TEXAS DEPARTMENT OF WATER RESOURCES

REPORT 242

ANALYTICAL STUDY OF THE OGALLALA AQUIFER IN CARSON COUNTY, TEXAS

Projections of Saturated Thickness, Volume of Water in Storage, Pumpage Rates, Pumping Lifts, and Well Yields

By

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ANALYTICAL STUDY OF THE OGALLALA AQUIFER IN CARSON COUNTY, TEXAS

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CONCLUSIONS

The Ogallala aquifer in Carson County contained approximately 9.6 million acre-feet (11.8 km^3) of water in 1974. Historical pumpage has exceeded 150,000 acre-feet (0.18 km^3) annually, which is approximately six times the rate of natural recharge to the aquifer in the county. This overdraft is expected to continue, ultimately resulting in reduced well yields, reduced acreage irrigated, and reduced agricultural production.

There is a very uneven distribution of ground water in the county. Some areas have ample ground-water resources to support current usage through the year 2020; whereas, in other areas of the county, ground water is currently in short supply.

To obtain maximum benefits from the remaining ground-water resources, Carson County water users should implement all possible conservation measures so that the remaining ground-water supply is used in the most prudent manner possible and with the least amount of waste.

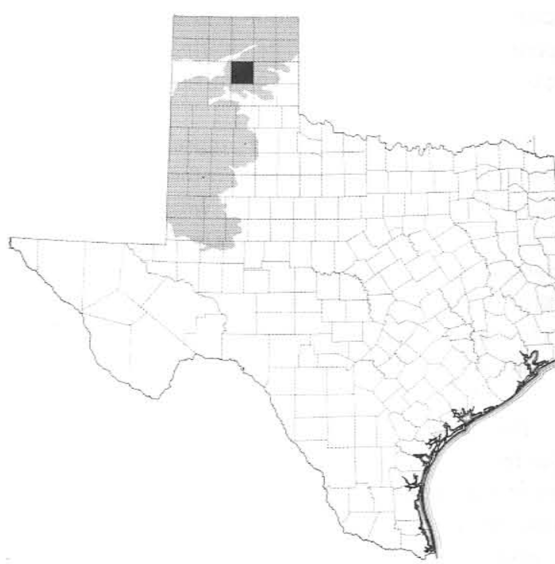
INTRODUCTION

Carson County is situated in the northeastern part of the Southern High Plains of Texas. Panhandle, the county seat, is located approximately 30 miles (48 km) northeast of Amarillo. The county contains an area of about 900 square miles (2,331 km^2) and has a population of approximately 6,200.

Carson County is one of the leading producers of agricultural crops in the State with a total farm income of over $35 million annually. Leading crops in the county are grain sorghums, wheat, and corn. Numerous agribusinesses, including livestock feeding and sale of irrigation equipment supplies, feed and seed, and fertilizer, also make significant contributions to the total county income.

Ground water is extremely important to the economy of the county inasmuch as most of the crops are irrigated with ground water. Additionally, the water used by rural residents, municipalities, and local industries is mostly ground water.

The principal source of fresh ground water in the county is the Ogallala aquifer. During the past three decades, the withdrawal of ground water has greatly exceeded the natural recharge to the aquifer. If this overdraft continues, the aquifer ultimately will be depleted to the point that it may not be economically feasible to produce water for irrigation.



Location of Carson County and Extent of the Ogallala Aquifer in Texas

This is one of numerous planned county studies covering the declining ground-water resource of the Ogallala aquifer in the High Plains of Texas. The report contains maps, charts, and tabulations which reflect estimates of the volume of water in storage in the Ogallala aquifer in Carson County and the projected depletion of this water supply by decade periods through the year 2020. The report also contains estimates of pumpage, pumping lifts, and other data related to current and future water use in the county. However, the report does not attempt to project that portion of the volume of water in underground storage which may be ultimately recoverable.

PURPOSE AND SCOPE OF STUDY

This study resulted from an immediate need for information to illustrate to the High Plains water users that the ground-water supply is being depleted. It is hoped that this study will help persuade the water users to implement all possible conservation measures, so that the remaining ground-water supply will be used in the most prudent manner possible and with the least amount of waste.

The study was also conducted to provide information to local, State, and federal officials for their use in implementing plans to alleviate the water-shortage problem in the High Plains of Texas.

These immediate needs for current information have resulted in a concerted effort by the Texas Department of Water Resources to utilize high-speed computers to conduct evaluation and projection studies of ground-water resources. The results of one of these computer studies is contained in this report.

This report does not represent a detailed ground-water study of the county; rather, the report was prepared using only those data which were readily available in the files of the Texas Department of Water Resources. Information provided for 1974 is considered reliable; however, the projections of future conditions should be used only as a guide to reasonable expectations.

This study represents a new approach by the Department of Water Resources in making and presenting appraisals of ground-water resources. Consequently, a detailed explanation of the methods and assumptions used in the study is included. A complete set of tabulations and illustrations resulting from this study is presented at the end of the report.

The illustrations were prepared to answer four questions believed to be of prime importance to the Carson County landowners and water users. These questions, and methods by which a set of answers can be obtained from the illustrations, are as follows:

1. Question: How much water is in storage under any given tract of land in the county and what is expected to happen to this water in the future?

   Answer: First, determine the approximate location of the tract on the most current (1974) map of saturated thickness. Read the value of the contour line at this location (if midway between two contour lines, take an average of the two). This thickness value can then be converted to the approximate volume of water in storage, in acre-feet per surface acre, by multiplying it by the coefficient of storage of 0.15, or 15 percent. To obtain estimates of what can be expected in the future, the same procedure can be followed by using the maps which illustrate projected saturated thickness in the years 1980, 1990, 2000, 2010, and 2020.

2. Question: What can be expected to happen to well yields if the saturated thickness diminishes as illustrated by the maps?

   Answer: Well yields are expected to decline as the aquifer thins; therefore, a map of estimated well yields has been prepared for each year of the study. The landowner need only find the approximate location of his property on the well-yield map that applies to the year in question and read the well-yield estimates directly from the map.

3. Question: With energy cost increasing, pumping lifts (pumping levels) are becoming more and more important. What are the estimates of current pumping lifts and what are they expected to be in the future?

   Answer: Contour maps depicting estimated pumping lifts have been prepared for each year of the study. These maps are contoured in feet below land surface. The landowner need only find the approximate location of his property on the map that applies to the year in question to read the pumping-lift estimates.

4. Question: If an all-out effort is made to conserve ground-water resources, how can landowners and water users determine how they are doing compared to the projections in the study?

   Answer: Using the maps that show rates of water-level declines, the landowners and water users can determine what the changes in water levels are in their area and what they are projected to be in the future. This can be accomplished by finding the approximate location of their property on the map pertaining to the year in question and by reading the estimates of water-level changes which are recorded in feet. To determine how he is doing from year to year, the landowner or water user can make measurements of depth to water in his own wells or obtain copies of measurements made by the Department or the ground-water district for his area. These measurements can then be compared to the projected values on the map nearest to the year of interest to obtain an estimate of the effectiveness of the conservation efforts.

NATURE OF THE OGALLALA AQUIFER

Because thorough understanding of the Ogallala aquifer is not necessary for the water user, the following discussion of aquifer geology and hydrology is rather general. Readers interested in pursuing the subject in more detail may do so from the numerous reports which have been published on the Ogallala. Most of these publications are included in the list of selected references of this report.

General Geology

Fresh ground water in Carson County is obtained principally from the Ogallala Formation of Pliocene age. Water in the Ogallala Formation is unconfined and is contained in the pore spaces of unconsolidated or partly consolidated sediments.

The Ogallala Formation principally consists of interfingering bodies of fine to coarse sand, gravel, silt, and clay—material eroded from the Rocky Mountains which was carried southeastward and deposited by streams. The earliest sediments, mainly gravel and coarse sand, filled the valleys cut in the pre-Ogallala surface. Pebbles and cobbles of quartz, quartzite, and chert are typical of these early sediments. After filling the valleys, deposition continued until the entire area that is now the Texas High Plains was covered by sediments from the shifting streams.

The upper part of the formation contains several hard, caliche-cemented, erosionally resistant beds called the "caprock." A wind-blown cover of fine silt, sand, and soil overlies the caprock.

The Ogallala deposits overlie rocks of Triassic and Permian ages. These rocks, principally red sandy clays and red shales, serve as a nearly impermeable floor for the aquifer. On a broad scale, the erosional surface at the top of the Triassic and Permian rocks dips gently (about 10 feet per mile [2 m/km]) toward the southeast, similar to the slope of the land surface. In general, however, this pre-Ogallala surface had greater relief than the present land surface. Low hills and wide valleys which contain deep, narrow stream channels are typical features of the Triassic and Permian erosional surface. Because the Ogallala was deposited on top of this irregular surface, the formation is very thin in some areas and very thick in others. Often this contrast occurs in relatively short distances.

The Canadian River has cut deeply through the Ogallala Formation in the northern part of the Texas High Plains area. The valley effectively separates the formation geographically into two units having little hydraulic interconnection. Erosion has also removed the Ogallala from much of its former extent to the east, and to the west in New Mexico. As a result, the Southern High Plains, although relatively flat, stands in high relief and is hydraulically independent of adjacent areas. For this reason, coupled with the scarcity of local rainfall, water that is being withdrawn from the aquifer cannot be replaced quickly by natural recharge and is in effect being mined.

Storage Properties

The coefficient of storage of an aquifer is defined as the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. In water-table aquifers such as the Ogallala, the coefficient of storage is nearly equal to the specific yield, which is defined as the quantity of water that a formation will yield under the force of gravity, if it is first saturated and then allowed to drain, the quantity of water being expressed as a percentage of the volume of the material drained.

A coefficient of storage of 15 percent has been selected for use in this study based on past studies and the results of numerous aquifer tests published in Texas Water Development Board Report 98 (Myers, 1969). The following chart shows the volumes of water corresponding to various amounts of aquifer saturated thickness, based on a storage coefficient of 15 percent. These are the approximate amounts of water that would drain from the aquifer material by gravity flow if the entire saturated thickness could be drained.

SATURATED THICKNESS (feet)	VOLUME OF WATER IN STORAGE (acre-feet, per surface acre)
25	3.75
50	7.50
75	11.25
100	15.00
150	22.50
200	30.00
250	37.50
300	45.00
400	60.00
500	75.00

Natural Recharge and Irrigation Recirculation

Recharge is the addition of water to an aquifer by either natural or artificial means. Natural recharge results chiefly from infiltration of precipitation. The Ogallala aquifer in Carson County receives natural recharge by precipitation that falls within the county and in adjoining areas.

The amount and rate of natural recharge from precipitation depend on the amount, distribution, and intensity of the precipitation; the amount of moisture in the soil when the rain or snowmelt begins; and the temperature, vegetative cover, and permeability of the materials at the site of infiltration. Because of the wide variations in these factors, it is difficult to estimate the amount of natural recharge to the ground-water reservoir. Estimates of annual natural recharge to the Ogallala aquifer made by Barnes and others (1949, p. 26-27) indicate only a fraction of an inch. Theis (1937, p. 546-568) suggested less than half an inch, and Havens (1966, p. F1), in a study of the Ogallala in New Mexico, indicated about 0.8 inch (2 cm) per year.

