE	30	18	3W	531	36.45	103.70	95.74	--	--	79	IR
3169		SE	SE	36	18	4W	262	66.70	224.01	138.33	155.99	--	147	IR
3196		NW	SW	7	19	3W	240	1.32	37.35	16.60	--	51.87	27	IR
												(1971)		
3269	NW	SW	SW	18	19	3W	173	NONE	75.48	64.44	58.92	--	67	IR
7140	NW	SW	NW	16	19	3W	180		--	--	--	--		IR
6764	NW	NW	SE	27	19	4W	403	8.4	186.82	479.13	210.66	532.14	284	ID
												(1962)		
4685	SW	SW	NW	26	19	4W	750	3.68	193.38	184.13	--	220.95	151	IR
5388		NE	NW	34	19	4W	650	129.95	308.90	432.19	351.32	--	306	ID
2981		NW	NW	35	19	4W	129	5.52	53.17	33.88	22.46	--	29	IR
3522	N½ of NW			31	19	3W	411	NONE	--	58.00	--	165.71	112	IR
												(1970)		

Application No.	Location ¼	¼	¼	Sec.	Township	Range	Allocated or Requested Annual Pumpage (Ac.Ft.)	Reported Pumpage (Ac.Ft.) 1977	1976	1975	1974	1973	Average	Remarks
5455	SE	SE	NW	15	20	4W	240	33.14	132.57	121.52	116.00	--	101	IR
8429	E½ of SE			25	20	4W	140	110.47	--	128.89	184.13	--	142	IR
6788	CENTER SE			25	20	4W	131	NONE	--	--	88.38	70.70	80	IR
4495	N CO N½		NW	30	20	3W	320	59.35	220.95	220.95	220.95	--	181	IR
667		NW		35	20	4W	15	--	--	--	--	--		IR
28735	SE	SE	SW	22	19	4W	350							FISH POND
	NE	NW	NE	27	19	4W	350							+ IR
25365	NW	NE	SE	27	19	4W	100	27.84	92.06	--	--	--	60	

[a] IR, Irrigation; ID, Industrial; M, Municipal

*10 year average of compromise with DWR

Plate 1 -- Generalized map showing configuration of Permian bedrock surface

Legend:

————	Model Boundary
---------	Moratorium Boundary
—1320—	Bedrock contour with elevation above sea level

Contour interval 40 feet

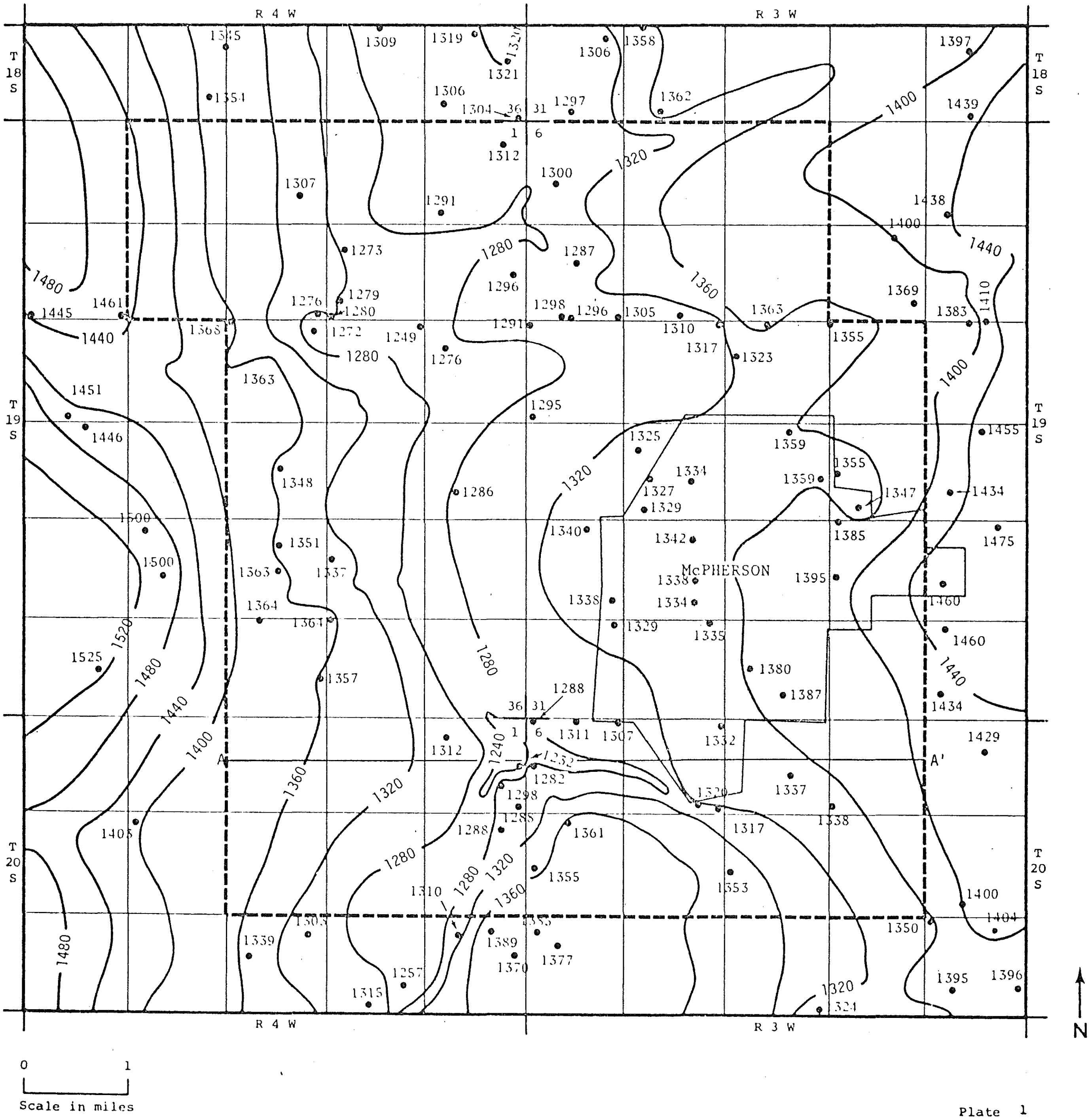


Plate 1

Plate 2 -- Generalized map showing water-table elevation (January 1978)

Legend:

————	Model Boundary
-------	Moratorium Boundary
—1430—	Water table contour with elevation above sea level
— —1430— —	Dashed where approximate

Contour interval 10, 20, and 30 feet

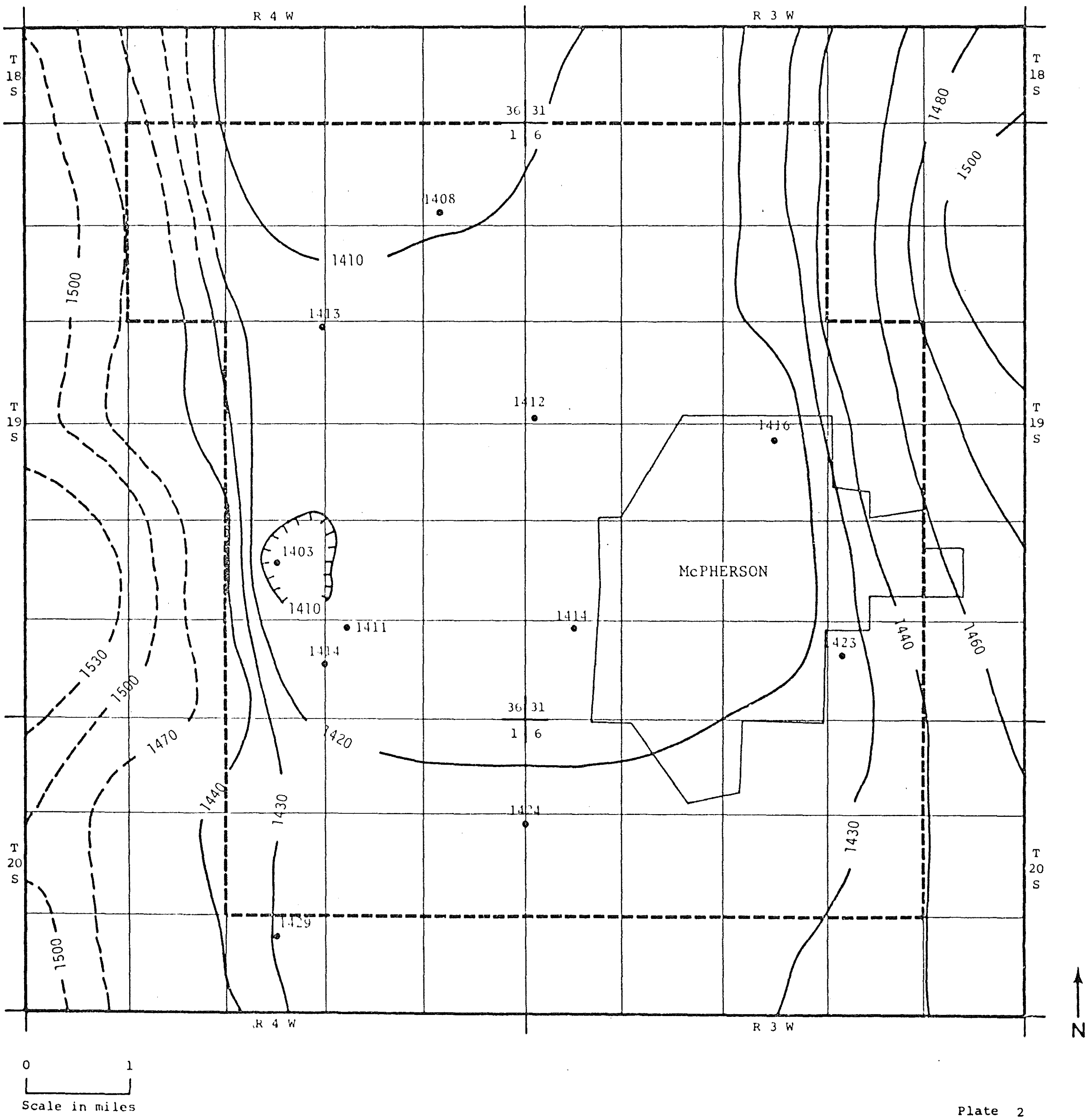

R 4 W
R 3 W
T 18 S
T 19 S
T 20 S
36 31
1 6
1408
1410
1413
1412
1416
1403
1411
1414
1423
1420
1421
1429
McPHERSON
1500
1530
1470
1440
1430
1460
1480
N
0
1
Scale in miles

Plate 2

Legend for all remaining odd numbered plates:

————	Model Boundary
-------	Moratorium Boundary
——40——	Contour showing saturated thickness

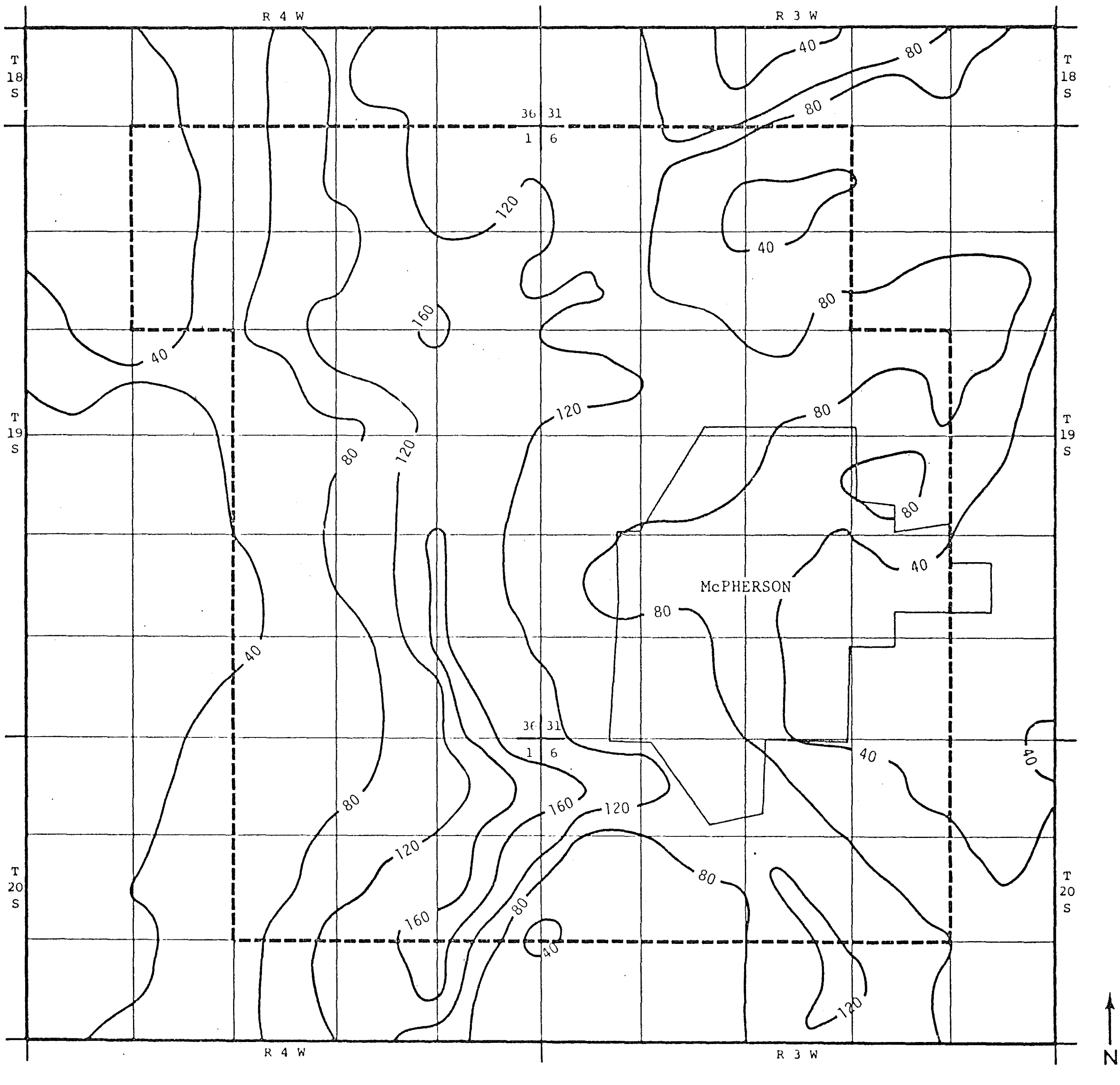
Contour interval 40 feet

Legend for all remaining even numbered plates:

————	Model Boundary
-------	Moratorium Boundary
——10——	Contour showing amount of water level decline

Contour interval 10 feet

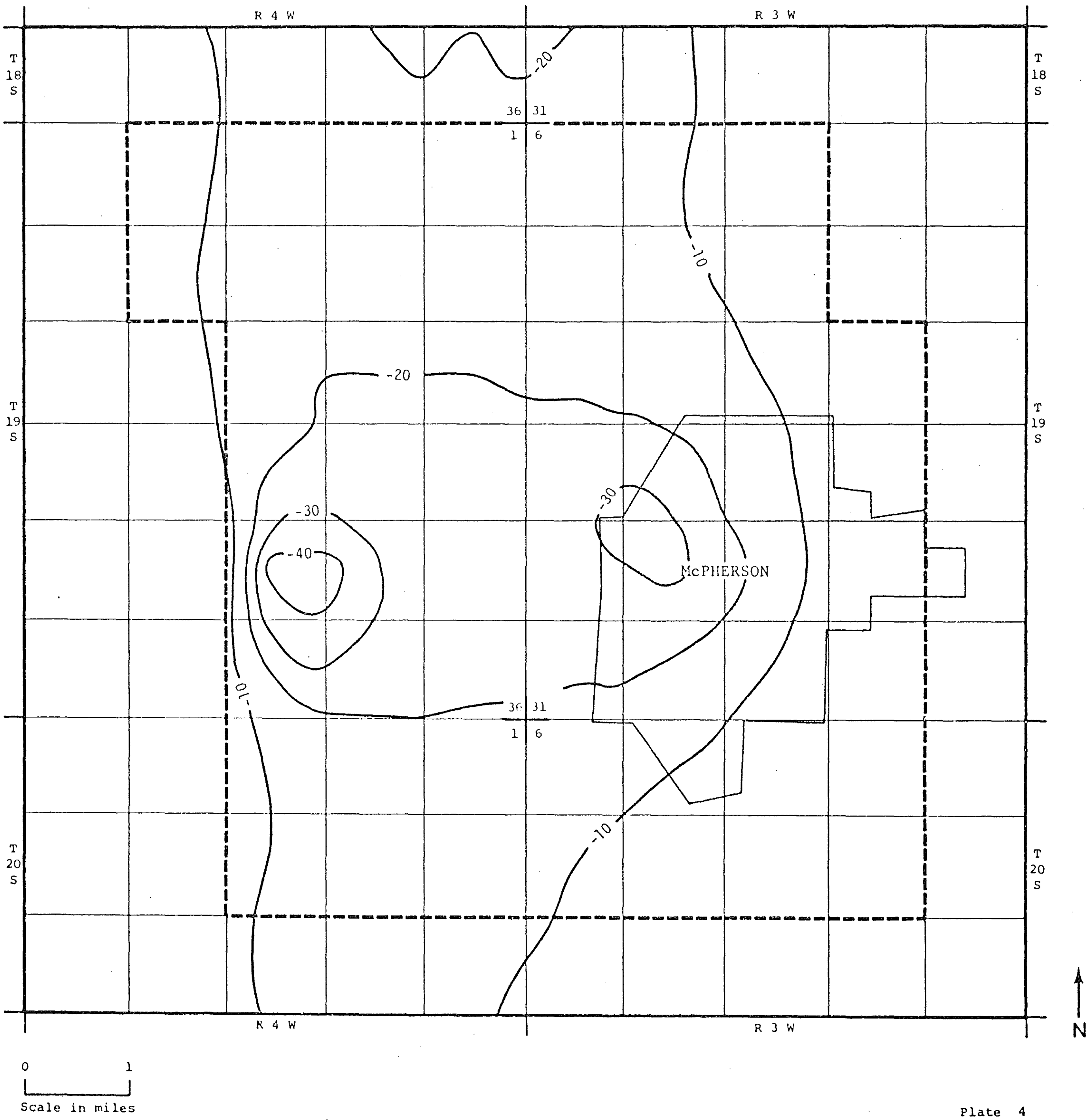
Plate 3 -- Generalized map showing saturated thickness (January 1978)



0 1
Scale in miles

Plate 3

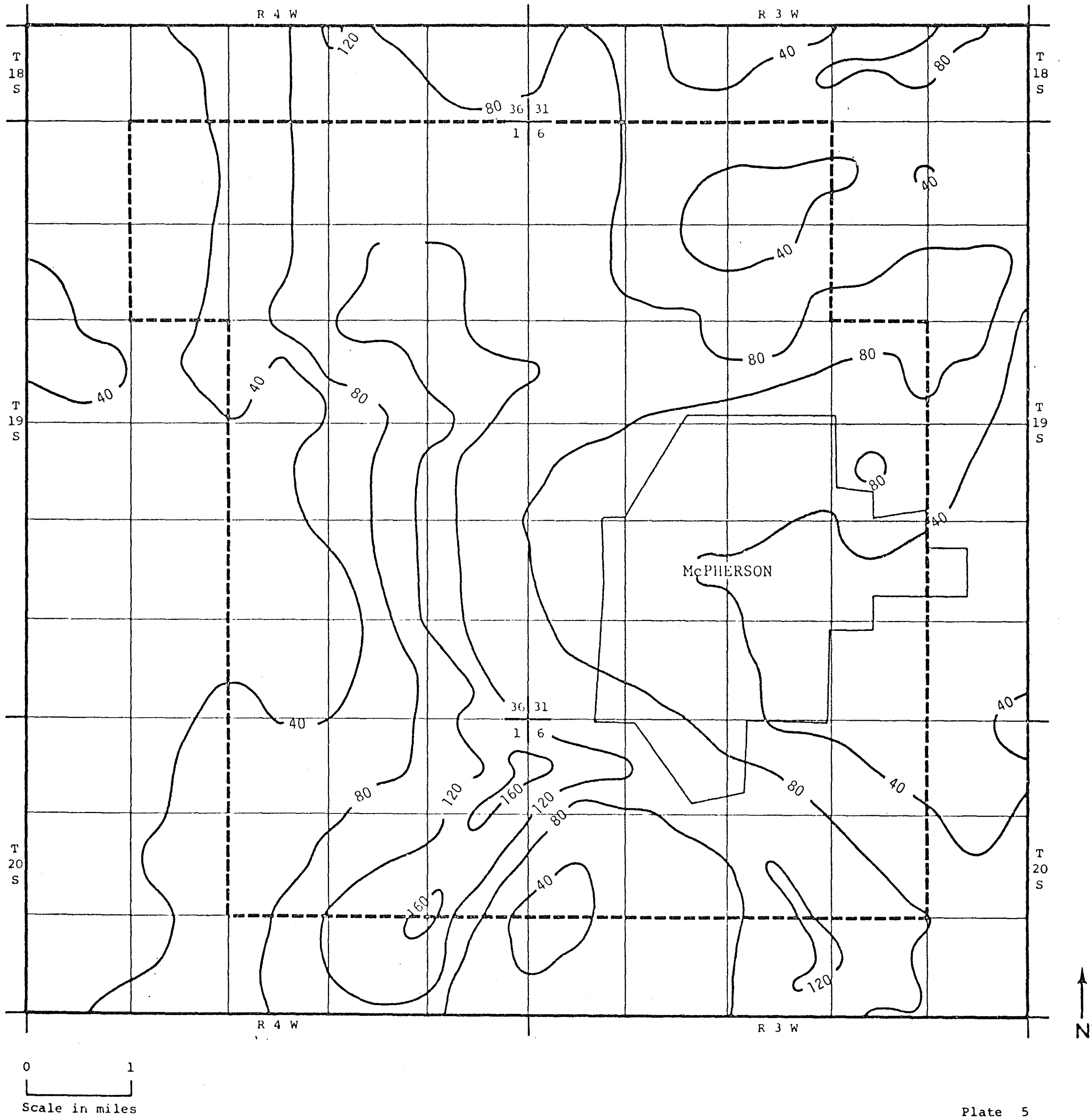
Plate 4 -- Water-level decline after 5 years using maximum allocated pumpage of 25,612 AcFt/yr



R 4 W
R 3 W
T 18 S
T 19 S
T 20 S
-20
-10
-30
-40
36
31
1
6
McPHERSON
N
0
1
Scale in miles

Plate 4

Plate 5 -- Saturated thickness after 5 years using maximum allocated pumpage of 25,612 AcFt/yr



R 4 W
R 3 W
T 18 S
T 19 S
T 20 S
McPHERSON
36 31
1 6
40
80
120
160
N
0 1
Scale in miles

Plate 5

Plate 6 -- Water-level decline after 10 years using maximum allocated pumpage of 25,612 AcFt/yr

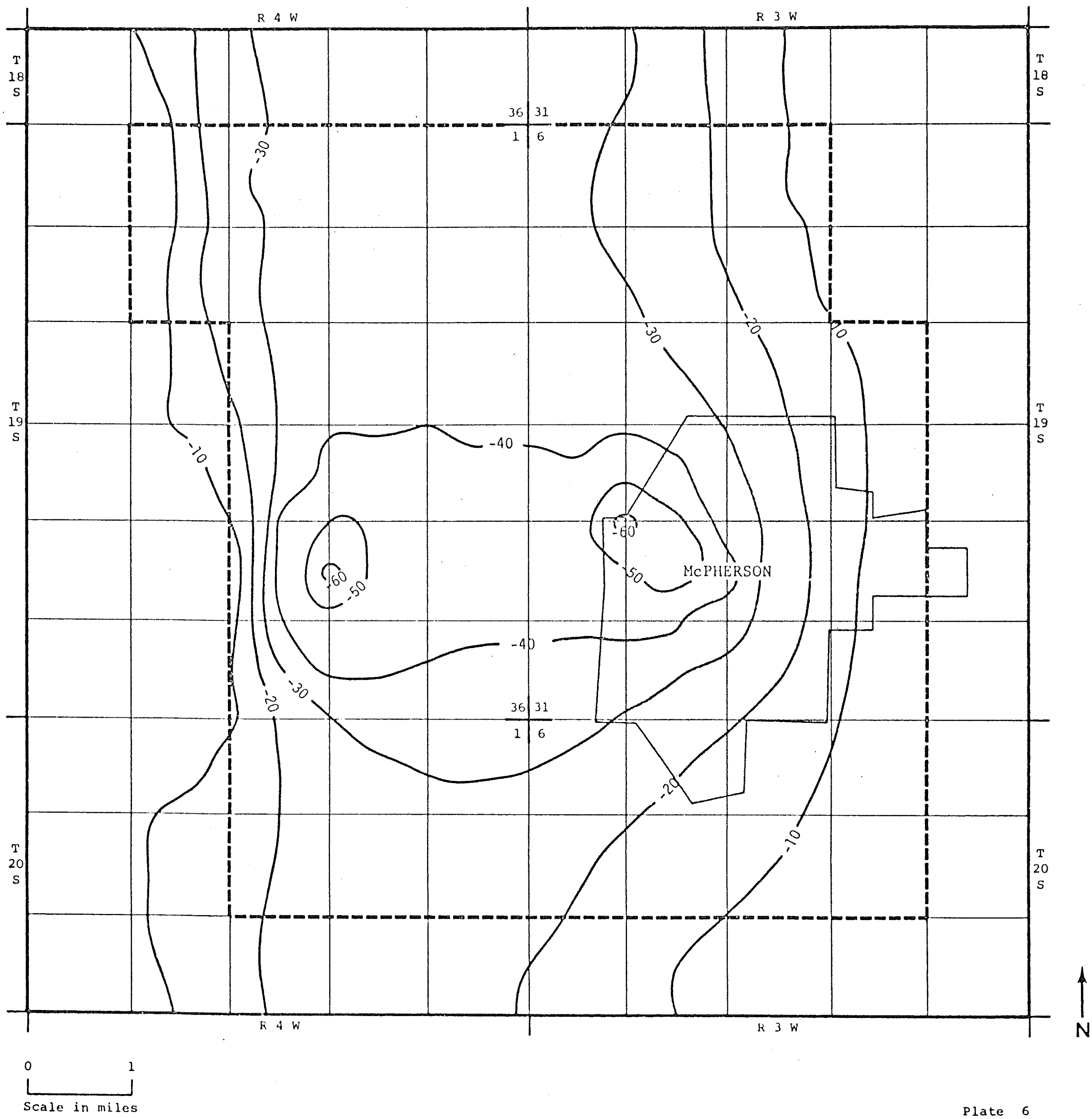
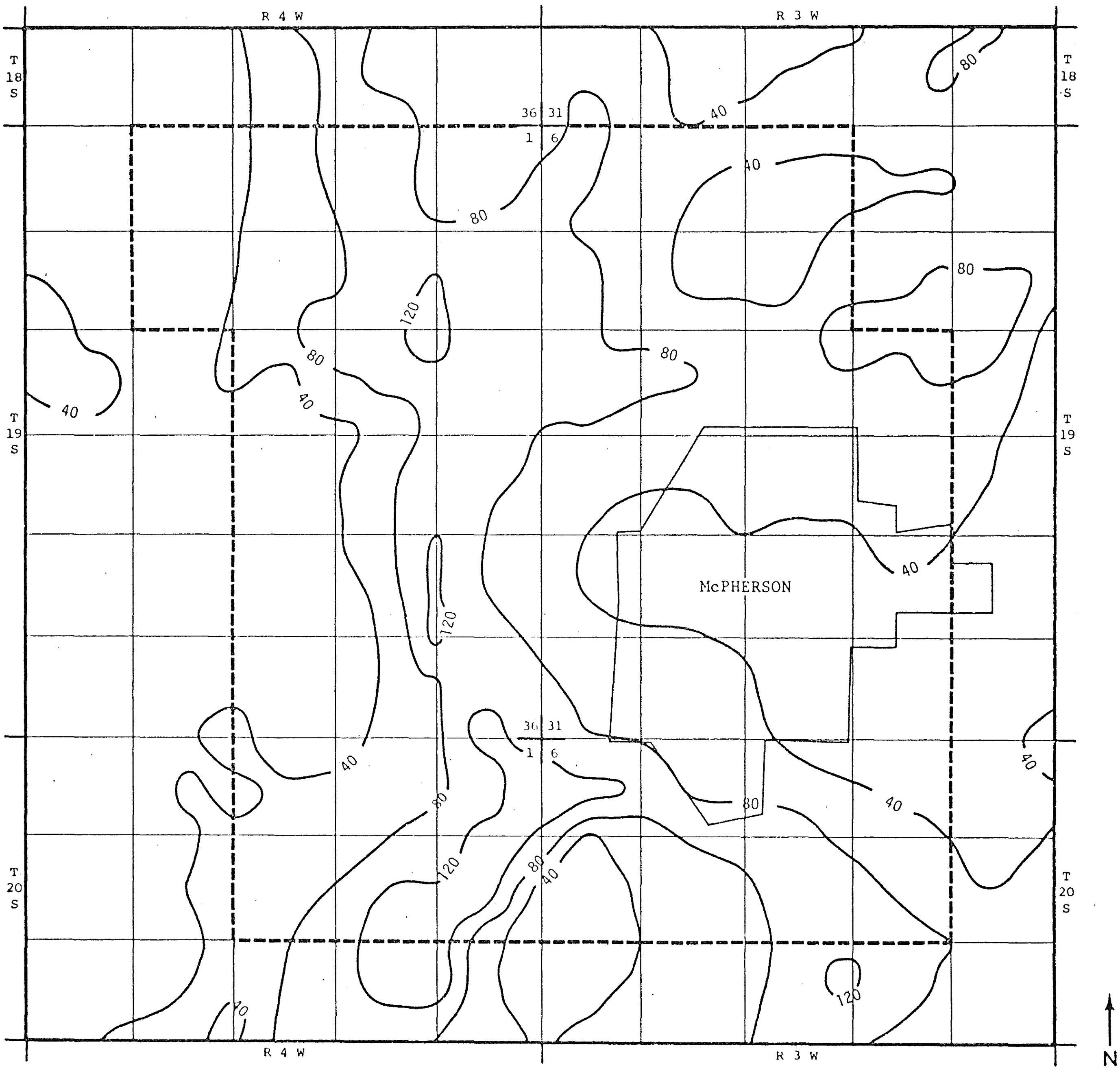