The authors of this report believe that recharge from precipitation may be more than these earlier estimates, due to changes in the soil and land surface that have accompanied large-scale irrigation development in the county. Some of the farming practices which are believed to have altered the recharge rate are: clearing the land of deep-rooted native vegetation; deep plowing of fields, which eliminates compacted zones in the soil (locally called "hard pans"), and the plowing of playa lake bottoms and sides; bench leveling, contour farming, and terracing; maintaining a generally higher soil moisture condition by application of irrigation water prior to large rains; and increasing the humus level in the root zone by plowing under a large amount of foliage from crops grown under irrigation.

Obtaining a reliable estimate of the present recharge rate is further complicated by the consideration which must be given to irrigation recirculation. A substantial portion of the water pumped from the Ogallala for irrigation percolates back to the aquifer. This does not constitute an additional supply of water, but reduces the net depletion of the aquifer. As with natural recharge, many factors are involved in making estimates of recirculation. Some of these factors are the rate, amount, and type of irrigation application; the soil type and the infiltration rate of the soil profile in the root zone; the amount of moisture in the soil prior to the irrigation application; the type of crop being grown, its root development, and its moisture extraction pattern; and the climatic conditions during and following the irrigation application. Tentative estimates of the actual amounts of recharge and irrigation recirculation in Carson County will be found in a subsequent section on "Calculating Pumpage."

PROCEDURES USED TO OBTAIN PROJECTIONS

Hydrologic Data Base

The Texas Department of Water Resources and the Panhandle Ground Water Conservation District No. 3 cooperatively maintain a network of water level observation wells in Carson County. Records from these wells provided the principal data base used in this study. This data base was supplemented in some areas with records from water well drillers' logs collected by both the District and the Department.

The data base included: (1) measurements of the depth to water below land surface, which have been made annually in the wells in the observation network; (2) the dates these measurements were made; and (3) the depth from land surface to the base of the Ogallala aquifer (In many cases, this was identical to the well depth). To facilitate automatic data processing with modern, high-speed computers, the data base also included a unique number for each well and the geographical coordinates of each well location.

Wells chosen from the data base for use in obtaining projections of future conditions were those in which depth to the base of the aquifer could be determined or estimated, and those needed to provide spaced data coverage in the county. Locations of the wells that were selected and used for control are shown on the various maps in this report.

Projecting the Depletion of Saturated Thickness

The water-use patterns between 1960 and 1972 as reflected in the changes in water levels in wells measured in the High Plains of Texas were used as the principal data source for developing an aquifer depletion schedule. The depletion schedule generally reflects average precipitation and precipitation distribution in the area for the duration of the study period. Additionally, in developing and applying the depletion schedule, adjustments through time were made to reflect the effects of depletion of the aquifer on its ability to yield water. That is, as the aquifer's saturated thickness decreases, its ability to yield water to wells is reduced, the well yields decline, less water is pumped, and there results a lessened rate of further aquifer depletion.

The aquifer's hydraulics are such that if a well penetrates the total saturated section and the pump is sized to produce the maximum the aquifer will yield, the well yield will decline at a disproportionately greater rate than the reduction in saturated thickness. Actually, the remaining well yield expressed as a percentage of former yield will be only about half of the remaining saturated thickness expressed as a percentage of former thickness. For example, a well with 60 feet (18.3 m) of saturated section and a maximum yield of 900 gallons per minute (56.8 l/s) will probably yield only 225 gallons per minute (14.2 l/s) when the saturated section is reduced to 30 feet (9.1 m).

The depletion schedule for Carson and surrounding counties was developed in the following manner:

1. The records for all water level observation wells for the years 1960 through 1972 in Armstrong, Carson, Donley, Gray, Oldham, Potter, Randall, and Wheeler Counties were separated from the master file. These counties have similar soil types, cropping patterns, depths to water, saturated thickness, and climatic conditions.

2. These well records were then sorted into groups according to the saturated thickness in each well as of 1966 (the middle year). Each group included records of all wells in a 20-foot (6.1-meter) range of saturated thickness. (Ranges are shown in the tabulation below.)

3. The average decline in water level was calculated for each year for each well group, and these decline values were adjusted to remove the effects of each year's deviation from long-term average precipitation.

4. The average annual decline in water level for the total period (1960-72) was calculated for each well group, incorporating the adjustments for departure from average precipitation.

From the foregoing procedure, the following depletion schedule was developed (no depletion was allowed for areas with 10 feet or less of saturated thickness):

RANGE OF SATURATED THICKNESS (feet)	AVERAGE ANNUAL WATER-LEVEL DECLINE, 1960-72 (feet)
0 to 10	0.00
10 to 20	.40
20 to 40	.85
40 to 60	1.47
60 to 80	1.60
80 to 100	1.80
100 to 120	2.07
120 to 140	2.56
140 to 160	2.50
160 to 180	2.47
180 to 200	3.04
200 to 220	2.97
220 to 240	2.87
240 to 260	3.49
260 to 280	4.05

Based on this depletion schedule, a computer program was written to calculate future saturated thickness at individual well sites. The following problem is presented to show the computational procedures used.

Problem: A well has a saturated thickness of 110 feet in 1974 and one wants to project what the saturated thickness will be in this well for every year to the year 2020.

Factors:

1. The beginning saturated thickness is 110 feet in 1974.
2. The average decline rate is 2.07 feet per year for wells with saturated sections of 100 to 120 feet.

3. The average decline rate is 1.80 feet per year for wells with saturated sections of 80 to 100 feet.

4. The average decline rate is 1.60 feet per year for wells with saturated sections of 60 to 80 feet.

5. The average decline rate is 1.47 feet per year for wells with saturated sections of 40 to 60 feet.

6. The average decline rate is 0.85 foot per year for wells with saturated sections of 20 to 40 feet.

7. The average decline rate is 0.40 foot per year for wells with saturated sections of 10 to 20 feet.

8. The time interval is 1974 through 2020.

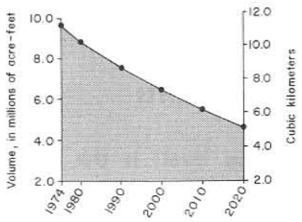
The projected saturated thicknesses in the subject well are calculated and shown in the following table:

YEAR	SATURATED THICKNESS, BEGINNING OF YEAR (feet)	AVERAGE DECLINE RATE (feet)	SATURATED THICKNESS, END OF YEAR (feet)
1974	110.00	2.07	107.93
1975	107.93	2.07	105.86
1976	105.86	2.07	103.79
1977	103.79	2.07	101.72
1978	101.72	2.07	99.65
1979	99.65	1.80	97.85
1980	97.85	1.80	96.05
1981	96.05	1.80	94.25
1982	94.25	1.80	92.45
1983	92.45	1.80	90.65
1984	90.65	1.80	88.85
1985	88.85	1.80	87.05
1986	87.05	1.80	85.25
1987	85.25	1.80	83.45
1988	83.45	1.80	81.65
1989	81.65	1.80	79.85
1990	79.85	1.60	78.25
1991	78.25	1.60	76.65
1992	76.65	1.60	75.05
1993	75.05	1.60	73.45
1994	73.45	1.60	71.85
1995	71.85	1.60	70.25
1996	70.25	1.60	68.65
1997	68.65	1.60	67.05
1998	67.05	1.60	65.45
1999	65.45	1.60	63.85
2000	63.85	1.60	62.25
2001	62.25	1.60	60.65
2002	60.65	1.60	59.05
2003	59.05	1.47	57.58
2004	57.58	1.47	56.11
2005	56.11	1.47	54.64
2006	54.64	1.47	53.17
2007	53.17	1.47	51.70
2008	51.70	1.47	50.23
2009	50.23	1.47	48.76
2010	48.76	1.47	47.29
2011	47.29	1.47	45.82
2012	45.82	1.47	44.35
2013	44.35	1.47	42.88
2014	42.88	1.47	41.41
2015	41.41	1.47	39.94
2016	39.94	.85	39.09
2017	39.09	.85	38.24
2018	38.24	.85	37.39
2019	37.39	.85	36.54
2020	36.54	.85	35.69

Similar computations were made for each of the selected data-control wells in Carson County, and the saturated-thickness values for 1974, 1980, 1990, 2000, 2010, and 2020 were extracted from this data set for use in further calculations and mapping.

Mapping Saturated Thickness, and Calculating Volume of Water in Storage

To obtain estimates of the volume of water in storage in the Ogallala aquifer, an electronic digital computer was used to construct maps which reflect the saturated thickness of the aquifer for those years included in the study. These maps were then refined by the computer to reflect the number of acres corresponding to each range of saturated thickness. The number of acres for each range was multiplied by the saturated thickness in feet for that range and then by the coefficient of storage (0.15 or 15 percent), to yield an estimate of the volume of water in storage in each saturated-thickness range. Totaling these volumes produced an estimate of the volume of water in storage in the county. The current (1974) and projected volume estimates are shown in the following graph:



Year	Acre-Feet
1974	9,640,000
1980	8,820,000
1990	7,540,000
2000	6,420,000
2010	5,430,000
2020	4,540,000

Estimated Volume of Water in Storage

Preparing a data base and writing the necessary programs for the computer to use in constructing the saturated-thickness maps and in making the necessary calculations is time consuming; however, once the data base is prepared and programs written, the computer can perform in a few hours calculations that would have required many years of manual effort.

A generalized description of the methodology used in mapping and in computing water volume follows: A base map with a scale of 1 inch equals 2 miles (1:125,000) was selected to prepare data for computer processing. All data points (observation wells) were plotted on these base maps by hand and assigned identifying numbers. A machine called a *digitizer* was then used to translate these mapped location data (well locations, county boundaries, etc.) into information processible by the computer. To accomplish this, a latitude and longitude coordinate was recorded on each base map as a central reference point, and all data points and county boundaries were then digitized; that is, measurements were made by the digitizer to reference these data points and boundaries to the initial latitude and longitude coordinate. Then the digitized information was processed by the computer and the maps were re-created by a computer-driven plotter. The computer-plotted image maps were ultimately checked against the hand-constructed maps to verify that the data were plotted accurately.

The assignment of a unique number to each data point (observation well) on the base maps made it possible to machine process the data related to these points and to plot these data back on the maps at the proper location.

To compute the volume of water in storage, the computer was instructed to subdivide the county into squares measuring approximately 0.5 mile (0.8 km). The known saturated-thickness values obtained from the data points were filled into the squares in which the data points were located. Based on these known values, the computer filled in a weighted-average value for each remaining square, taking into consideration all known values within a radius of 7 miles (11 km). After this step was completed, the computer then counted the numbers of squares having equal values, thus obtaining the approximate area in square miles (later converted to acres) corresponding to each range of saturated thickness. As previously stated, the number of acres in each 25-foot (7.6-meter) range of saturated thickness was multiplied by the corresponding saturated-thickness value and the storage coefficient (0.15 or 15 percent) to obtain the approximate volume of water in acre-feet in that saturated-thickness range.

Although the calculations were made by the computer from information stored in its image field, the data in the image field were printed out in the form of contoured saturated-thickness maps, which are reproduced in this report. Facing each saturated-thickness map in the report is a corresponding tabulation of the approximate volume of water in storage.

Calculating Pumpage

Estimates of current pumpage were obtained in this study by calculating the storage capacity of the dewatered section of the Ogallala aquifer as reflected in changes in the annual depth-to-water measurements made in the water level observation wells. Factors for natural recharge and irrigation recirculation were then added to these volumetric figures to obtain more realistic pumpage estimates.

The step-by-step procedure involved in making pumpage estimates is similar to the procedures used in calculating the estimates of volume of water in storage; therefore, a more general explanation follows.

Change in water level (decline) maps for the aquifer were made by the computer for the years considered. From these maps, the volume of desaturated material was multiplied by the number of acres corresponding to each 0.25-foot (.076-meter) range of decline and then multiplied by the storage coefficient of the aquifer (0.15 or 15 percent), which resulted in an estimate of the volume of water taken from storage for each decline range. Estimates for natural recharge and irrigation recirculation were added to these values to obtain estimates of pumpage.

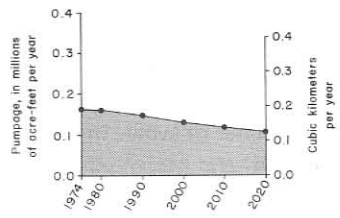
An attempt was made to obtain a reliable estimate of the natural recharge and recirculation for use in this study. This involved obtaining an estimate of the amount of water required by each of the major crops grown in the area. These values, generally referred to as "duty of water," were obtained from Texas Agricultural Experiment Stations located in the High Plains area. The duty of water figure for each major crop was multiplied by the number of crop acres, and the resulting numbers were added together to yield an estimate of the total crop water demand.

The amount of precipitation which fell just prior to and during the growing season was subtracted from the total water demand estimate. The difference between these values should equal that amount which would have been supplied by irrigation, which will be referred to as irrigation makeup water.

The volume figure represented by the dewatered section was then compared to the volume of water which should have been supplied to crops by irrigation makeup water. In all tests, the volume of water represented by the depletion of the aquifer was considerably less than the makeup water estimate. This difference was attributed to irrigation recirculation and natural recharge.

Various combinations of estimates for natural recharge and recirculation were added to the volume represented by aquifer depletion, in an attempt to obtain comparable values with the makeup water estimated for the test years. One-half inch (1.3 cm) per year of natural recharge added to the volume represented by the depletion of the aquifer, and then adding 10 percent of this for recirculation, most nearly equaled the makeup water estimated in the largest number of instances in Carson County and in adjoining counties with similar conditions.

These amounts were added to the previously calculated storage capacity of the dewatered section to obtain estimates for current (1974) and future pumpage. The following graph shows the current and projected estimates of pumpage:



Year	Acre - Feet
1974	166,000
1980	161,000
1990	148,000
2000	130,000
2010	119,000
2020	105,000

Estimated Pumpage

Calculating Pumping Lifts

The pumping lift (pumping level) is the depth from land surface to the water level in a pumping well; it is equal to the depth of the static water level plus the drawdown due to pumping. The amount of pumping lift largely determines the amount of energy required to produce the water, and thus strongly affects the pumping costs.

In calculating pumping lifts, procedures were used that are similar to those used in making estimates of the volume of water in storage and the estimates of pumpage. Again, the computer and original data base were used as previously described.

In making estimates of pumping lifts, it was assumed (1) that the yield of each pumping well is 900 gallons per minute (56.8 l/s) except as limited by the capacity of the aquifer (this conforms with the historical trend of equipping new wells with 8-inch [20-centimeter] or smaller pumps), (2) that the specific well yield is 15 gallons per minute per foot of drawdown (3.1 [l/s]/m), and (3) that once the well yield equals the capacity of the aquifer, the well will continue to be produced at a rate near the capacity of the aquifer until pumping lifts are within 10 feet (3 m) of the base of the aquifer. After that time, it is assumed that the pumping lift will remain constant because of greatly diminished well yields. It should be noted that this 10-foot (3-meter) minimum is somewhat arbitrarily chosen, as one cannot predict accurately the minimum saturated thickness that will be feasible for producing irrigation water under future economic conditions.

The above assumptions restrict the drawdown in wells to a maximum of 60 feet (18.3 m); that is, the maximum well yield of 900 gallons per minute (56.8 l/s) divided by specific well yield of 15 gallons per minute per foot (3.1 [l/s] /m) equals 60 feet (18.3 m) of maximum drawdown.

Based on the above assumptions, pumping lifts were calculated separately for each of the selected data-control wells in the county. The factors involved were the historical and projected saturated-thickness values, the historical and projected static water levels, and the drawdown value assigned to the Carson County area.

In all areas where the aquifer's saturated thickness was 70 feet (21.3 m) or greater (areas where a well, pumped at full capacity, would be drawn down 60 feet [18.3 m] to yield 900 gallons per minute [56.8 l/s]), the computer was instructed to add 60 feet (18.3 m)—the drawdown—to the static water level to determine pumping lift. For a well with a saturated thickness of less than 70 feet (21.3 m), the pumping lift was calculated by subtracting 10 feet (3 m) from the depth of the well (base of the aquifer). These calculations were made for each year of record to be reported (1974, 1980, 1990, 2000, 2010, and 2020) for each well. The pumping-lift values were stored in the computer and printed out in the form of contour maps. Additionally, the surface area corresponding to each interval between the mapped contours was calculated and printed out in tabular form.

Well-Yield Estimates

Estimates of the rate, in gallons per minute, at which the Ogallala aquifer should be capable of yielding water to wells in various areas of the county are presented on maps for each year of record reported (1974, 1980, 1990, 2000, 2010, and 2020). These well-yield estimates are based on capabilities of the aquifer to yield water to irrigation wells of prevailing construction as reflected by the very large number of pumping tests which have been conducted in various saturated-thickness intervals in the Texas High Plains. The estimates are adjusted to reflect the expected decreases in well yields through time due to the reduced saturated thickness as depletion of the aquifer progresses.

The well-yield estimates are subject to deviations caused by localized geological conditions. The Ogallala is not a homogeneous formation; that is, the silt, clay, sand, and gravel which generally comprise the formation vary from place to place in thickness of layers, layering position, and grain-size sorting. The physical composition of the formation material can drastically affect the ability of the formation to yield water to wells. As an example, in areas where the saturated portion of the formation is comprised of thick beds of coarse and well-sorted grains of sand, the well yields probably will exceed the estimates shown on the maps. In other localized areas, the saturated portion of the formation may be comprised principally of thick beds of silt and clay which can be expected to restrict well yields to less than those shown on the maps.

The following can be used as a general guide in Carson County in estimating well yields based on saturated thickness:

SATURATED THICKNESS (feet)	WELL YIELD (gallons per minute)
Less than 20	Less than 100
20 to 30	100 to 250
30 to 40	250 to 500
40 to 60	500 to 800
60 to 80	800 to 1,000
More than 80	More than 1,000

The maps presented in this report are intended for use as general guidelines only and are not recommended for use in determining water availability when buying and selling specific tracts of land. Inasmuch as the availability of ground water constitutes a large portion of the price of land bought and sold in this area, it is recommended that a qualified ground-water hydrologist be consulted to make appraisals of ground-water conditions when such transactions are contemplated.

DISTINCTION BETWEEN PROJECTIONS AND PREDICTIONS

The actions of the Carson County water user will determine whether the projections of this study come to pass, as the rate of depletion of the ground-water resource is determined by the rate of water use. The authors have not made predictions of what will occur, but have furnished projections based on past trends and presently available information.

There are many unpredictable factors which can influence the future rates of withdrawal of ground water from the Ogallala aquifer for irrigation farming. These factors include: (1) the amounts and distribution of precipitation which will be received in the area in the future; (2) federal crop acreage controls or the lack of these; (3) the price and demand for food and fiber grown in the area; (4) the cost and availability of energy to produce water from the aquifer; (5) farm labor cost and availability of farm labor; (6) results of continuing research that seeks to develop more frugal water-application methods for irrigation, crops having less water demand, and methods for inducing clouds to yield more water as rain; and (7) most important, the degree to which feasible soil and water conservation measures are employed by the High Plains irrigator. Any of these factors could appreciably influence the rate of use of ground water in the future; however, the projections in this study provide a reasonable set of general expectations on the further depletion of the aquifer.

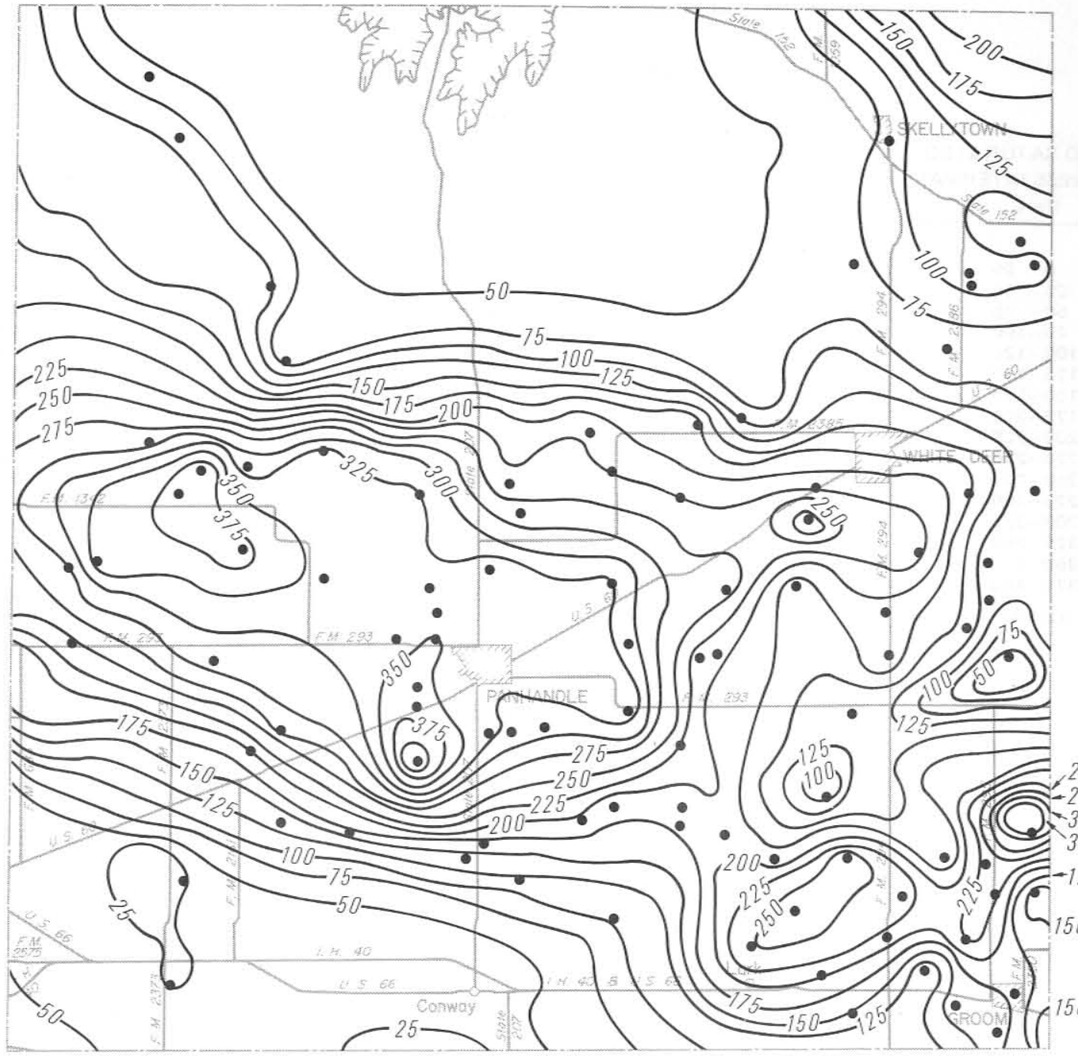
SATURATED THICKNESS AND VOLUME OF WATER IN THE OGALLALA AQUIFER

1974

Volume of Water in Storage Corresponding to Mapped Saturated-Thickness Intervals

(Coefficient of Storage: 15 percent)

MAPPED SATURATED-THICKNESS INTERVAL (feet)	SURFACE AREA (acres)	VOLUME OF WATER IN STORAGE (acre-feet)
0– 25	1,215	2,636
25– 50	3,224	18,590
50– 75	14,165	136,353
75–100	25,457	335,836
100–125	27,669	460,335
125–150	22,710	468,014
150–175	28,581	698,575
175–200	31,549	885,051
200–225	26,390	842,174
225–250	26,283	935,950
250–275	18,123	711,083
275–300	14,584	631,653
300–325	22,463	1,060,056
325–350	33,856	1,708,098
350–375	9,896	534,243
375–400	3,298	188,732
400–425	347	21,038
TOTAL	309,810	9,638,417

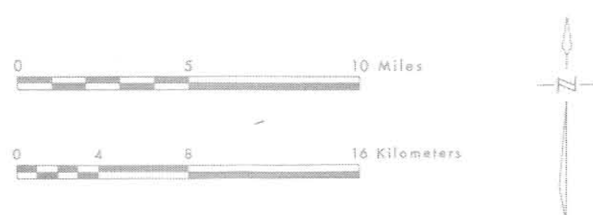


EXPLANATION

•
Well used for control

——— 150 ———
Line showing approximate saturated thickness of the Ogallala aquifer, in feet.