R 4 W
R 3 W
T 18 S
T 19 S
T 20 S
36 31
1 6
-30
-30
-20
-10
-10
-40
-60
-50
-60
-50
McPHERSON
-40
-30
-20
36 31
1 6
-20
-10
R 4 W
R 3 W
N
0 1
Scale in miles

Plate 6

Plate 7 -- Saturated thickness after 10 years using maximum allocated pumpage of 25,612 AcFt/yr



0 1
Scale in miles

Plate 7

Plate 8 -- Water-level decline after 15 years using maximum allocated pumpage of 25,612 AcFt/yr

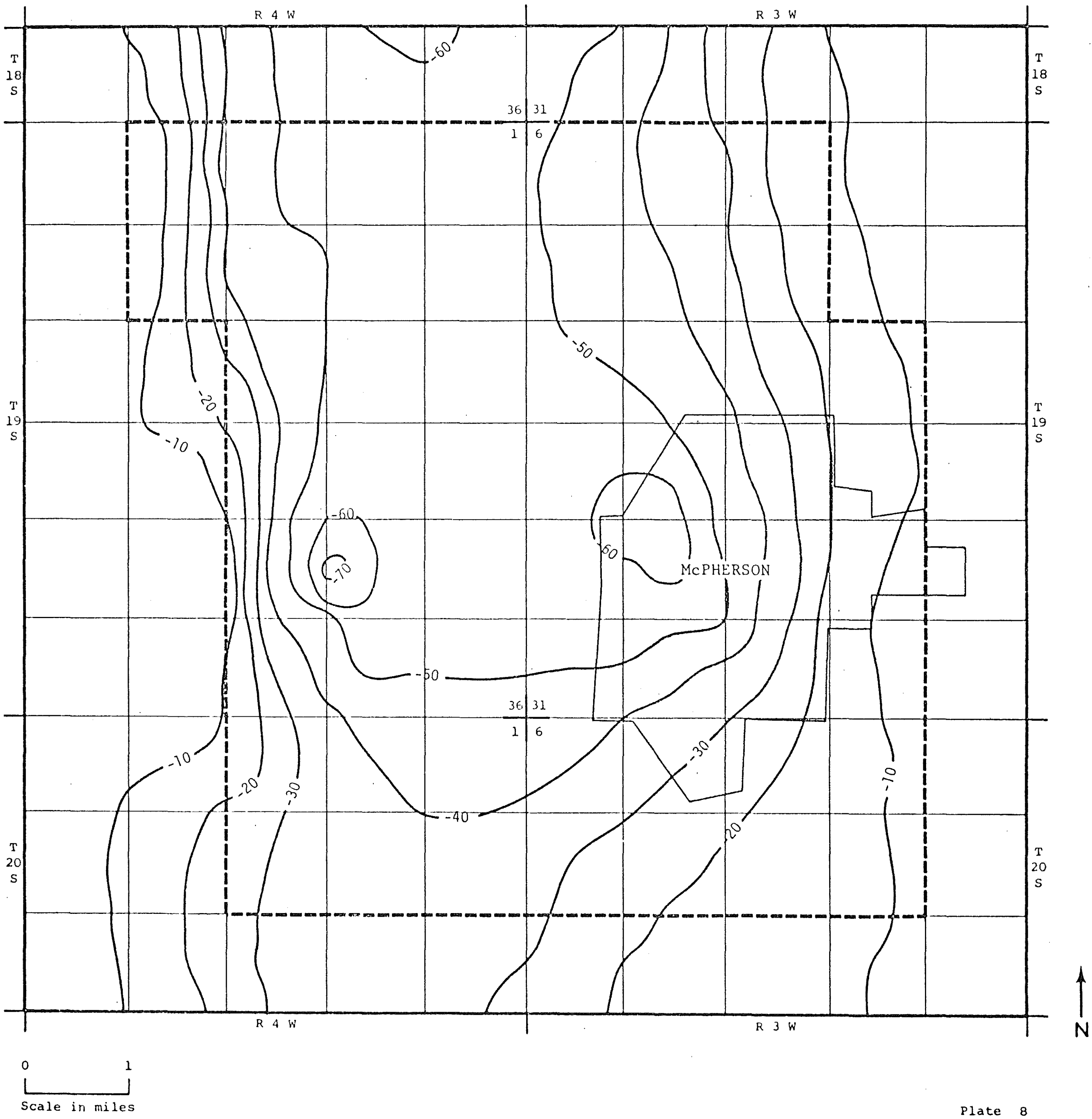

R 4 W
R 3 W
T 18 S
T 19 S
T 20 S
36 31
1 6
-60
-50
-70
-40
-30
-20
-10
McPHERSON
N
0 1
Scale in miles

Plate 8

Plate 9 -- Saturated thickness after 15 years using maximum allocated pumpage of 25,612 AcFt/yr

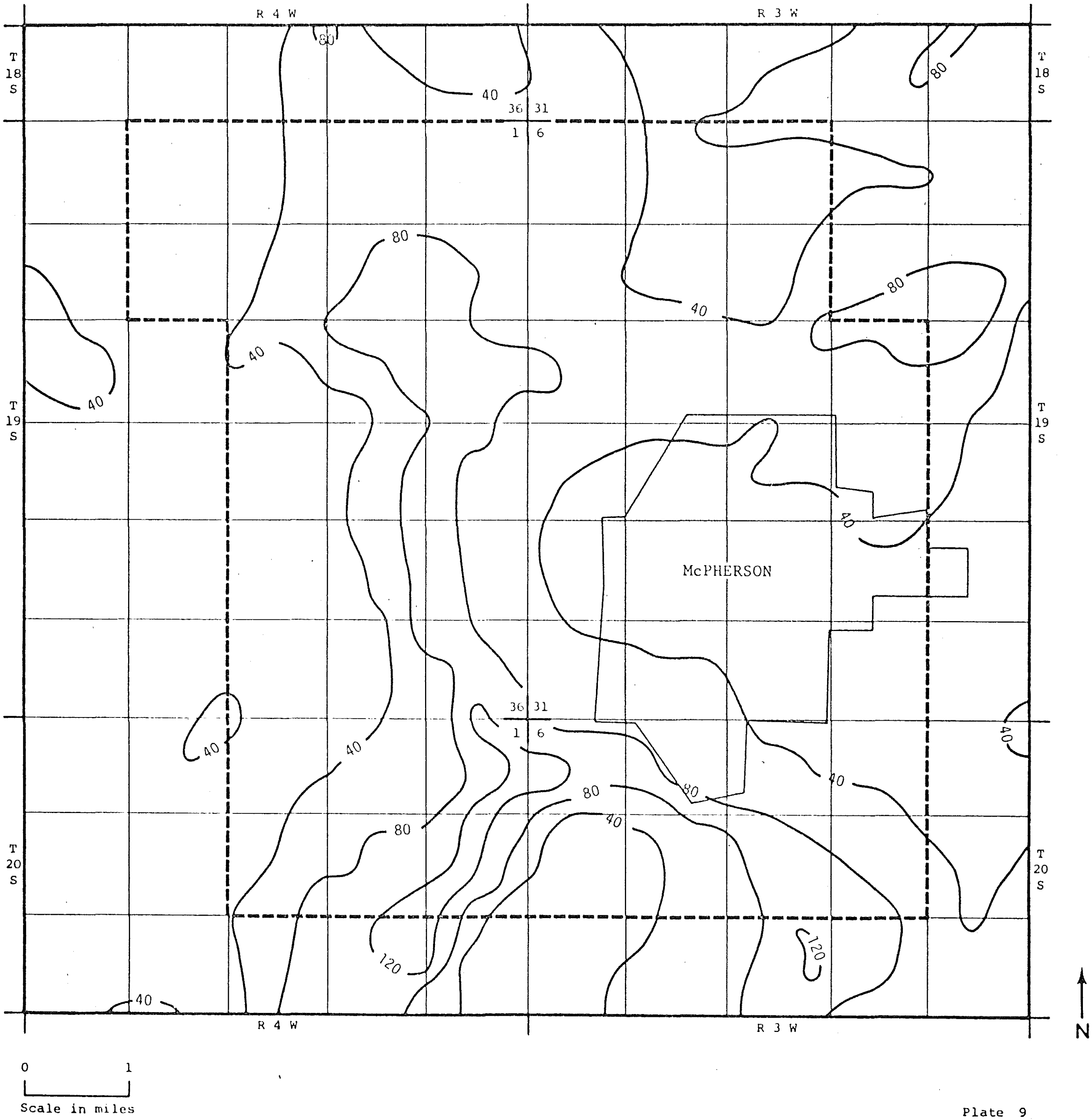

R 4 W
R 3 W
T 18 S
T 19 S
T 20 S
36 31
1 6
McPHERSON
40
80
120
N
0 1
Scale in miles

Plate 9

Plate 10 -- Water-level decline after 5 years using 1973-77 average annual reported pumpage of 16,263 AcFt/yr