Interval is 25 feet (7.62m)



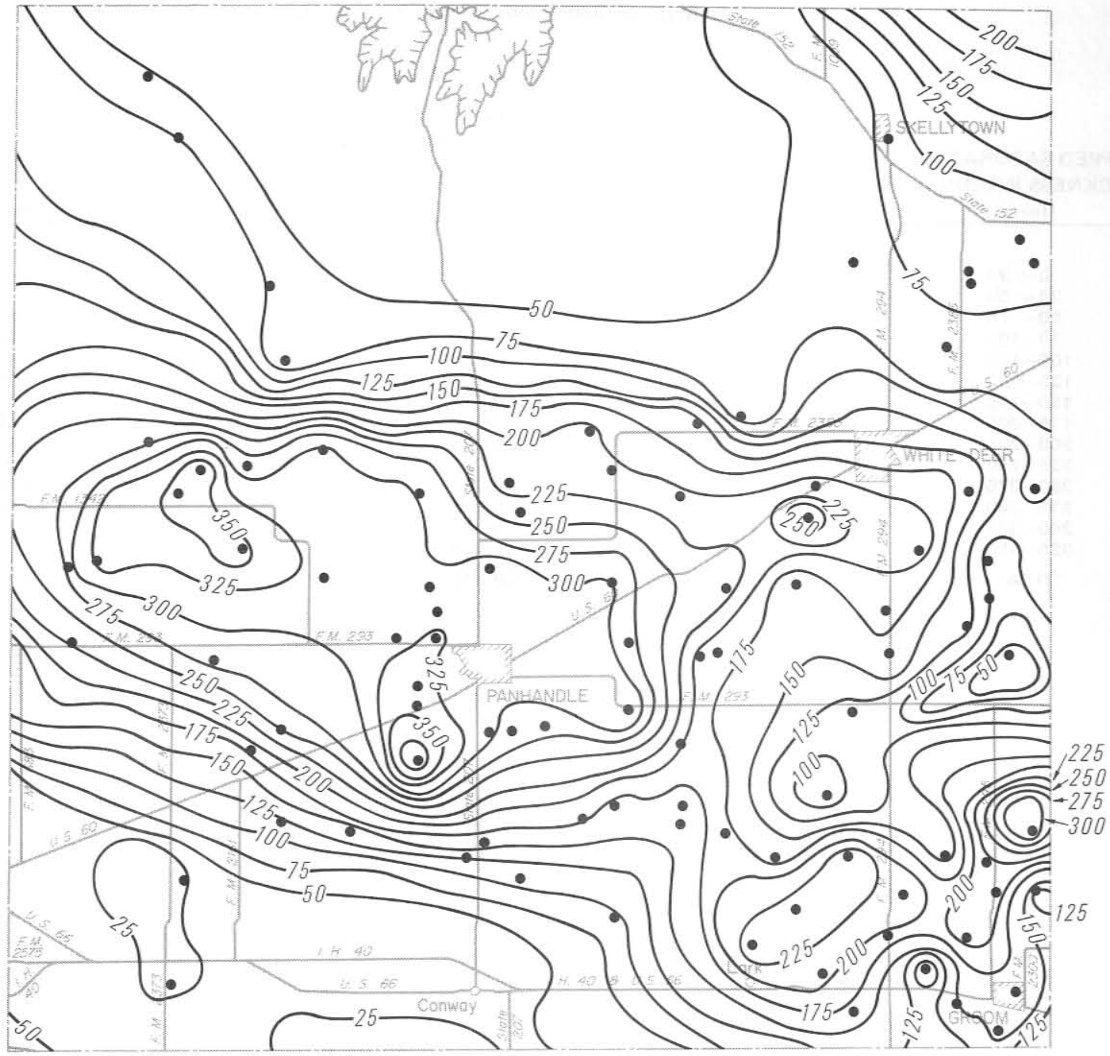
1974
Estimated Saturated Thickness

1980

Volume of Water in Storage Corresponding to Mapped Saturated-Thickness Intervals

(Coefficient of Storage: 15 percent)

MAPPED SATURATED-THICKNESS INTERVAL (feet)	SURFACE AREA (acres)	VOLUME OF WATER IN STORAGE (acre-feet)
0– 25	1,388	2,752
25– 50	5,638	33,564
50– 75	20,851	198,570
75–100	32,814	432,602
100–125	23,927	405,872
125–150	25,848	534,416
150–175	34,902	852,042
175–200	28,126	790,971
200–225	28,540	911,604
225–250	21,477	761,343
250–275	15,397	608,262
275–300	25,241	1,097,792
300–325	31,946	1,494,059
325–350	10,243	514,959
350–375	3,125	166,905
375–400	347	19,630
TOTAL	309,810	8,825,343



EXPLANATION

•
Well used for control

——— 150 ———
Line showing approximate saturated thickness of the Ogallala aquifer, in feet.

Interval is 25 feet (7.62m)

0 5 10 Miles

0 4 8 16 Kilometers

N

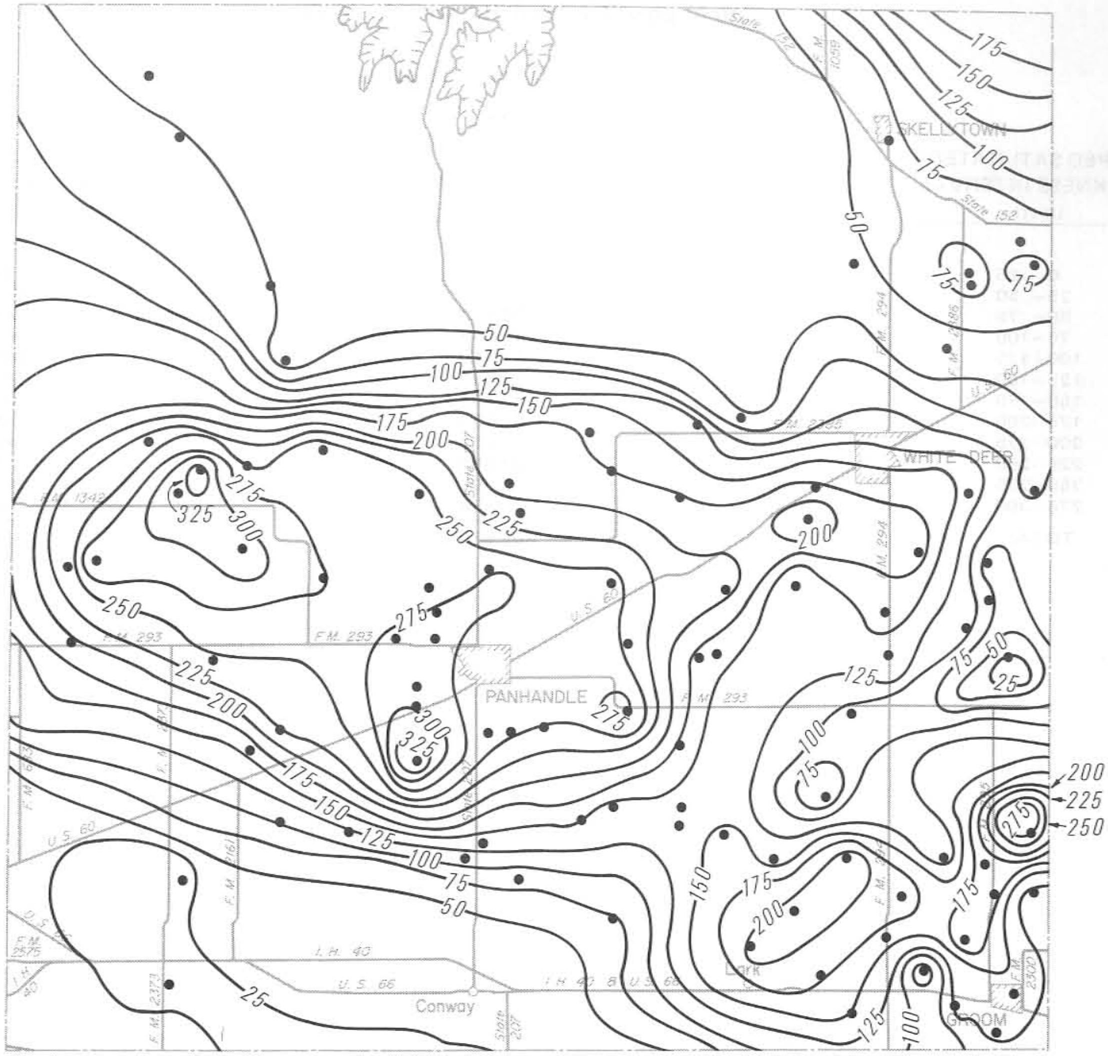
1980
Projected Saturated Thickness

1990

Volume of Water in Storage Corresponding to Mapped Saturated-Thickness Intervals

(Coefficient of Storage: 15 percent)

MAPPED SATURATED-THICKNESS INTERVAL (feet)	SURFACE AREA (acres)	VOLUME OF WATER IN STORAGE (acre-feet)
0– 25	2,902	6,955
25– 50	15,185	93,550
50– 75	32,302	308,881
75–100	29,540	384,594
100–125	28,626	484,167
125–150	37,159	765,790
150–175	30,731	745,225
175–200	31,492	882,138
200–225	21,248	672,111
225–250	20,033	716,217
250–275	38,023	1,496,844
275–300	16,146	687,275
300–325	5,903	274,228
325–350	520	26,001
TOTAL	309,810	7,543,976



EXPLANATION

• Well used for control

——150—— Line showing approximate saturated thickness of the Ogallala aquifer, in feet.

Interval is 25 feet (7.62m)

0 5 10 Miles

0 4 8 16 Kilometers

N

1990

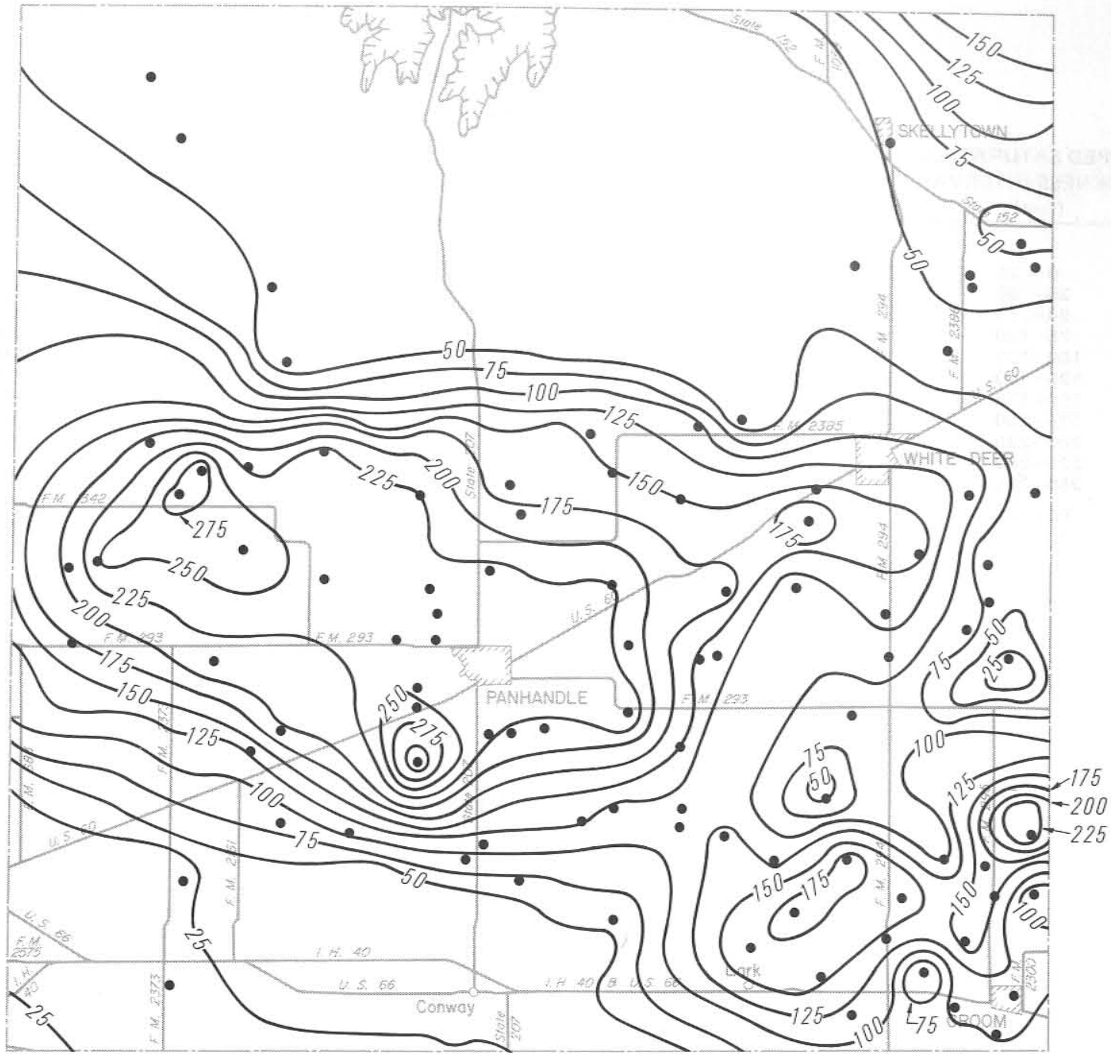
Projected Saturated Thickness

2000

Volume of Water in Storage Corresponding to Mapped Saturated-Thickness Intervals

(Coefficient of Storage: 15 percent)

MAPPED SATURATED-THICKNESS INTERVAL (feet)	SURFACE AREA (acres)	VOLUME OF WATER IN STORAGE (acre-feet)
0– 25	5,486	14,760
25– 50	28,626	171,246
50– 75	36,924	340,424
75–100	32,037	421,249
100–125	41,130	695,079
125–150	33,923	697,779
150–175	33,458	813,352
175–200	21,769	609,419
200–225	26,977	868,315
225–250	38,891	1,369,188
250–275	9,201	360,651
275–300	1,388	59,276
TOTAL	309,810	6,420,738

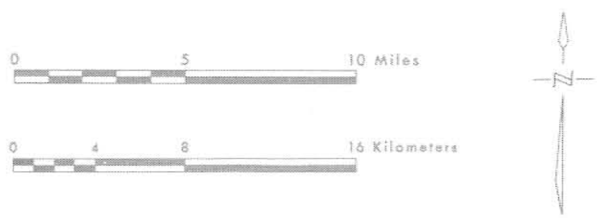


EXPLANATION

• Well used for control

——— 150 ———
Line showing approximate saturated thickness of the Ogallala aquifer, in feet.

Interval is 25 feet (7.62m)



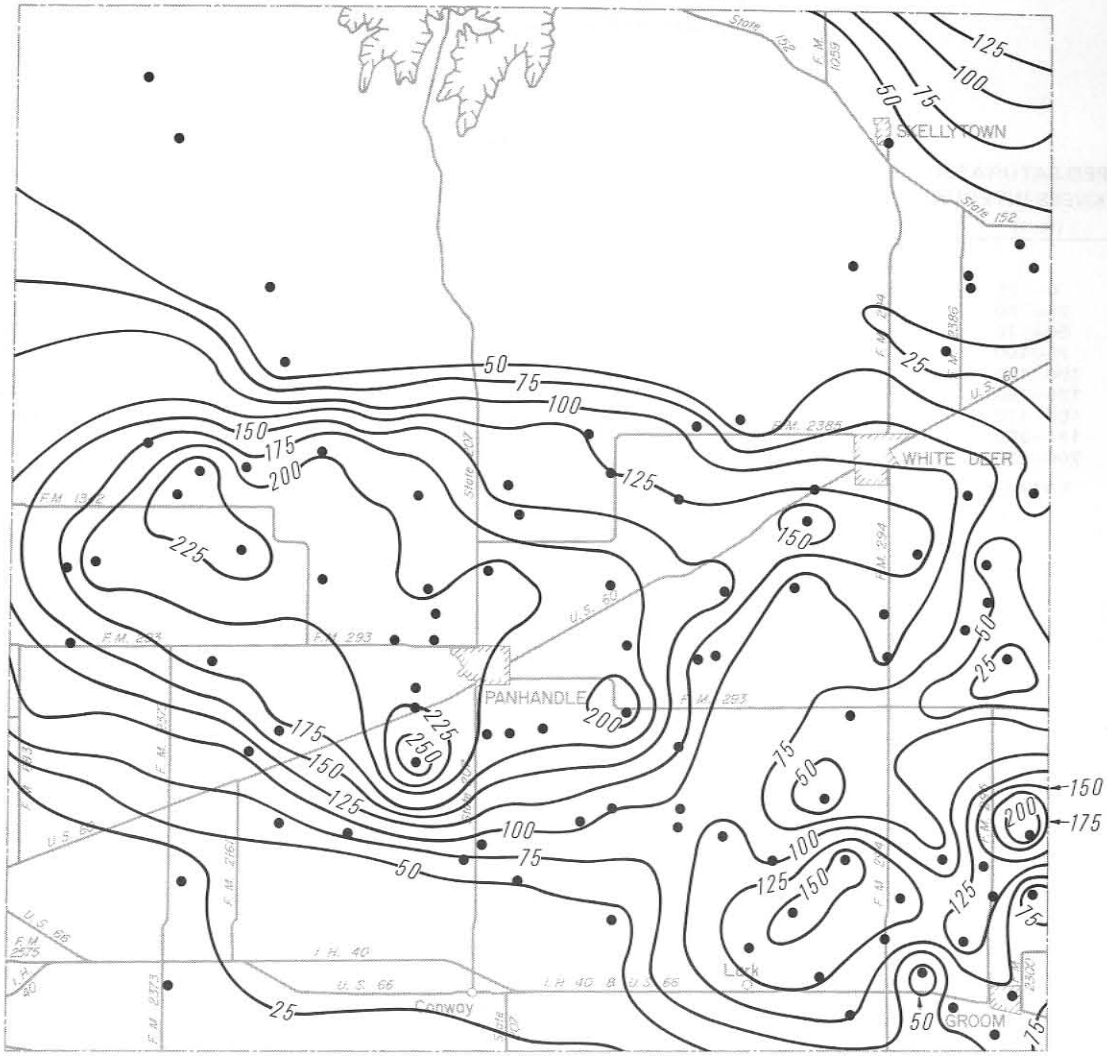
2000
Projected Saturated Thickness

2010

Volume of Water in Storage Corresponding to Mapped Saturated-Thickness Intervals

(Coefficient of Storage: 15 percent)

MAPPED SATURATED-THICKNESS INTERVAL (feet)	SURFACE AREA (acres)	VOLUME OF WATER IN STORAGE (acre-feet)
0– 25	11,365	30,588
25– 50	47,122	272,242
50– 75	34,389	324,553
75–100	45,249	599,182
100–125	38,494	646,038
125–150	36,353	746,990
150–175	22,810	553,104
175–200	36,700	1,046,172
200–225	31,078	976,166
225–250	6,250	218,488
250–275	347	13,286
TOTAL	310,157	5,426,809



EXPLANATION

•
Well used for control

——— 150 ———
Line showing approximate saturated thickness of the Ogallala aquifer, in feet.

Interval is 25 feet (7.62m)

0 5 10 Miles

0 4 8 16 Kilometers

N

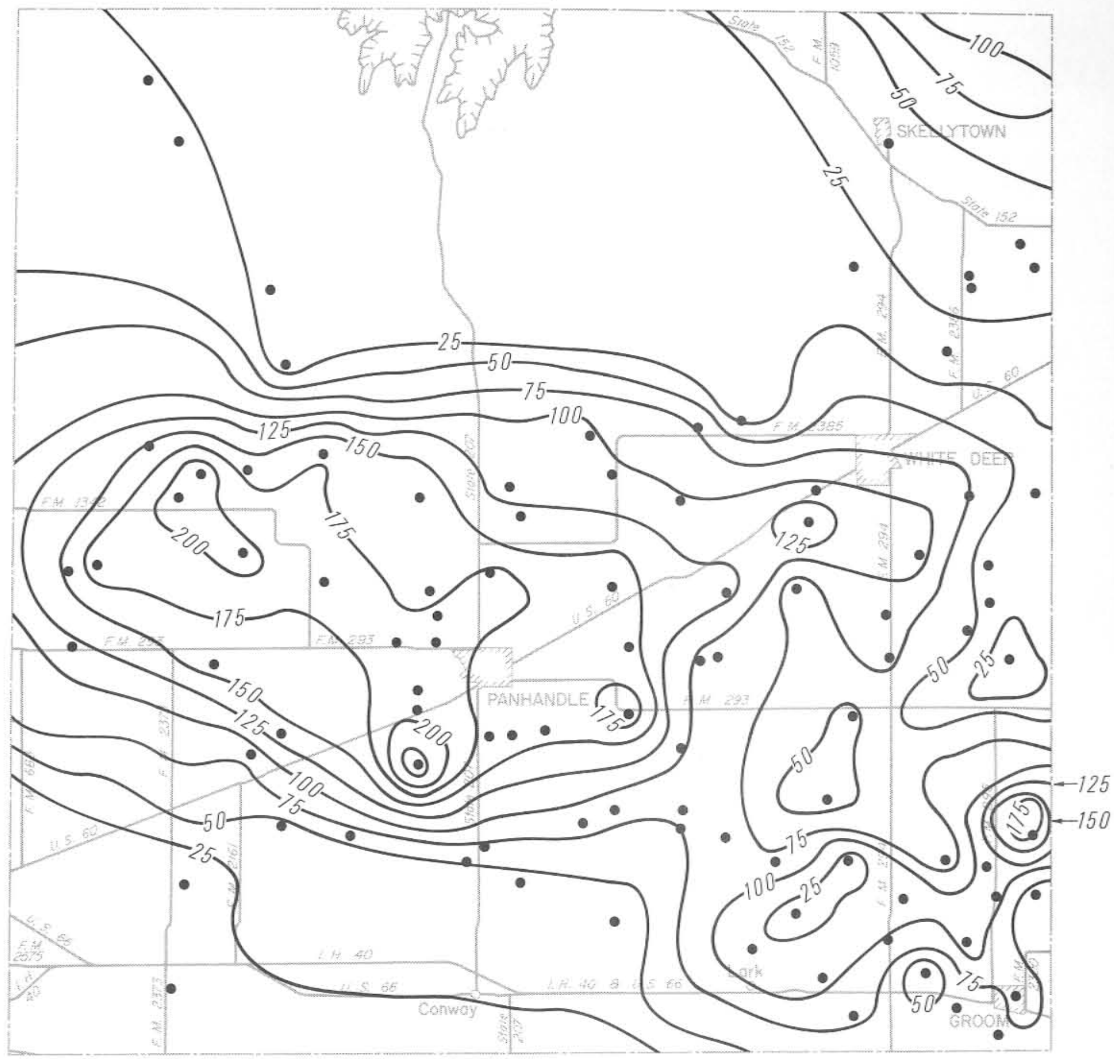
2010
Projected Saturated Thickness

2020

Volume of Water in Storage Corresponding to Mapped Saturated-Thickness Intervals

(Coefficient of Storage: 15 percent)