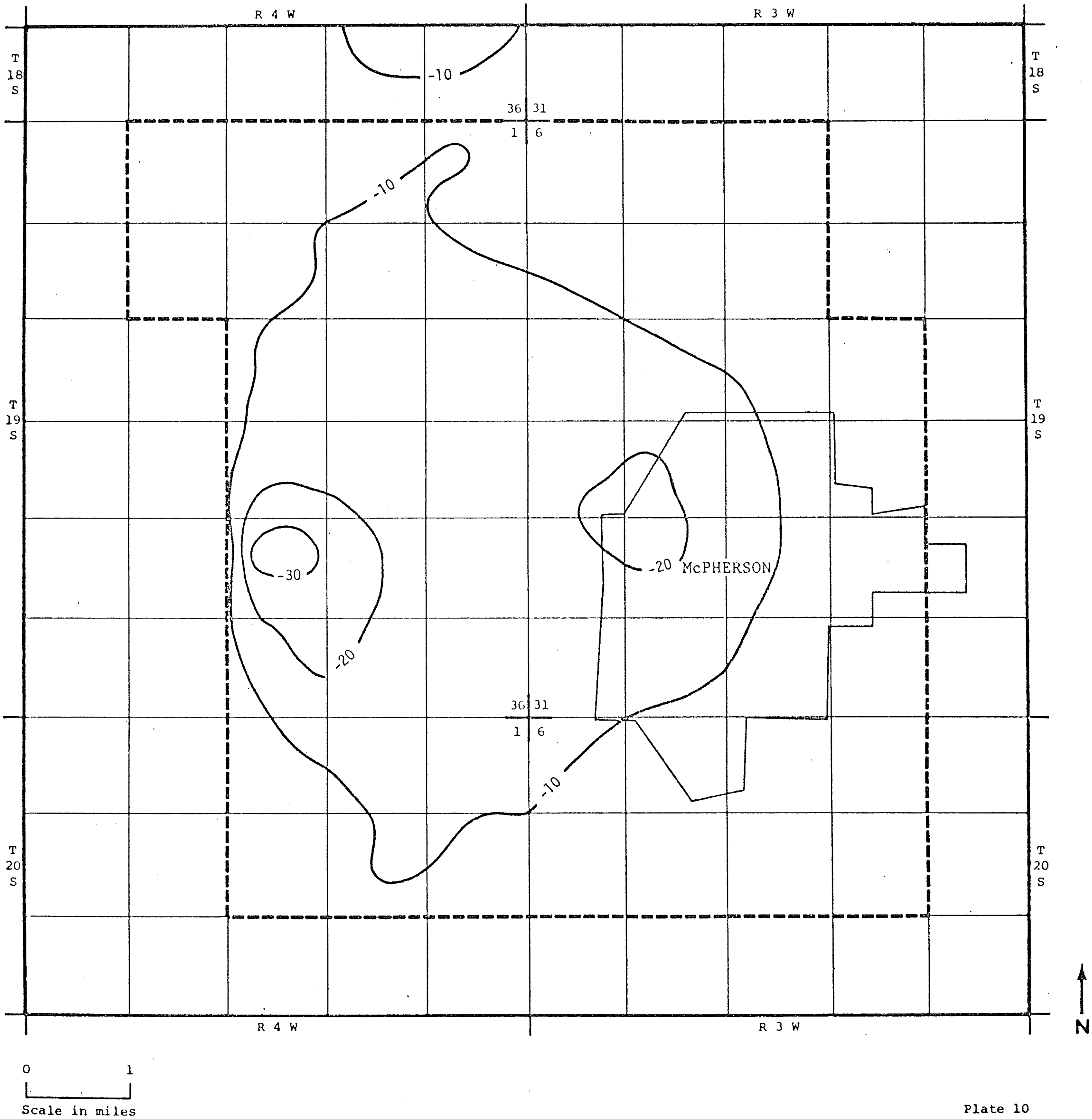
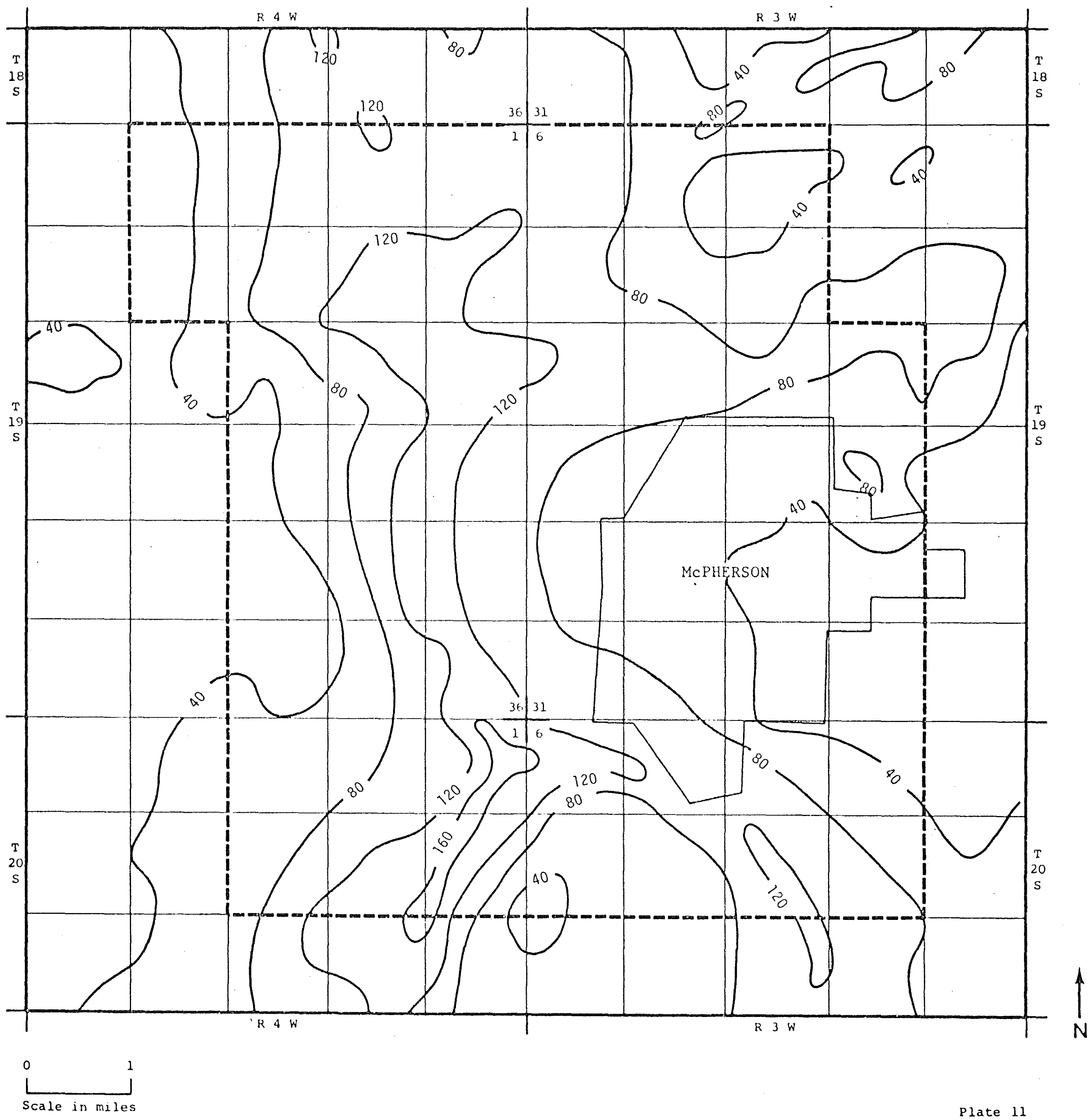

R 4 W
R 3 W
T 18 S
T 19 S
T 20 S
-10
36 31
1 6
-10
-30
-20
-20
McPHERSON
36 31
1 6
-10
R 4 W
R 3 W
N
0
1
Scale in miles

Plate 10

Plate 11 -- Saturated thickness after 5 years using 1973-77 average annual reported pumpage of 16,263 AcFt/yr



R 4 W
R 3 W
T 18 S
T 19 S
T 20 S
36 31
1 6
McPHERSON
120
80
40
160
N
0 1
Scale in miles

Plate 11

Plate 12 -- Water-level decline after 10 years using 1973-77 average annual reported pumpage of 16,263 AcFt/yr

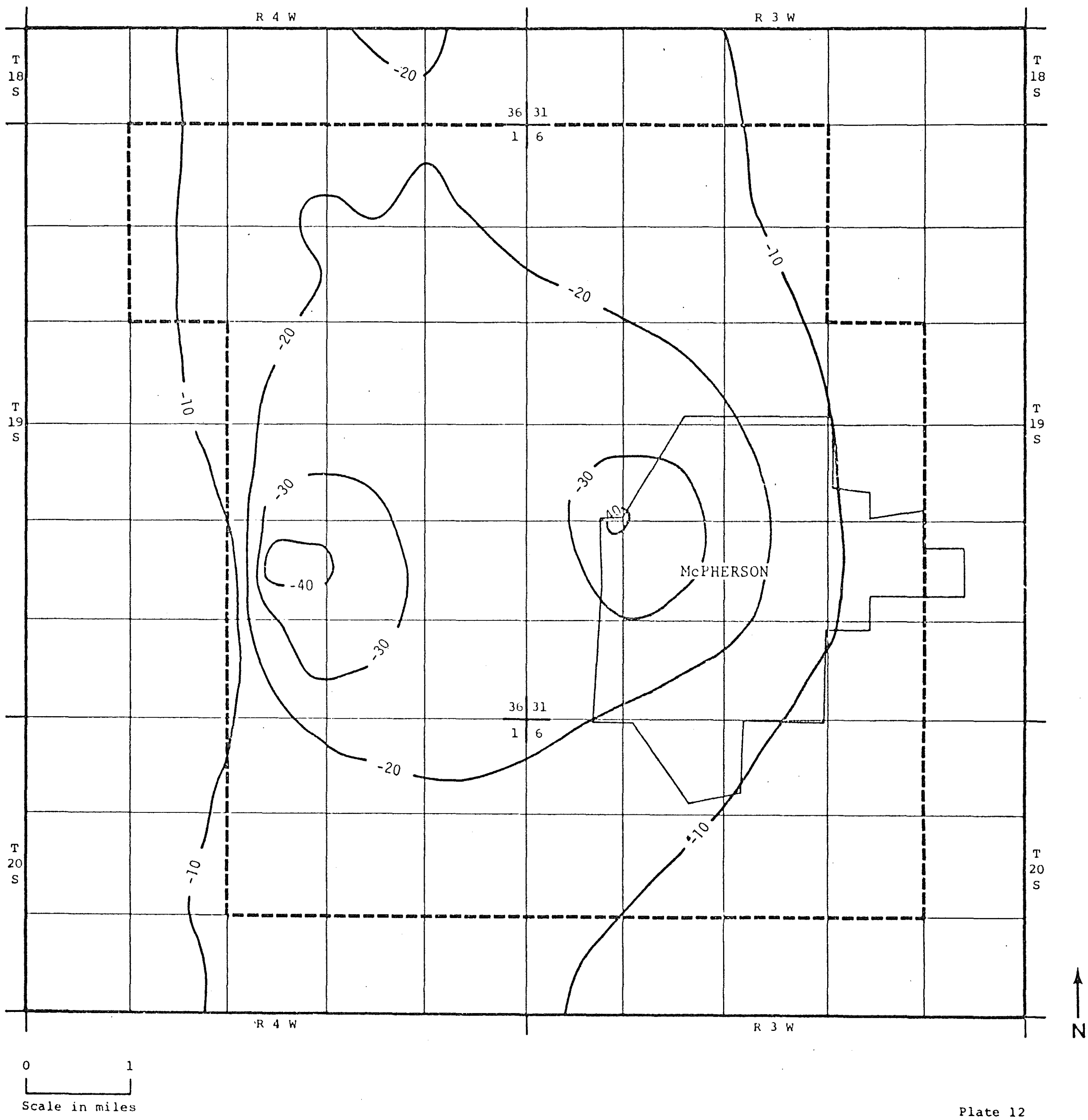

R 4 W
R 3 W
T 18 S
T 19 S
T 20 S
36 31
1 6
-10
-20
-30
-40
McPHERSON
N
0 1
Scale in miles

Plate 12

Plate 13 -- Saturated thickness after 10 years using 1973-77 average annual reported pumpage of 16,263 AcFt/yr

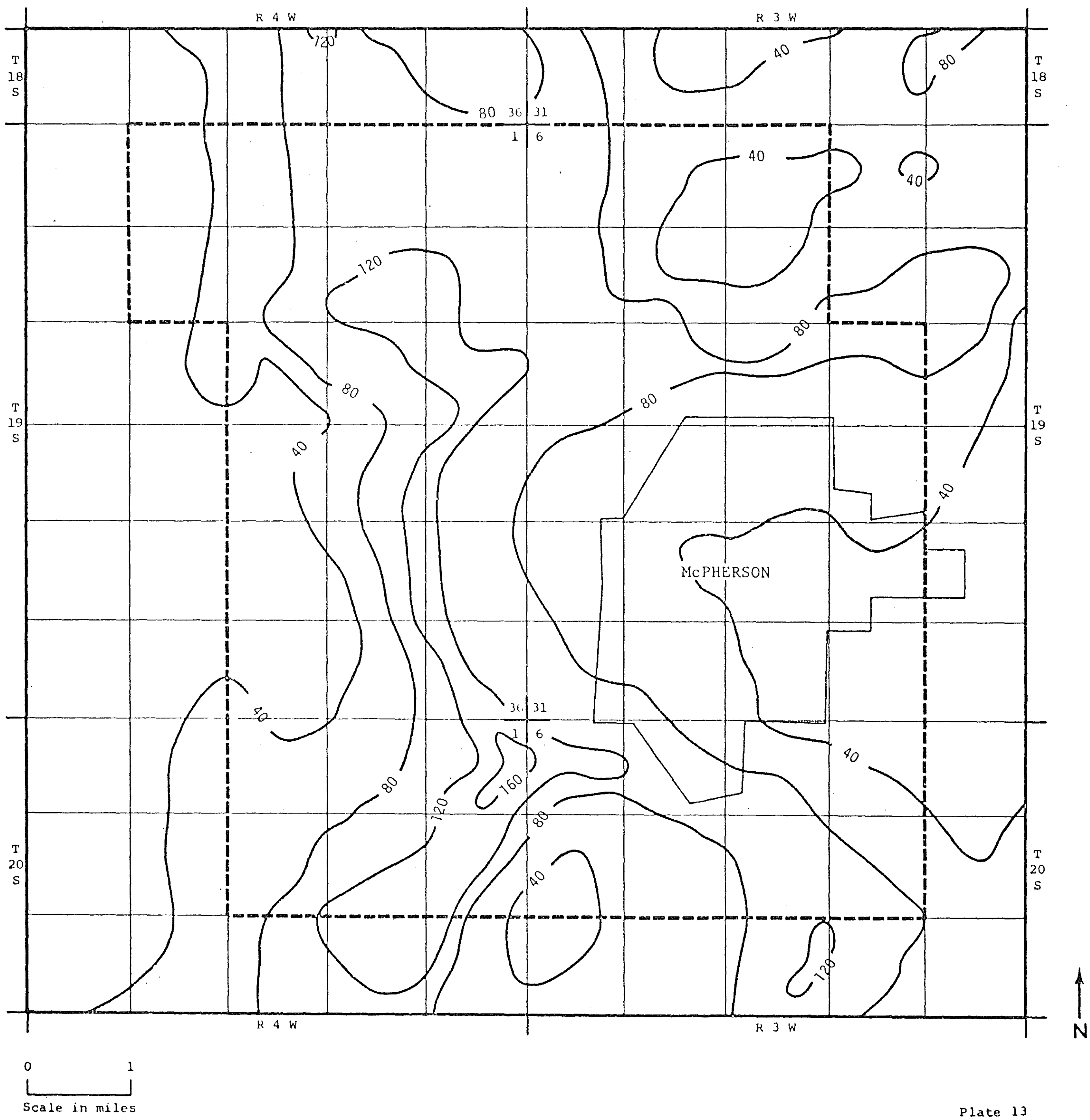

R 4 W
R 3 W
T 18 S
T 19 S
T 20 S
120
80
40
160
128
36
31
1
6
McPHERSON
N
0
1
Scale in miles

Plate 13

Plate 14 -- Water-level decline after 15 years using 1973-77 average annual reported pumpage of 16,263 AcFt/yr