MAPPED SATURATED-THICKNESS INTERVAL (feet)	SURFACE AREA (acres)	VOLUME OF WATER IN STORAGE (acre-feet)
0– 25	22,578	61,651
25– 50	53,268	289,327
50– 75	46,129	439,638
75–100	48,738	633,746
100–125	40,523	681,785
125–150	24,720	506,159
150–175	43,124	1,065,224
175–200	26,043	716,679
200–225	4,687	145,451
TOTAL	309,810	4,539,660



EXPLANATION

•
Well used for control

——— 150 ———
Line showing approximate saturated thickness of the Ogallala aquifer, in feet.

Interval is 25 feet (7.62m)

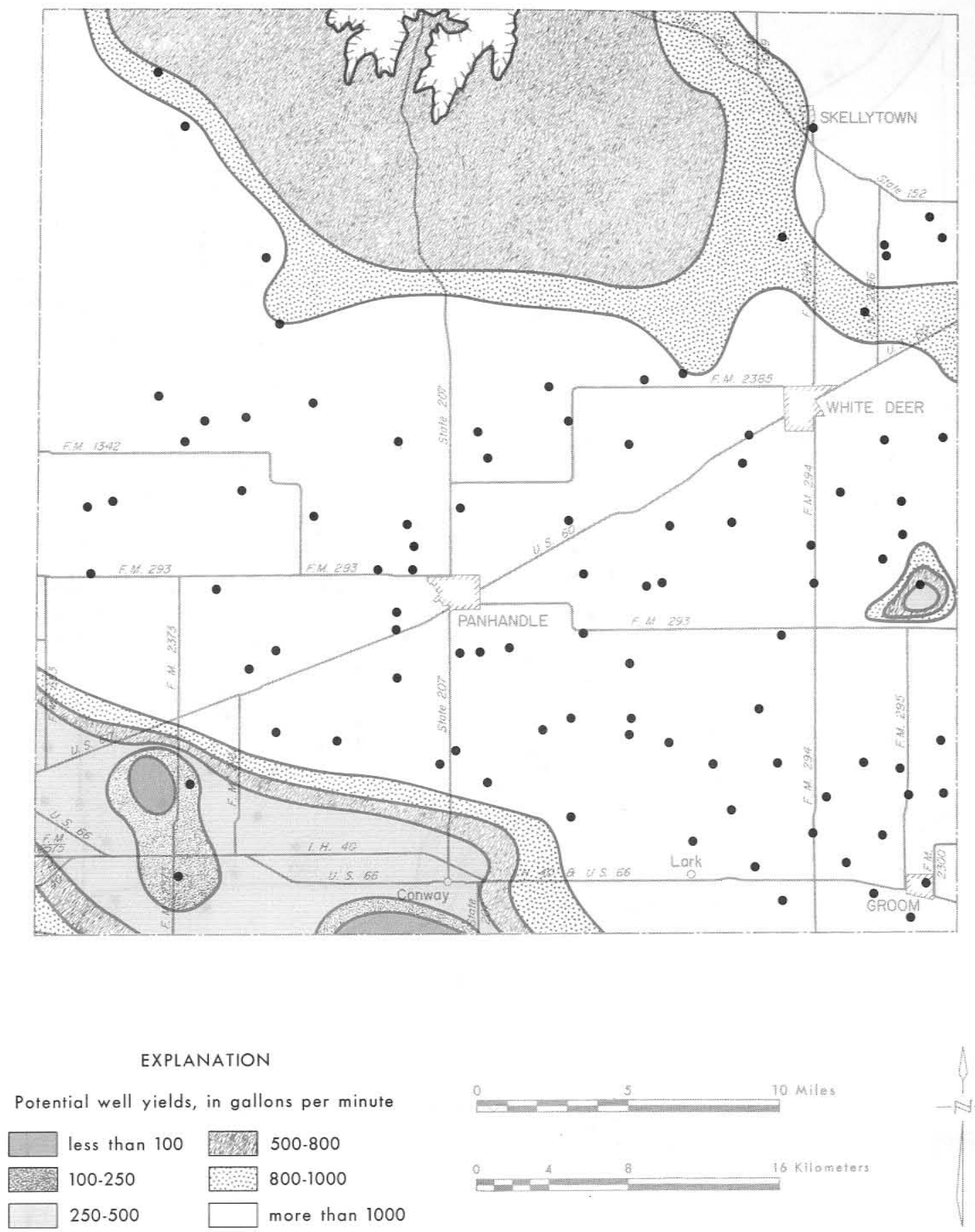
0 5 10 Miles

0 4 8 16 Kilometers

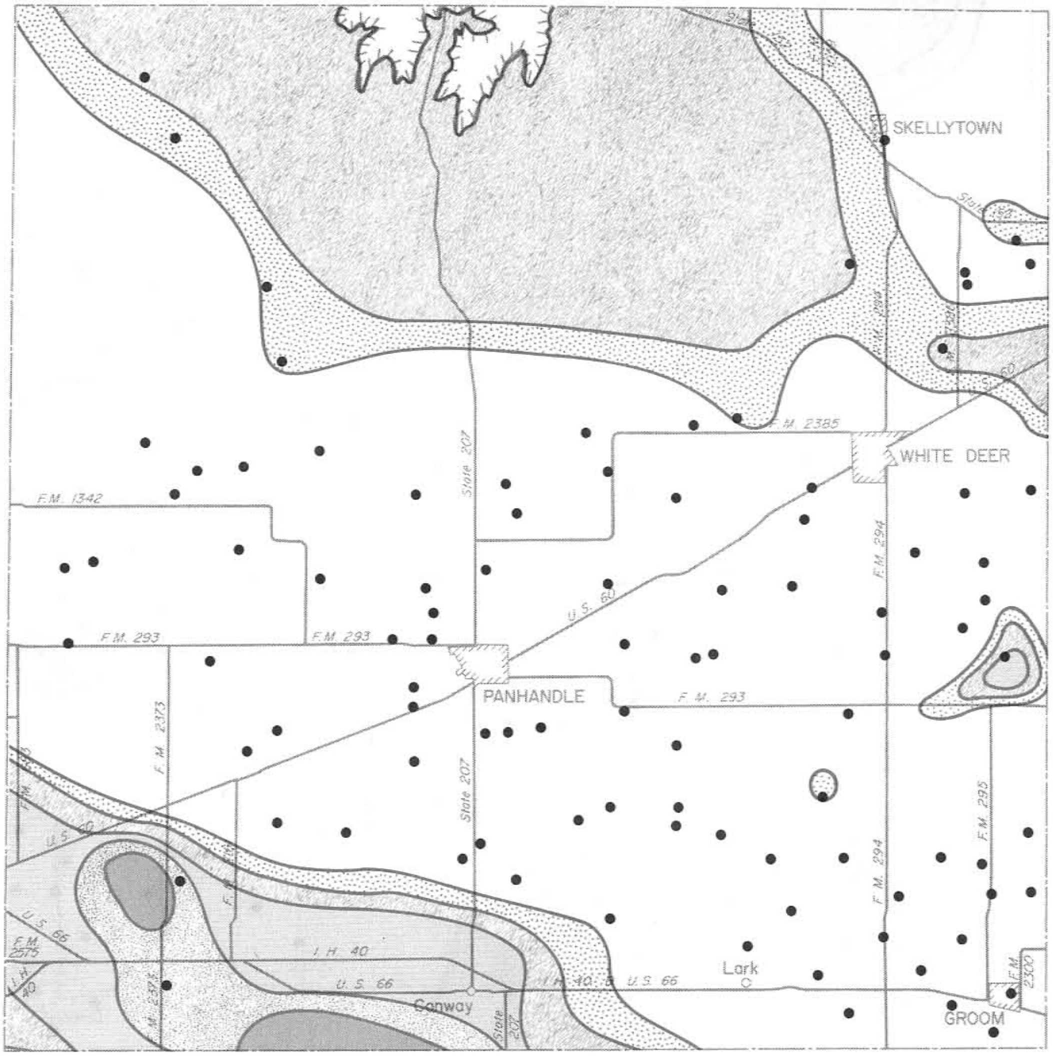
N

2020
Projected Saturated Thickness

POTENTIAL WELL YIELD OF THE OGALLALA AQUIFER



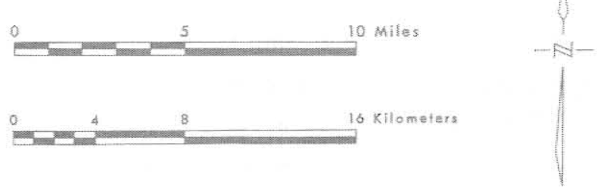
1974
Estimated Potential Yield



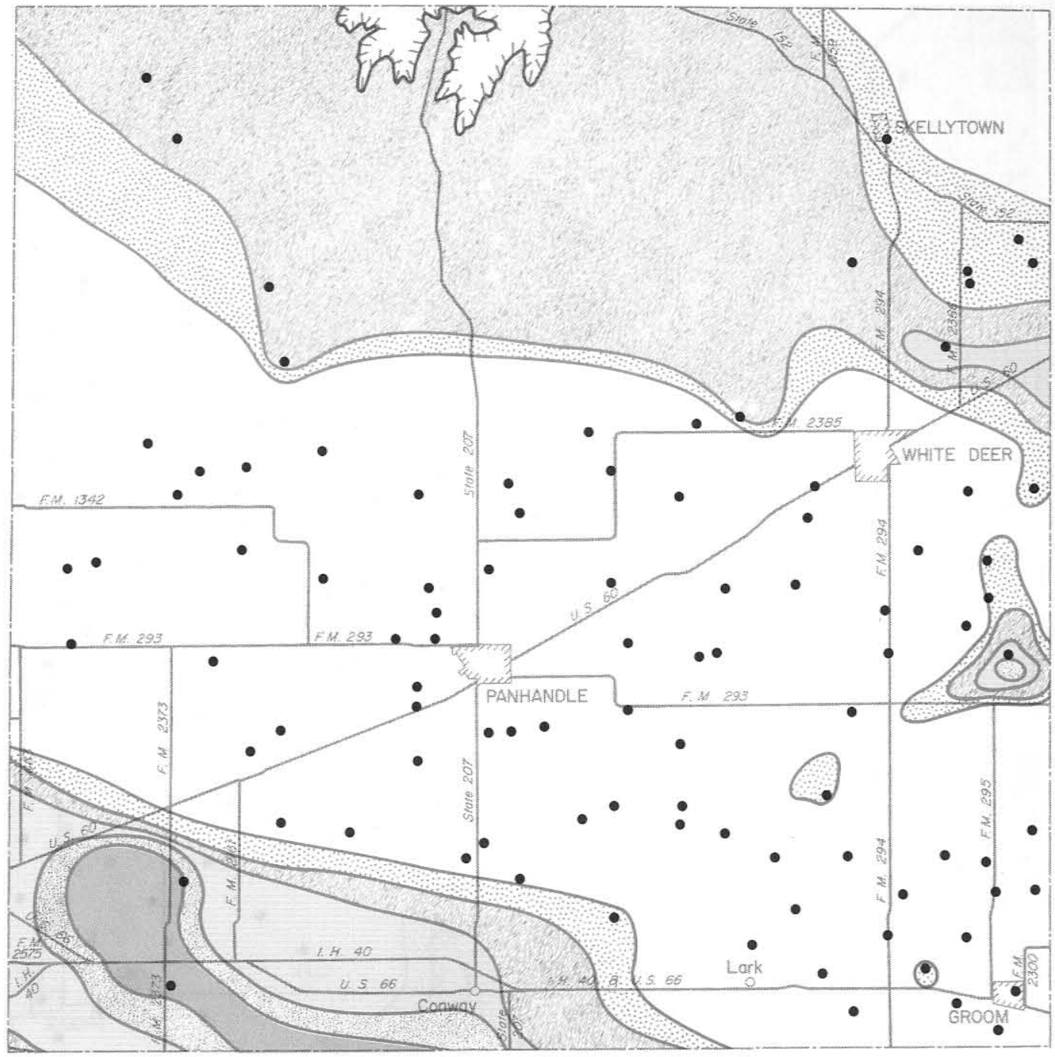
EXPLANATION

Potential well yields, in gallons per minute

less than 100	500-800
100-250	800-1000
250-500	more than 1000



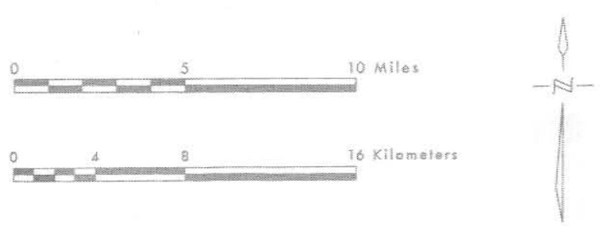
1980
Projected Potential Yield



EXPLANATION

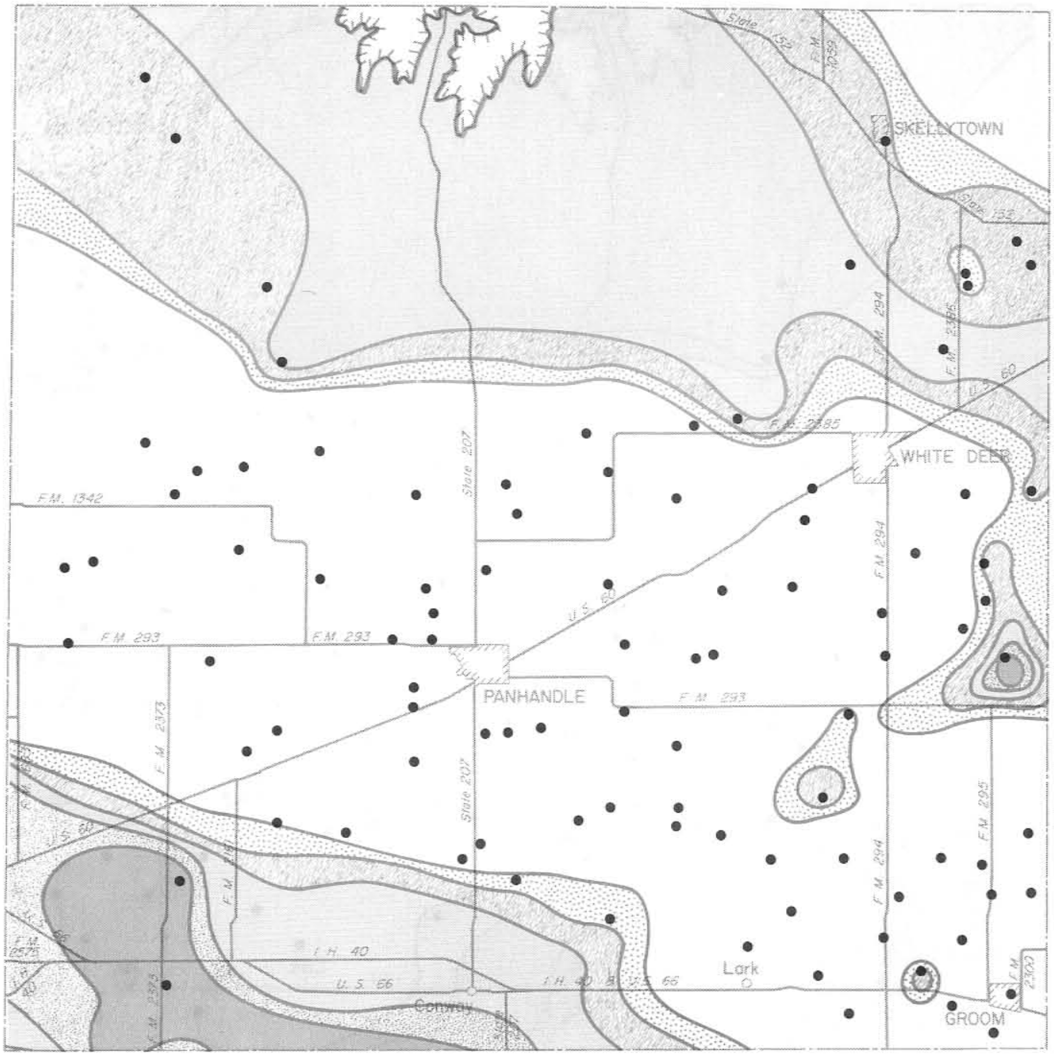
Potential well yields, in gallons per minute

- less than 100
- 100-250
- 250-500
- 500-800
- 800-1000
- more than 1000



1990

Projected Potential Yield



EXPLANATION

Potential well yields, in gallons per minute

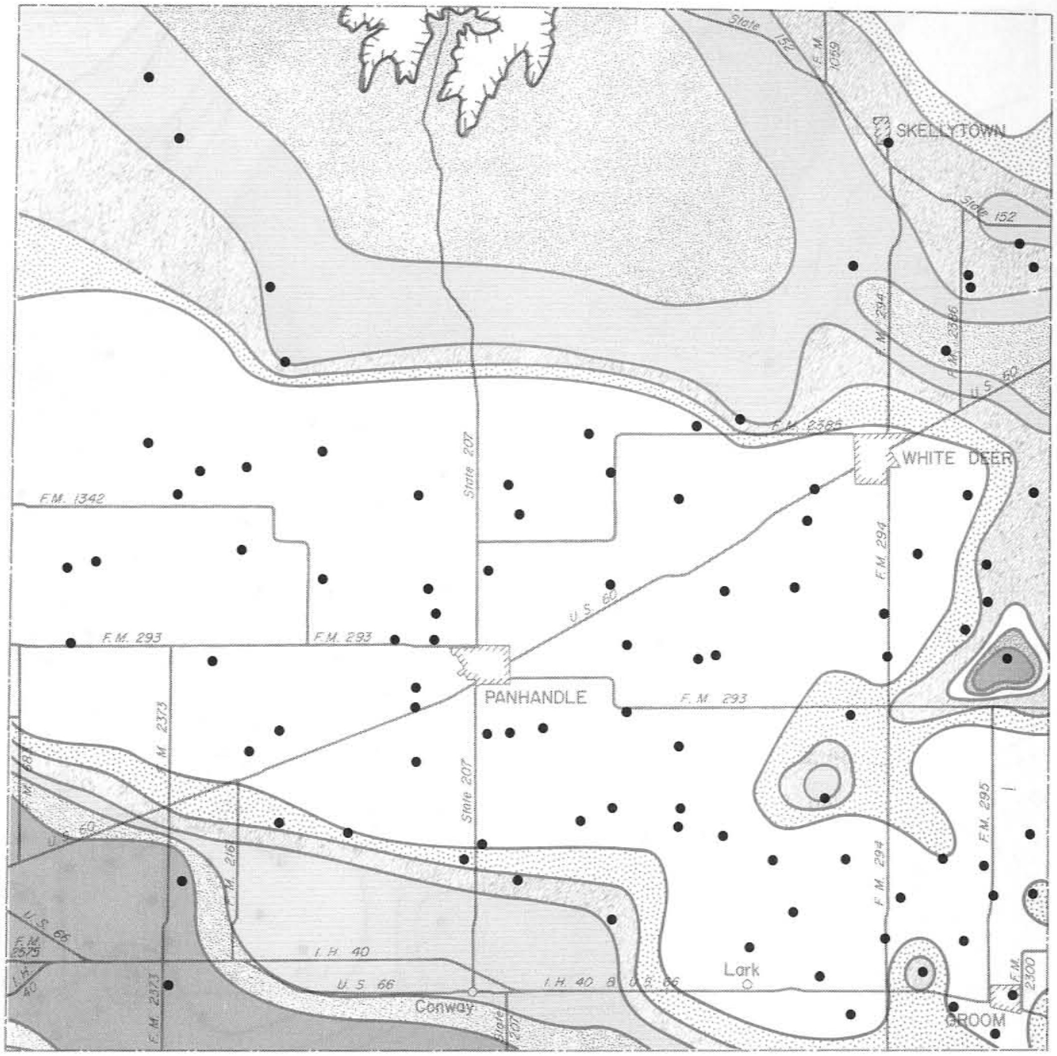
less than 100	500-800
100-250	800-1000
250-500	more than 1000