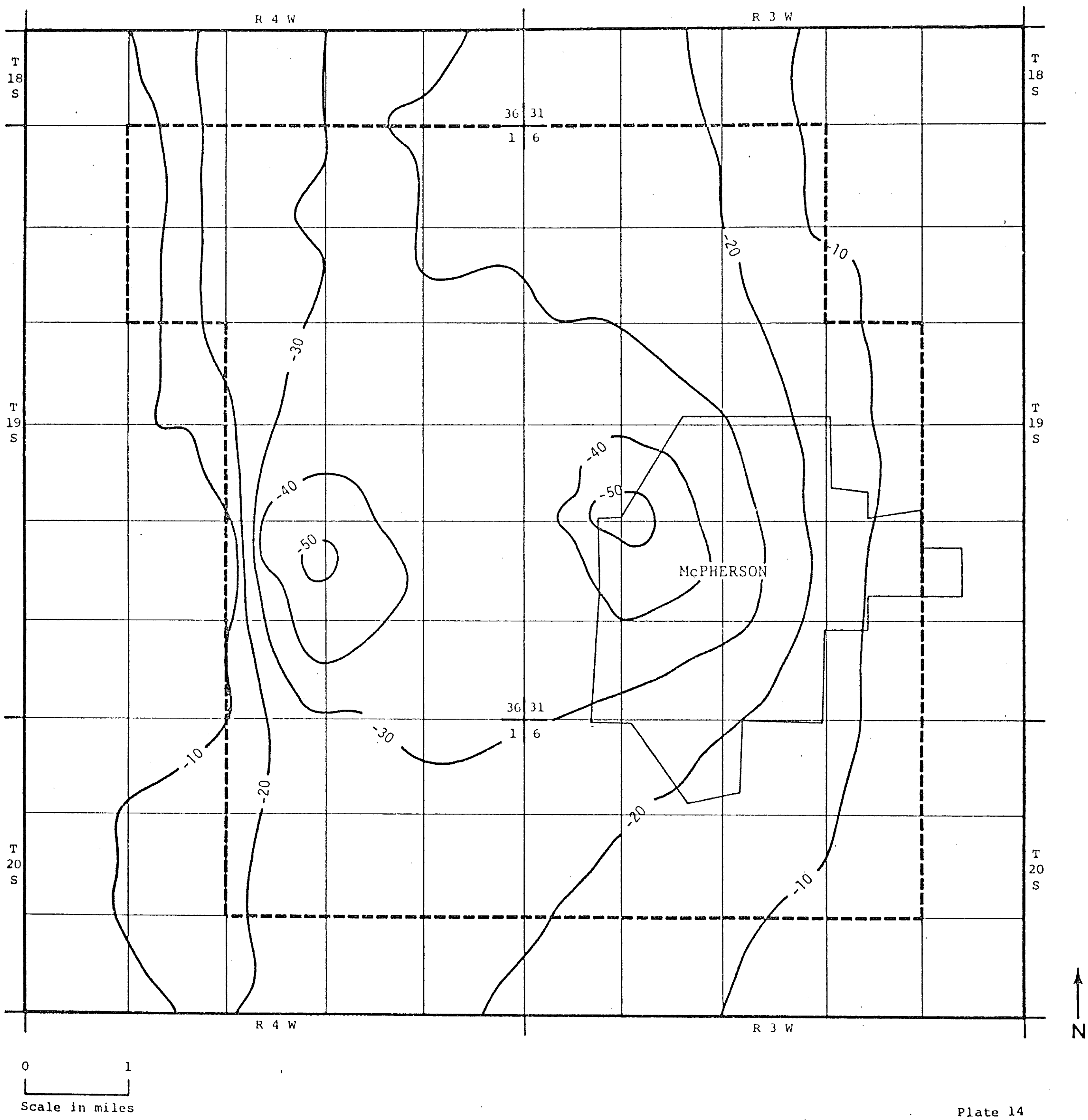

R 4 W
R 3 W
T 18 S
T 19 S
T 20 S
36 31
1 6
-10
-20
-30
-40
-50
McPHERSON
0 1
Scale in miles
N

Plate 14

Plate 15 -- Saturated thickness after 15 years using 1973-77 average annual reported pumpage of 16,263 AcFt/yr

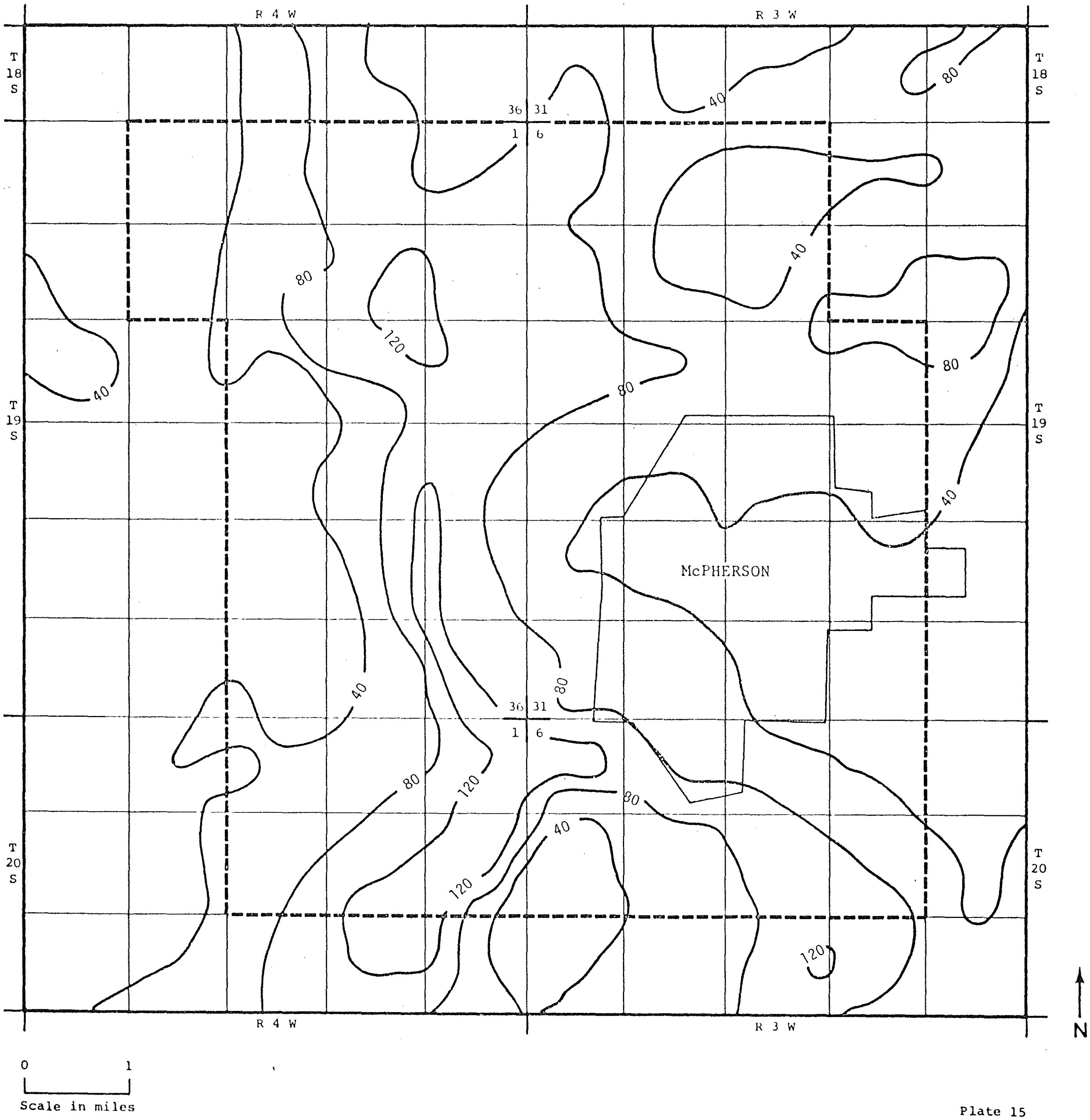

R 4 W
R 3 W
T 18 S
T 19 S
T 20 S
36 31
1 6
McPHERSON
40
80
120
N
0 1
Scale in miles

Plate 15

Plate 16 -- Water-level decline after 5 years using 90% of 1973-77
average annual reported pumpage -- 14,637 AcFt/yr

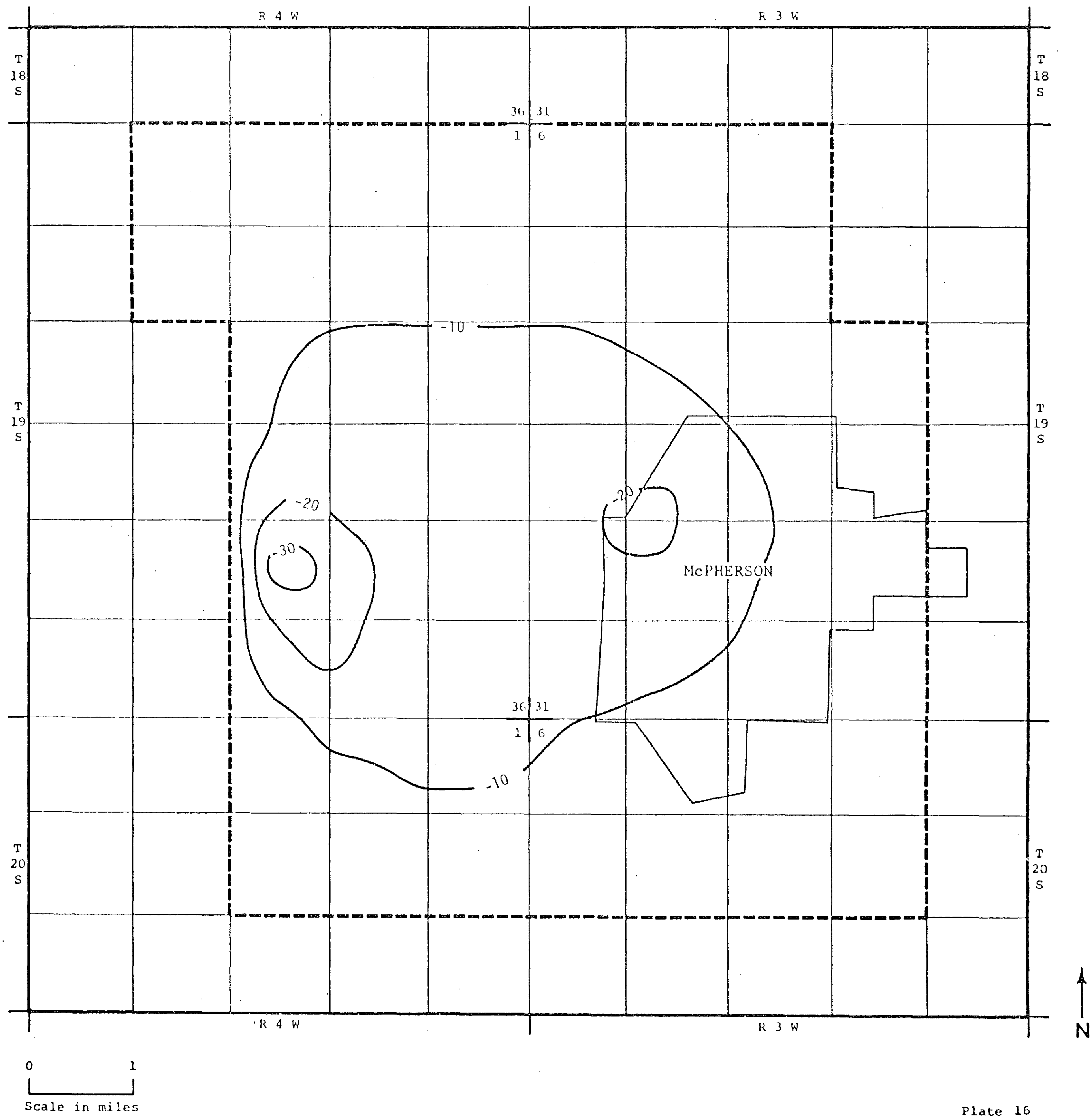

R 4 W
R 3 W
T 18 S
T 19 S
T 20 S
36 31
1 6
-10
-20
-30
McPHERSON
N
0 1
Scale in miles

Plate 16

Plate 17 -- Saturated thickness after 5 years using 90% of 1973-77 average annual reported pumpage -- 14,637 AcFt/yr

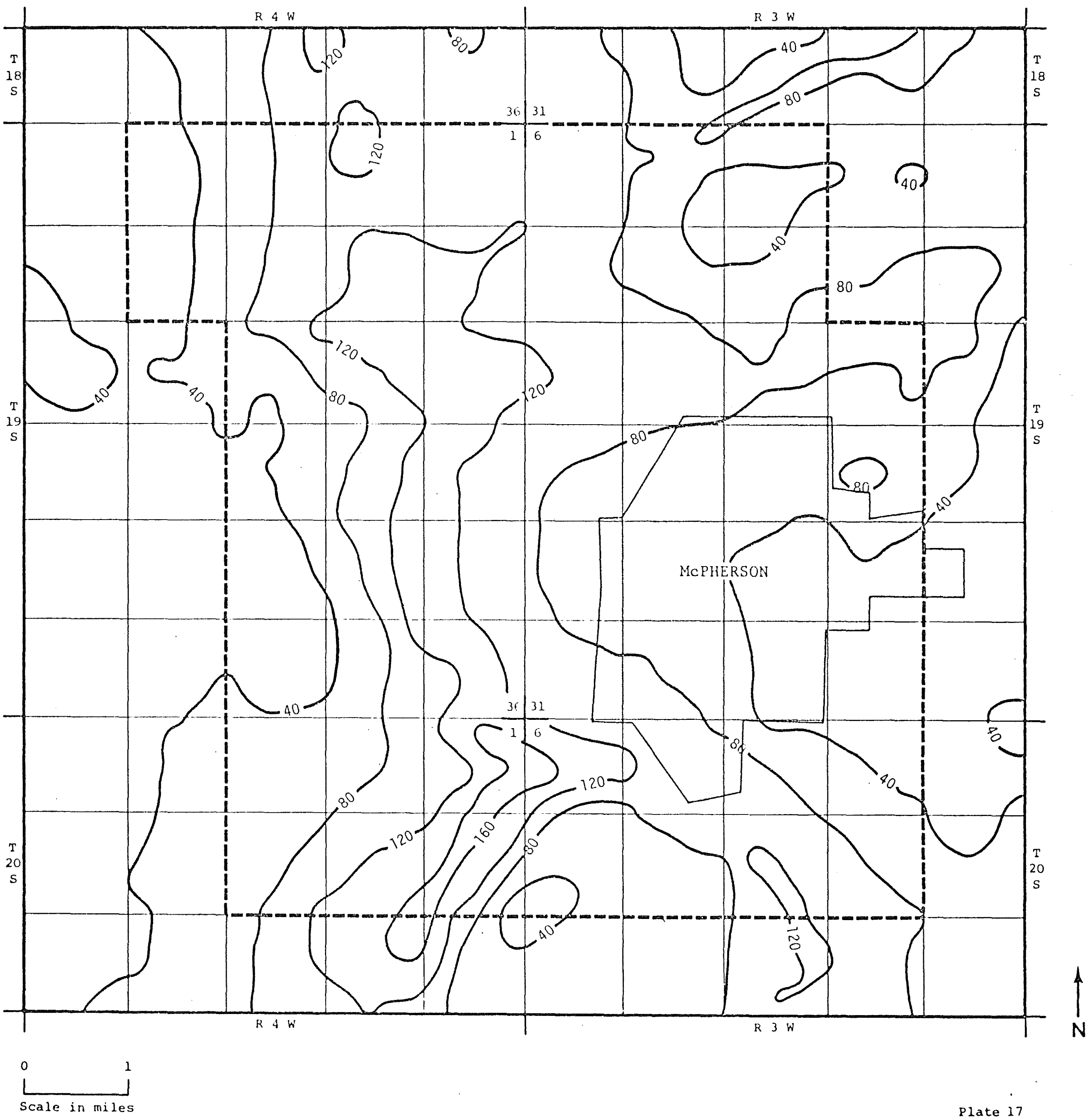

R 4 W
R 3 W
T 18 S
T 19 S
T 20 S
36 31
1 6
McPHERSON
120
80
40
160
N
0 1
Scale in miles

Plate 17

Plate 18 -- Water-level decline after 10 years using 90% of 1973-77 average annual reported pumpage -- 14,637 AcFt/yr

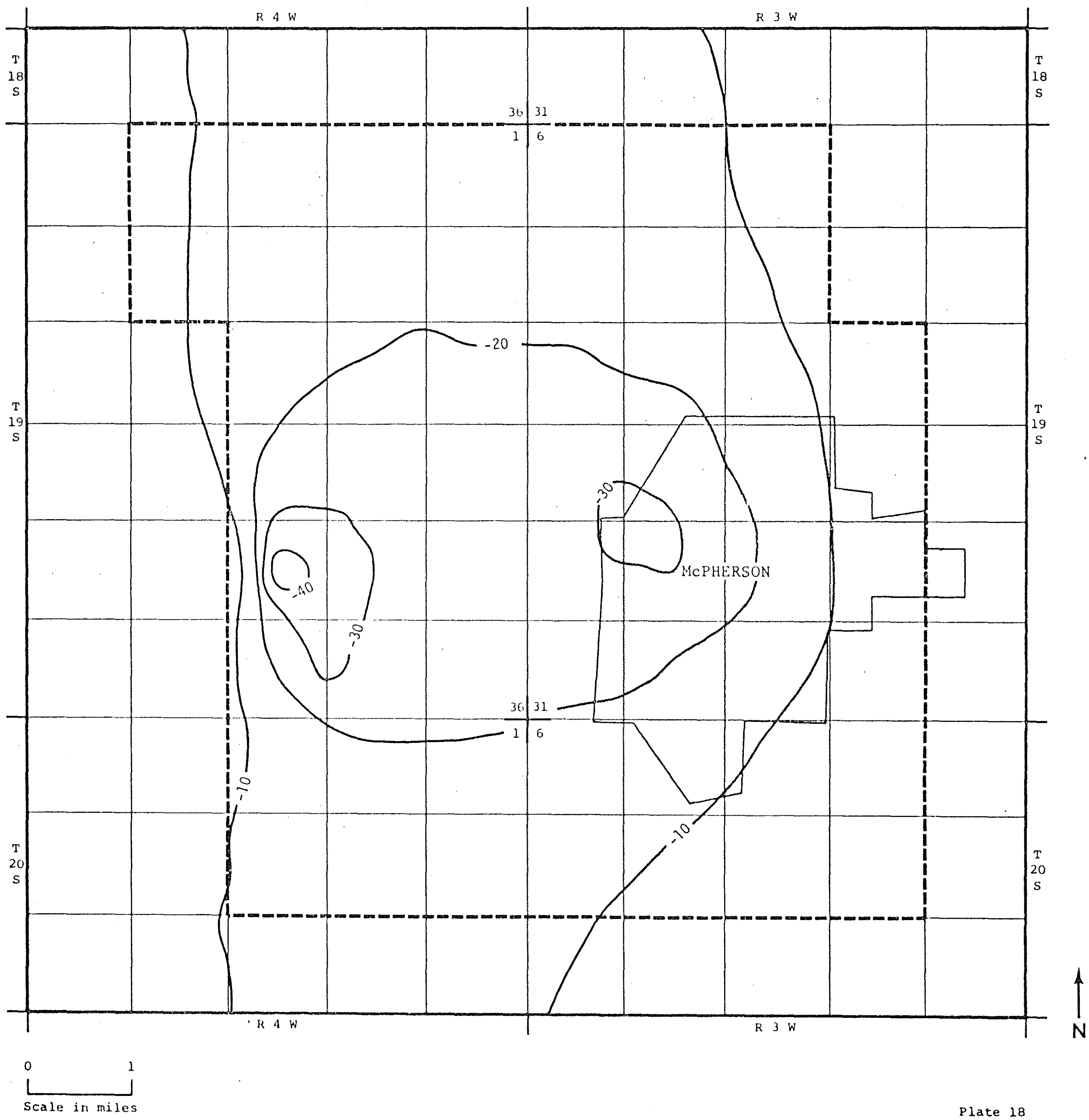

R 4 W
R 3 W
T 18 S
T 19 S
T 20 S
36 31
1 6
-20
-30
-40
-10
McPHERSON
N
0 1
Scale in miles

Plate 18

Plate 19 -- Saturated thickness after 10 years using 90% of 1973-77 average annual reported pumpage -- 14,637 AcFt/yr

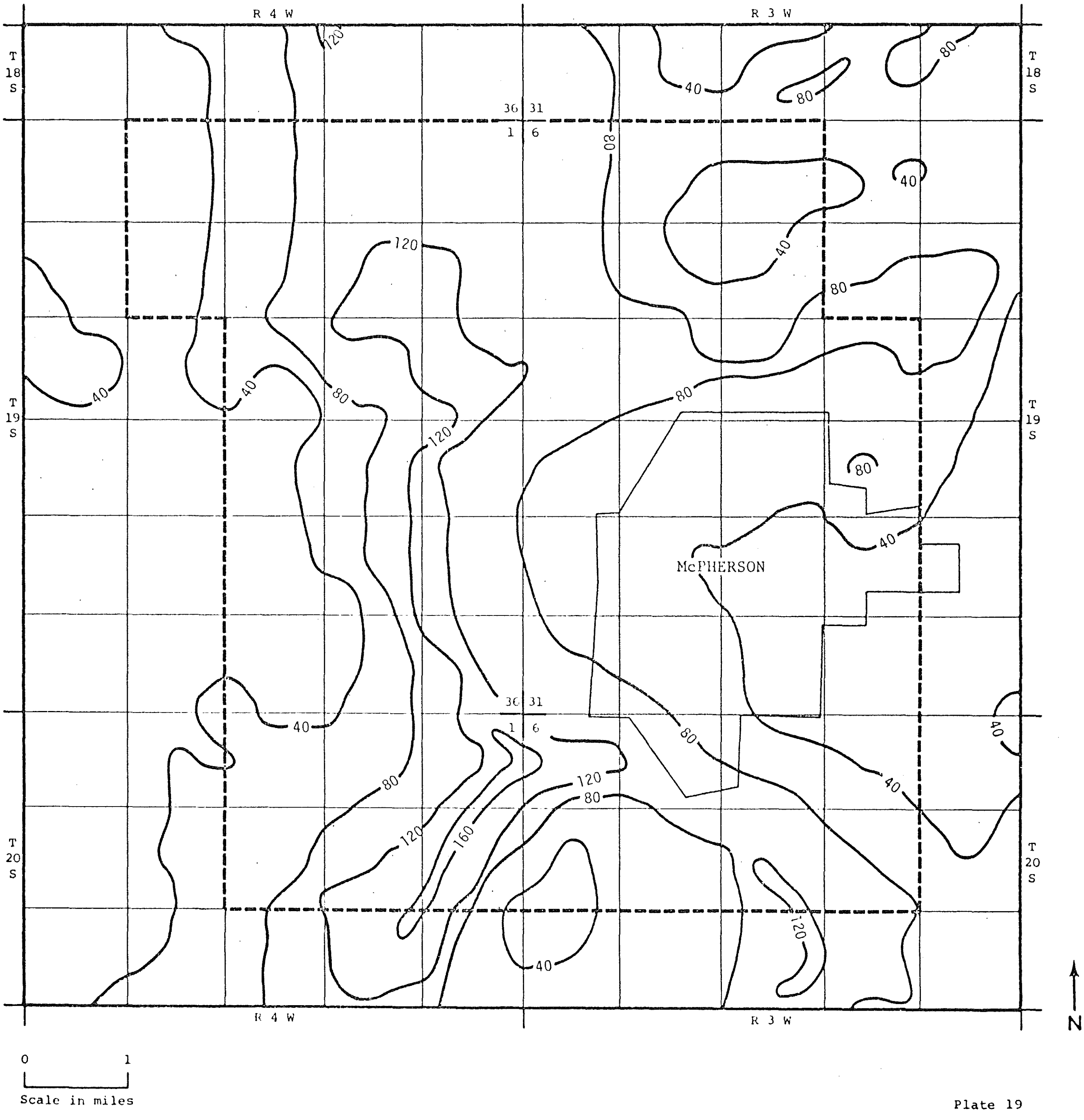

R 4 W
R 3 W
T 18 S
T 19 S
T 20 S
36 31
1 6
McPHERSON
40
80
120
160
N
0 1
Scale in miles

Plate 19

Plate 20 -- Water-level decline after 15 years using 90% of 1973-77
average annual reported pumpage -- 14,637 AcFt/yr

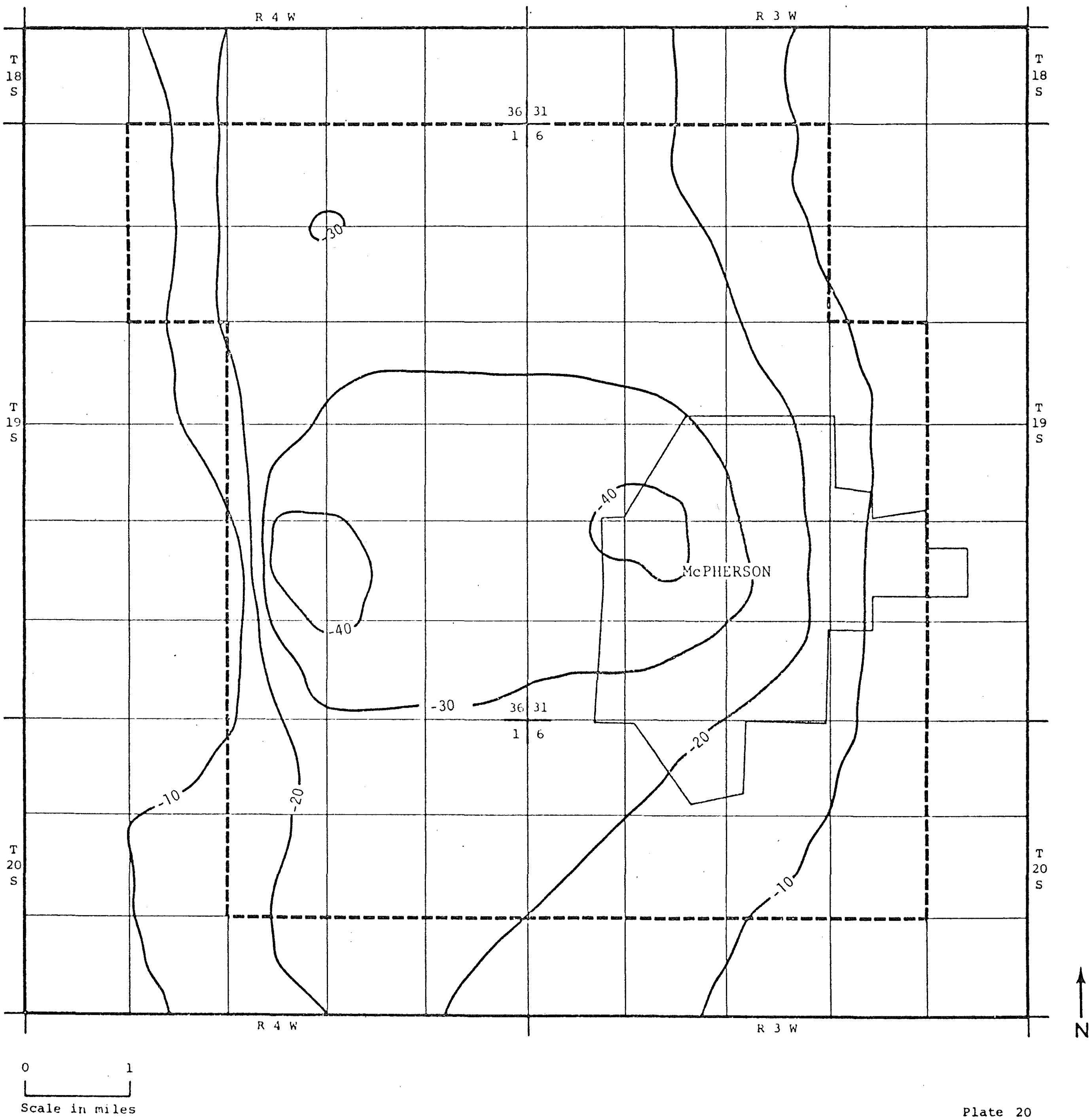

R 4 W
R 3 W
T 18 S
T 19 S
T 20 S
36
31
1
6
-30
-40
-40
McPHERSON
-30
36
31
1
6
-20
-10
-20
-10
R 4 W
R 3 W
N
0
1
Scale in miles

Plate 20

Plate 21 -- Saturated thickness after 15 years using 90% of 1973-77 average annual reported pumpage -- 14,637 AcFt/yr

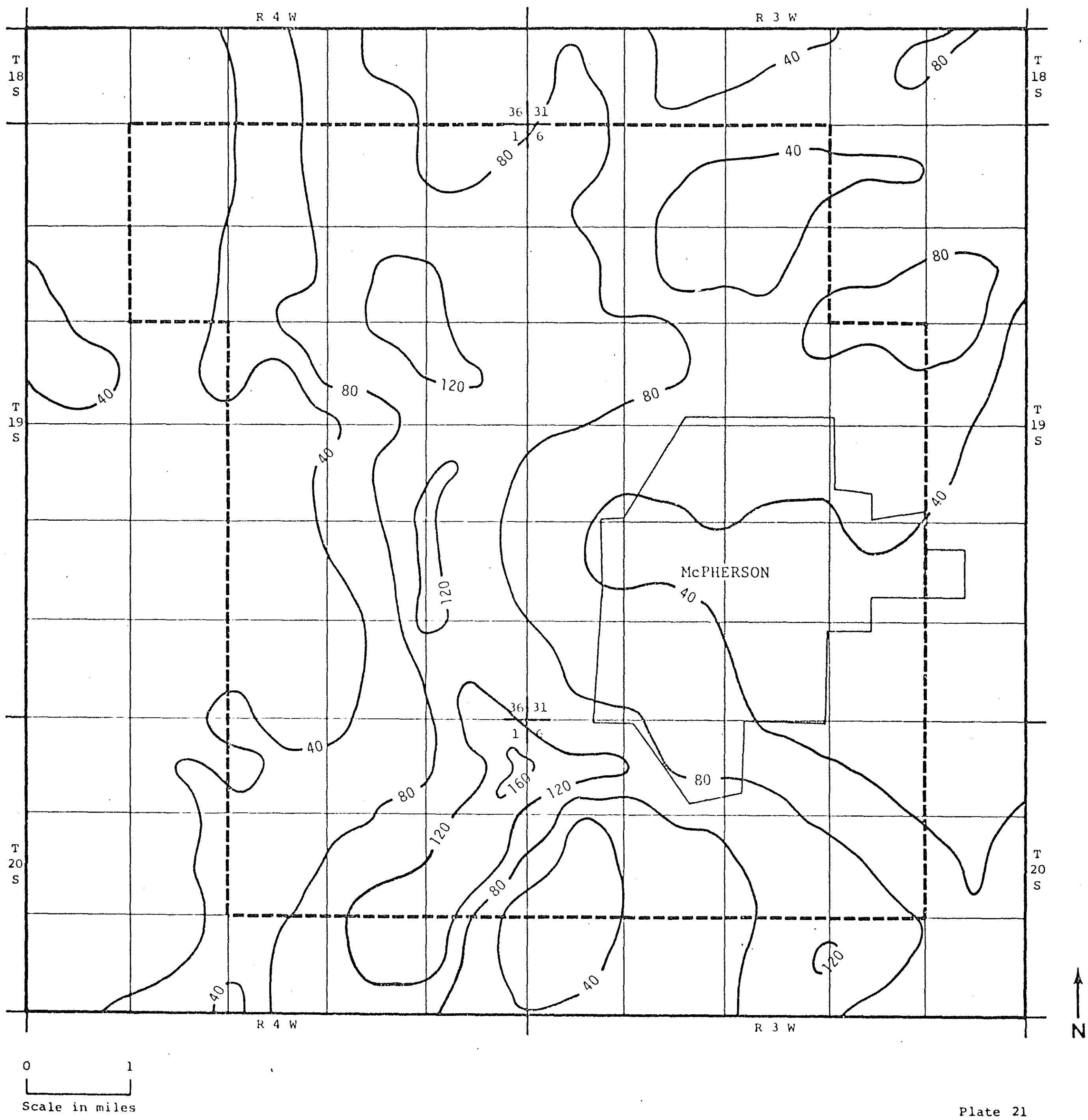
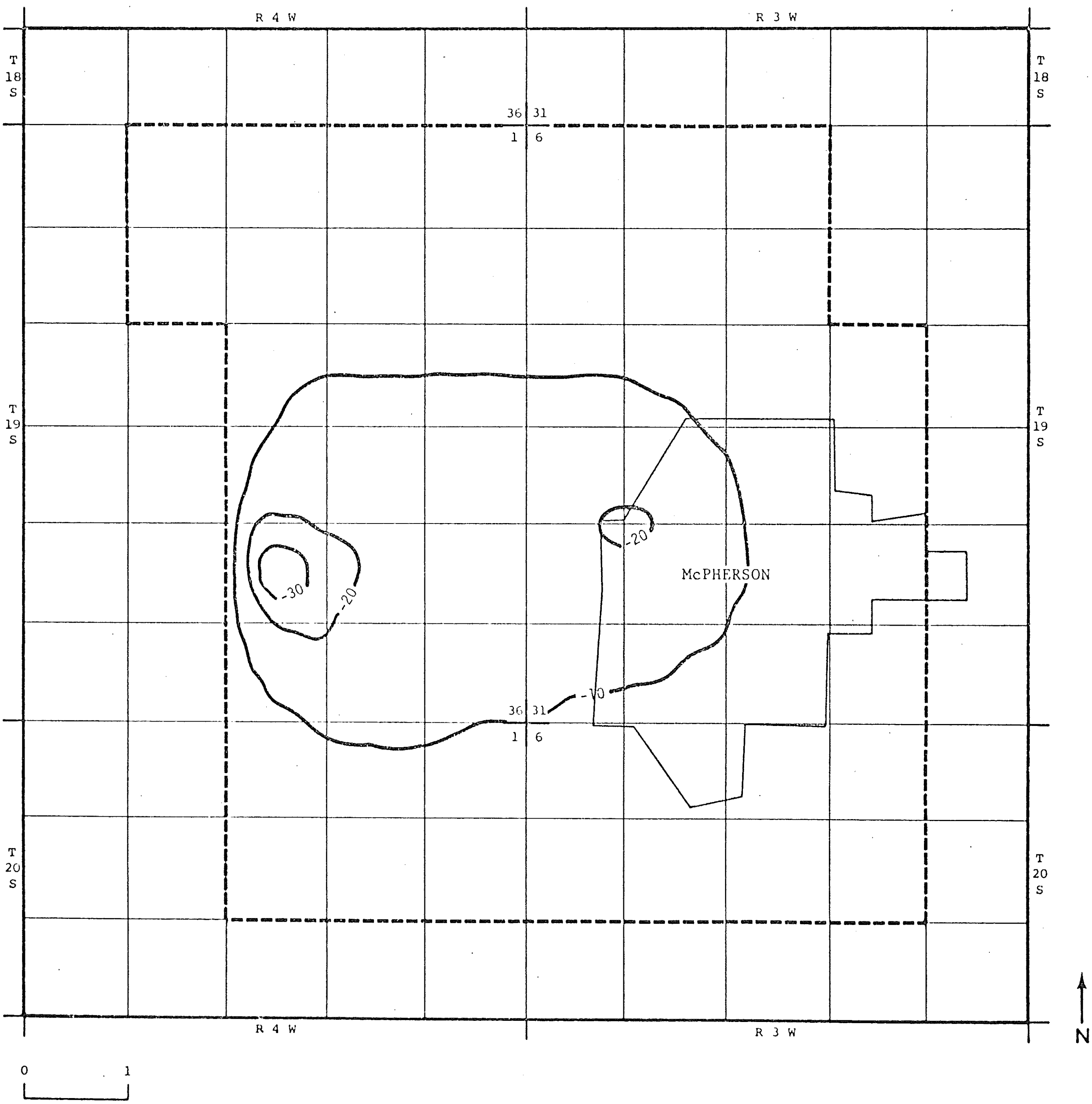

R 4 W
R 3 W
T 18 S
T 19 S
T 20 S
36 31
1 6
McPHERSON
40
80
120
160
N
0 1
Scale in miles

Plate 21

Plate 22 -- Water-level decline after 5 years using 80% of 1973-77 average annual reported pumpage -- 13,010 AcFt/yr



R 4 W
R 3 W
T 18 S
T 19 S
T 20 S
36
31
1
6
-30
-20
-20
-10
McPHERSON
N
0
1
Scale in miles

Plate 22

Plate 23 -- Saturated thickness after 5 years using 80% of 1973-77 average annual reported pumpage -- 13,010 AcFt/yr

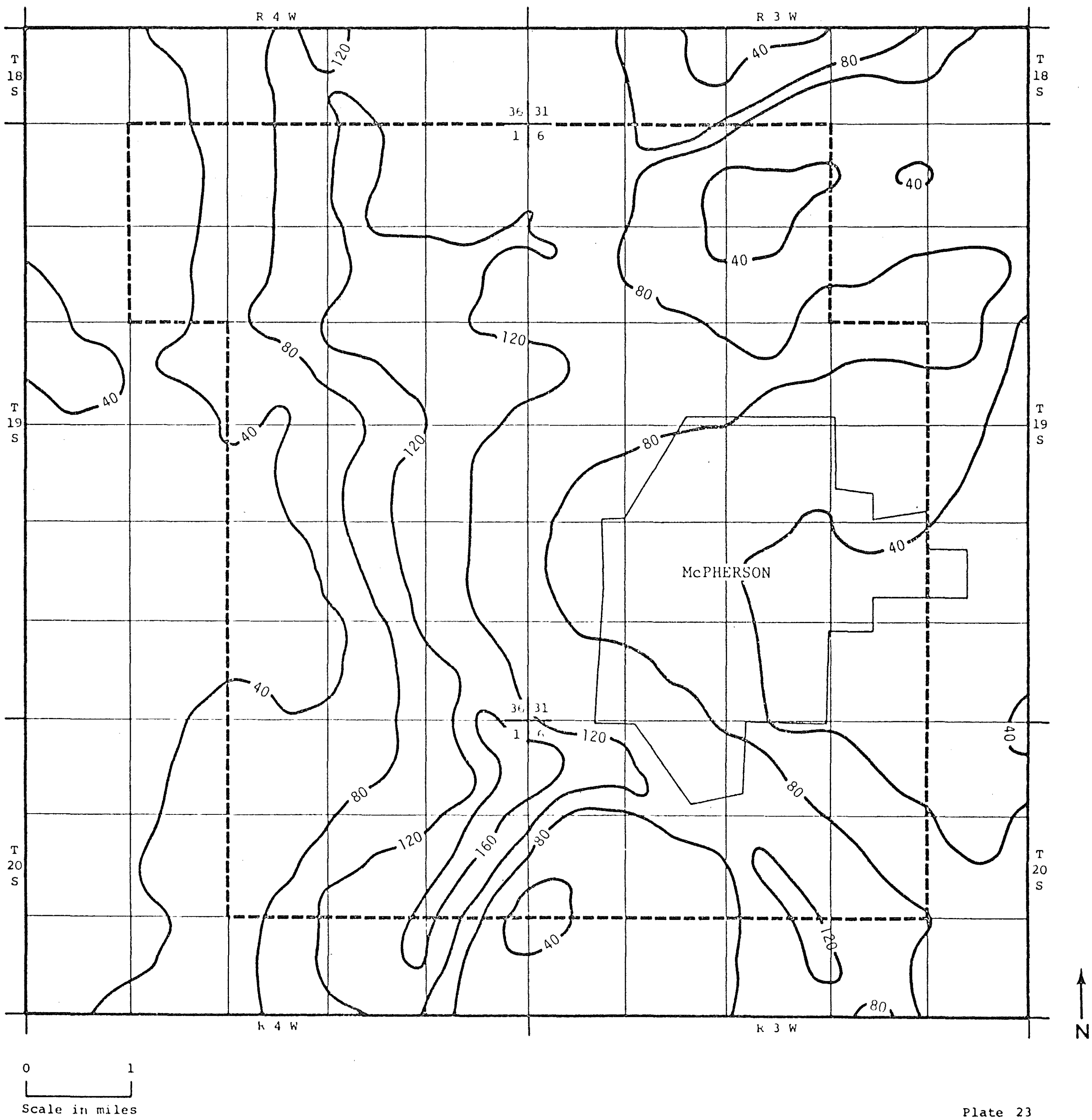

R 4 W
R 3 W
T 18 S
T 19 S
T 20 S
36 31
1 6
McPHERSON
40
80
120
160
N
0 1
Scale in miles

Plate 23

Plate 24 -- Water-level decline after 10 years using 80% of 1973-77 average annual reported pumpage -- 13,010 AcFt/yr

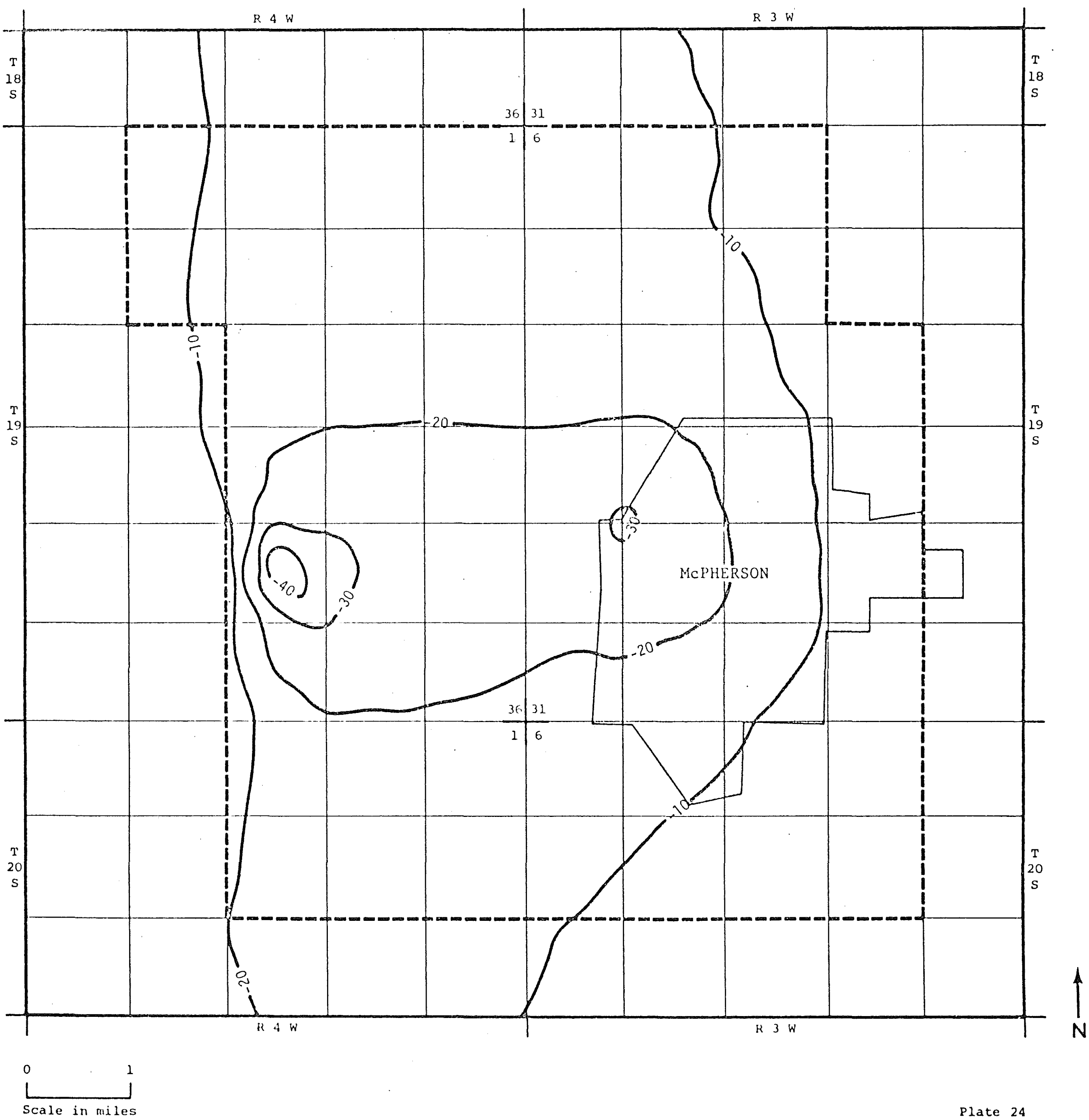

R 4 W
R 3 W
T 18 S
T 19 S
T 20 S
36
31
1
6
-10
-20
-30
-40
McPHERSON
N
0
1
Scale in miles

Plate 24

Plate 25 -- Saturated thickness after 10 years using 80% of 1973-77 average annual reported pumpage -- 13,010 AcFt/yr

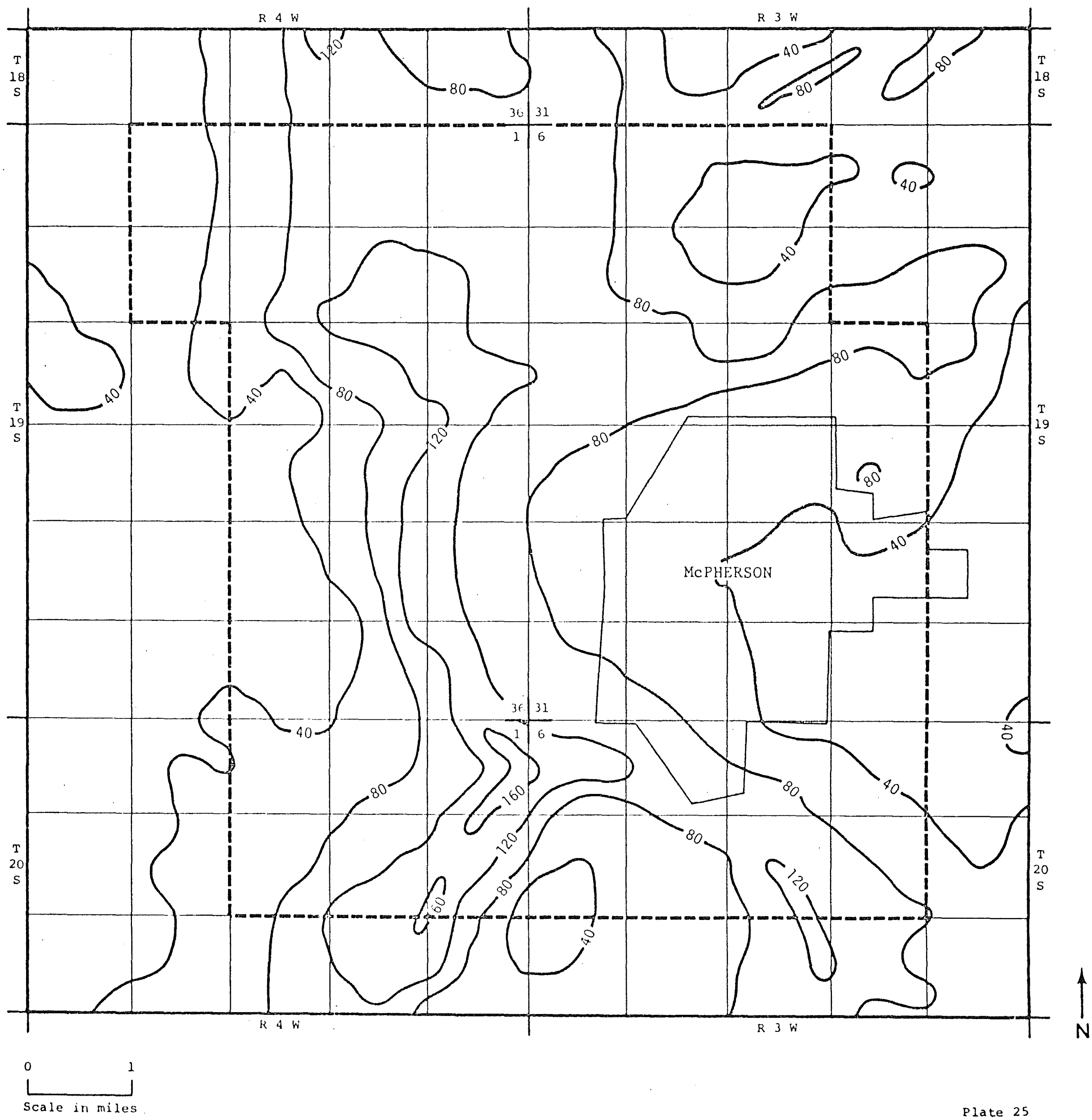
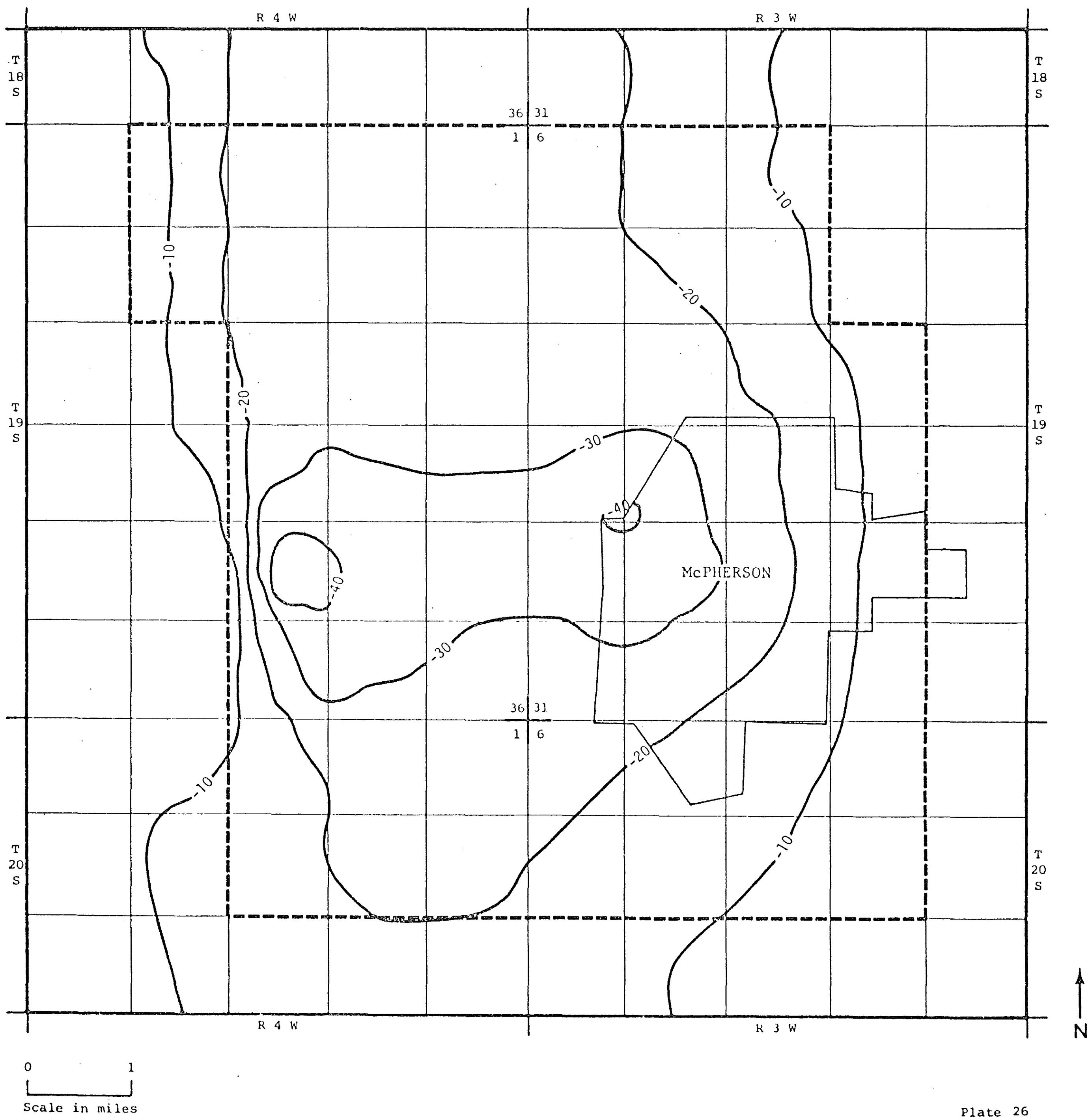

R 4 W
R 3 W
T 18 S
T 19 S
T 20 S
36 31
1 6
McPHERSON
40
80
120
160
N
0 1
Scale in miles

Plate 25

Plate 26 -- Water-level decline after 15 years using 80% of 1973-77
average annual reported pumpage -- 13,010 AcFt/yr



R 4 W
R 3 W
T 18 S
T 19 S
T 20 S
36 31
1 6
-10
-20
-30
-40
McPHERSON
N
0 1
Scale in miles

Plate 26

Plate 27 -- Saturated thickness after 15 years using 80% of 1973-77 average annual reported pumpage -- 13,010 AcFt/yr

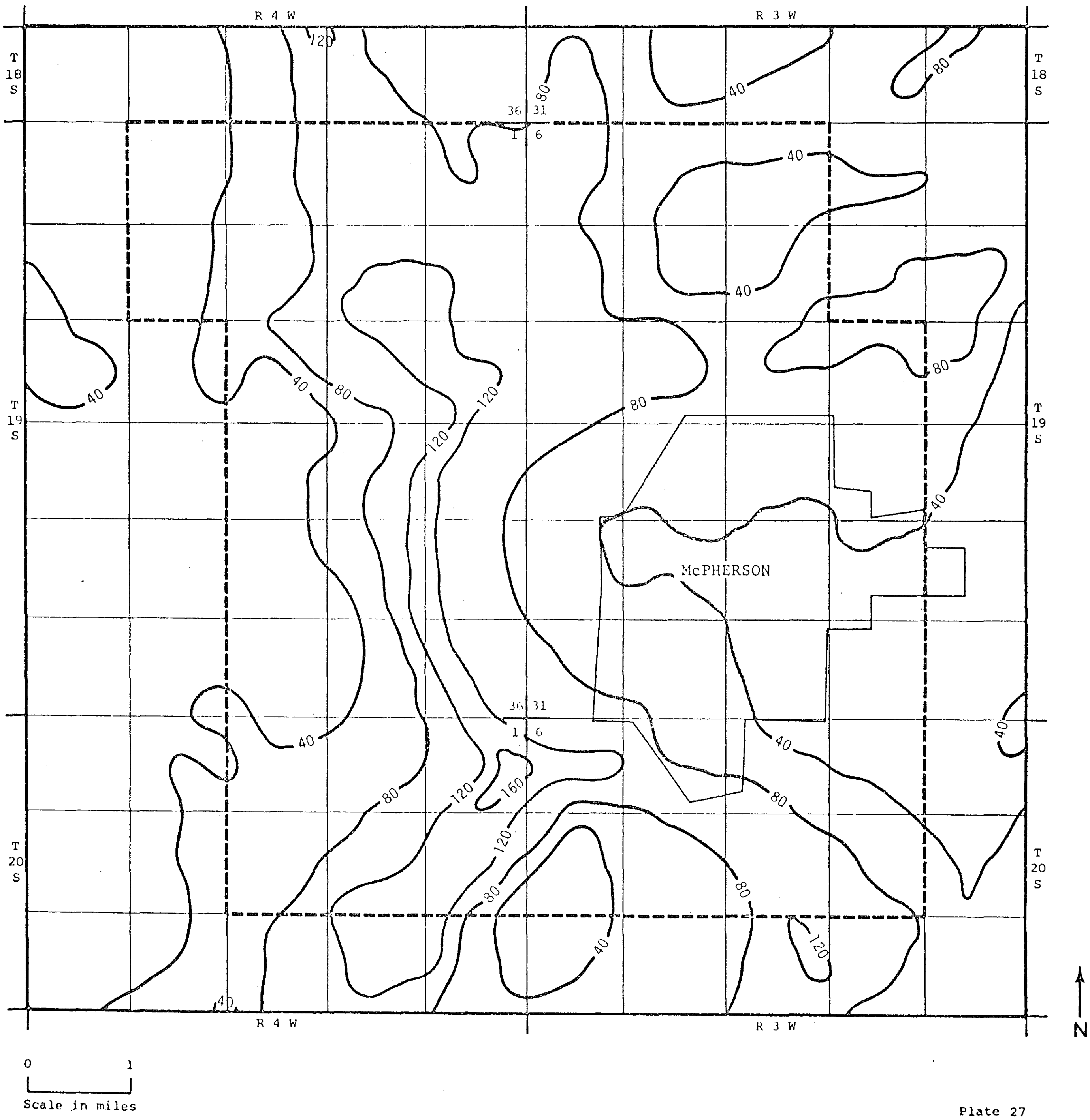

R 4 W
R 3 W
T
18
S
T
19
S
T
20
S
36 31
1 6
McPHERSON
40
80
120
160
30
N
0 1
Scale in miles

Plate 27