0 5 10 Miles

0 4 8 16 Kilometers

N

2000
Projected Potential Yield



EXPLANATION

Potential well yields, in gallons per minute

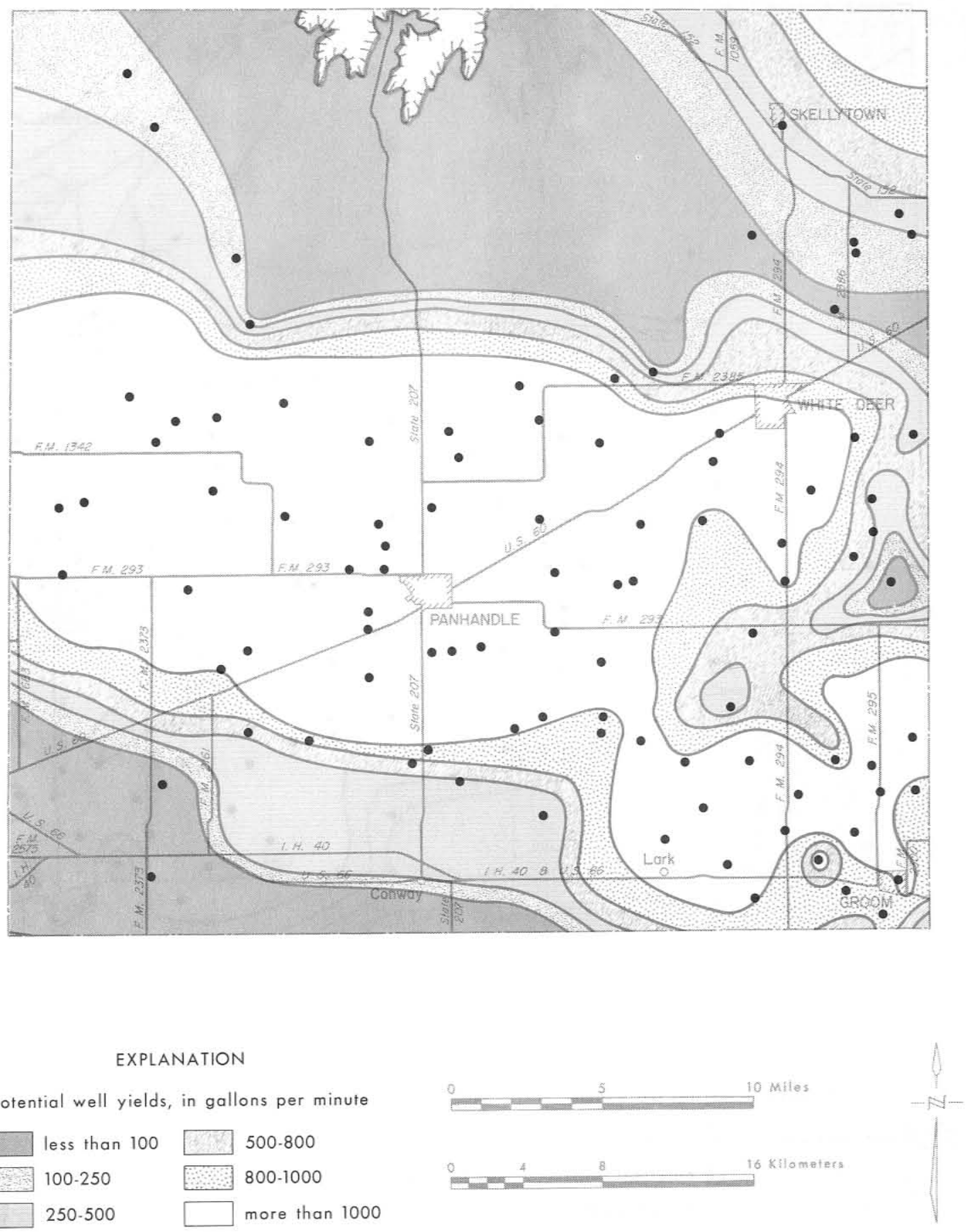
- less than 100
- 100-250
- 250-500
- 500-800
- 800-1000
- more than 1000

0 5 10 Miles

0 4 8 16 Kilometers

N

2010
Projected Potential Yield



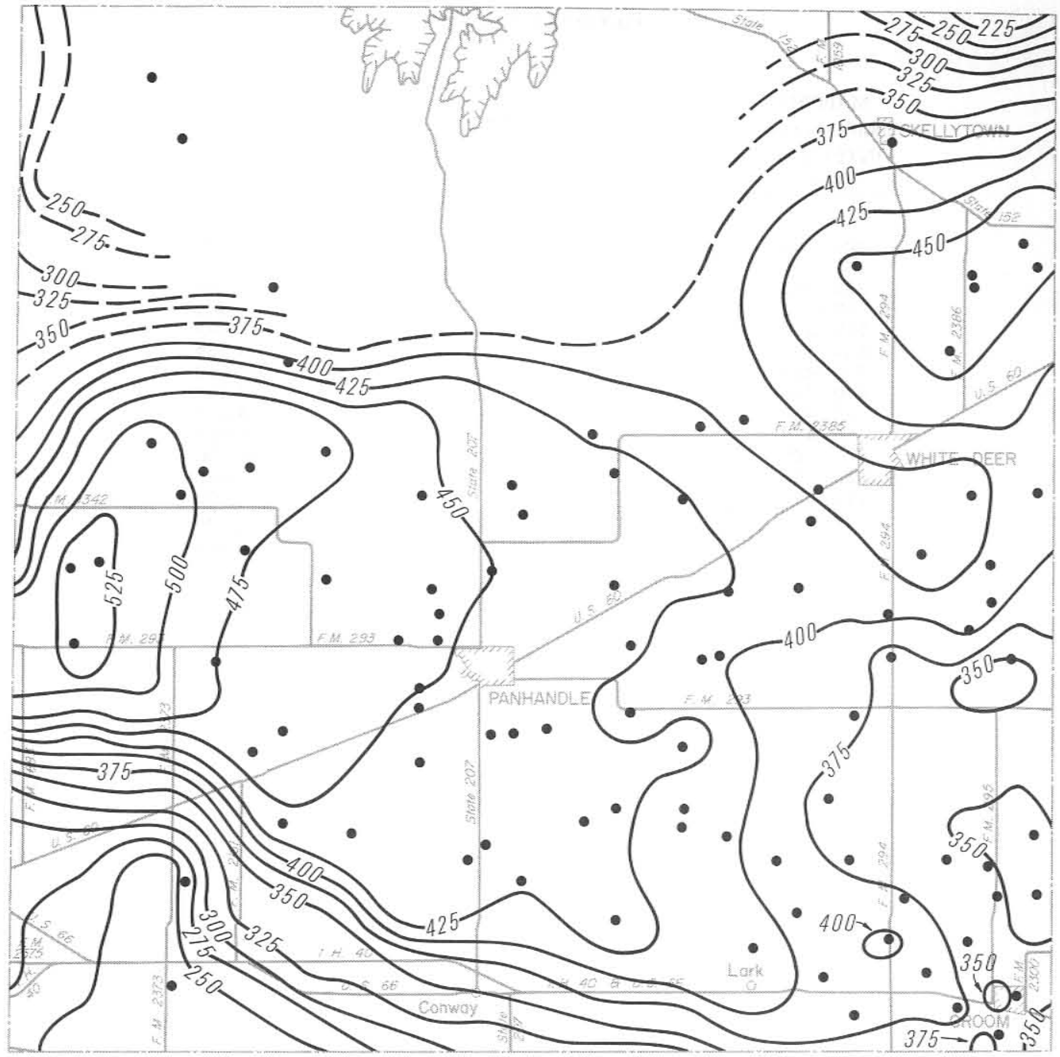
2020
Projected Potential Yield

PUMPING LIFTS IN THE OGALLALA AQUIFER

1974

Surface Area Corresponding to Mapped Pumping-Lift Intervals

MAPPED PUMPING-LIFT INTERVAL (feet)	SURFACE AREA (acres)
200–225	520
225–250	3,305
250–275	1,041
275–300	1,736
300–325	2,430
325–350	8,859
350–375	30,641
375–400	44,599
400–425	56,820
425–450	79,187
450–475	53,242
475–500	17,014
500–525	8,160
525–550	2,951
TOTAL	310,505



EXPLANATION

• Well used for control

——200—— Line showing approximate pumping lift, in feet.

Interval is 25 feet (7.62m)

0 5 10 Miles

0 4 8 16 Kilometers

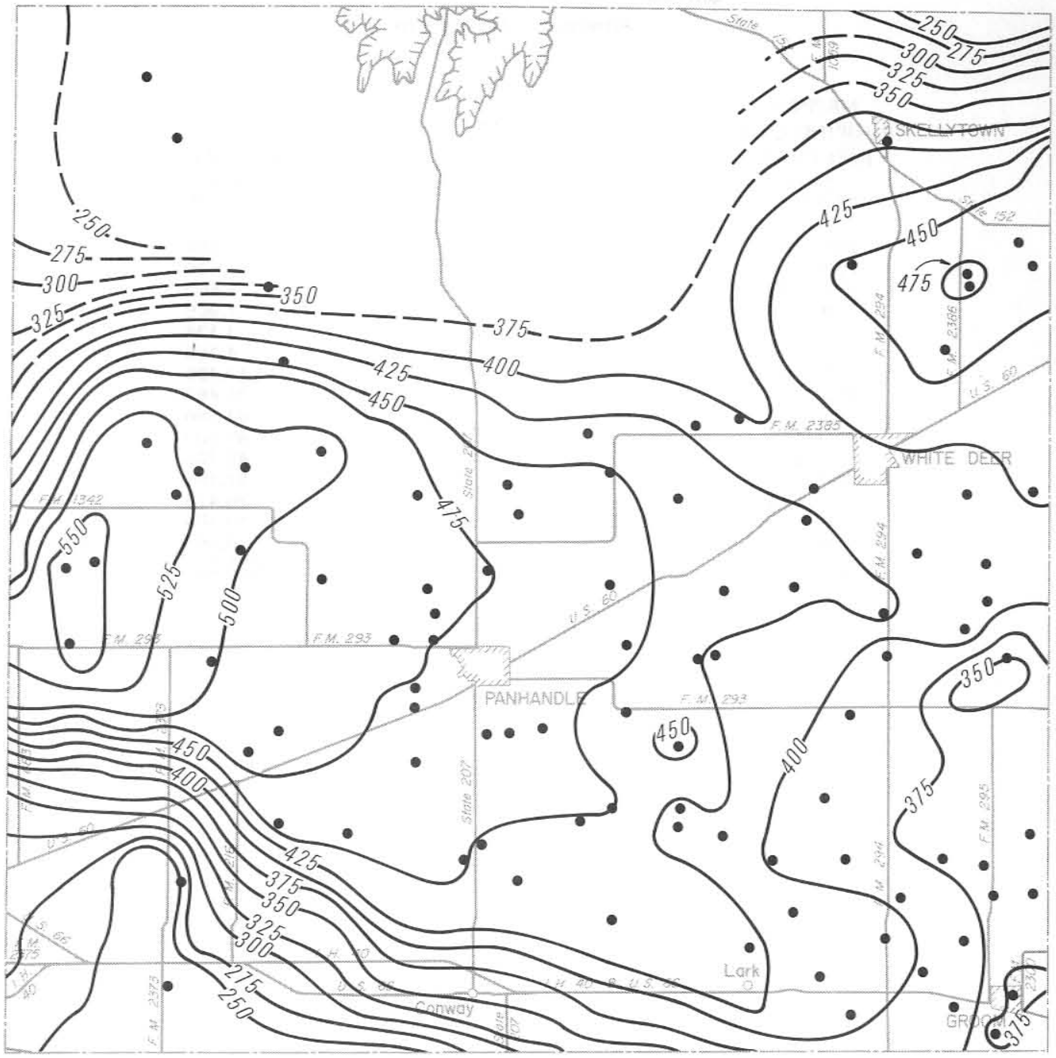
N

1974
Estimated Pumping Lifts

1980

Surface Area Corresponding to Mapped Pumping-Lift Intervals

MAPPED PUMPING-LIFT INTERVAL (feet)	SURFACE AREA (acres)
225–250	3,825
250–275	868
275–300	1,562
300–325	1,909
325–350	3,993
350–375	17,754
375–400	30,693
400–425	55,325
425–450	64,665
450–475	65,673
475–500	38,196
500–525	15,625
525–550	8,160
550–575	2,257
TOTAL	310,505



EXPLANATION

•
Well used for control

——200——
Line showing approximate pumping lift, in feet.

Interval is 25 feet (7.62m)

0 5 10 Miles

0 4 8 16 Kilometers

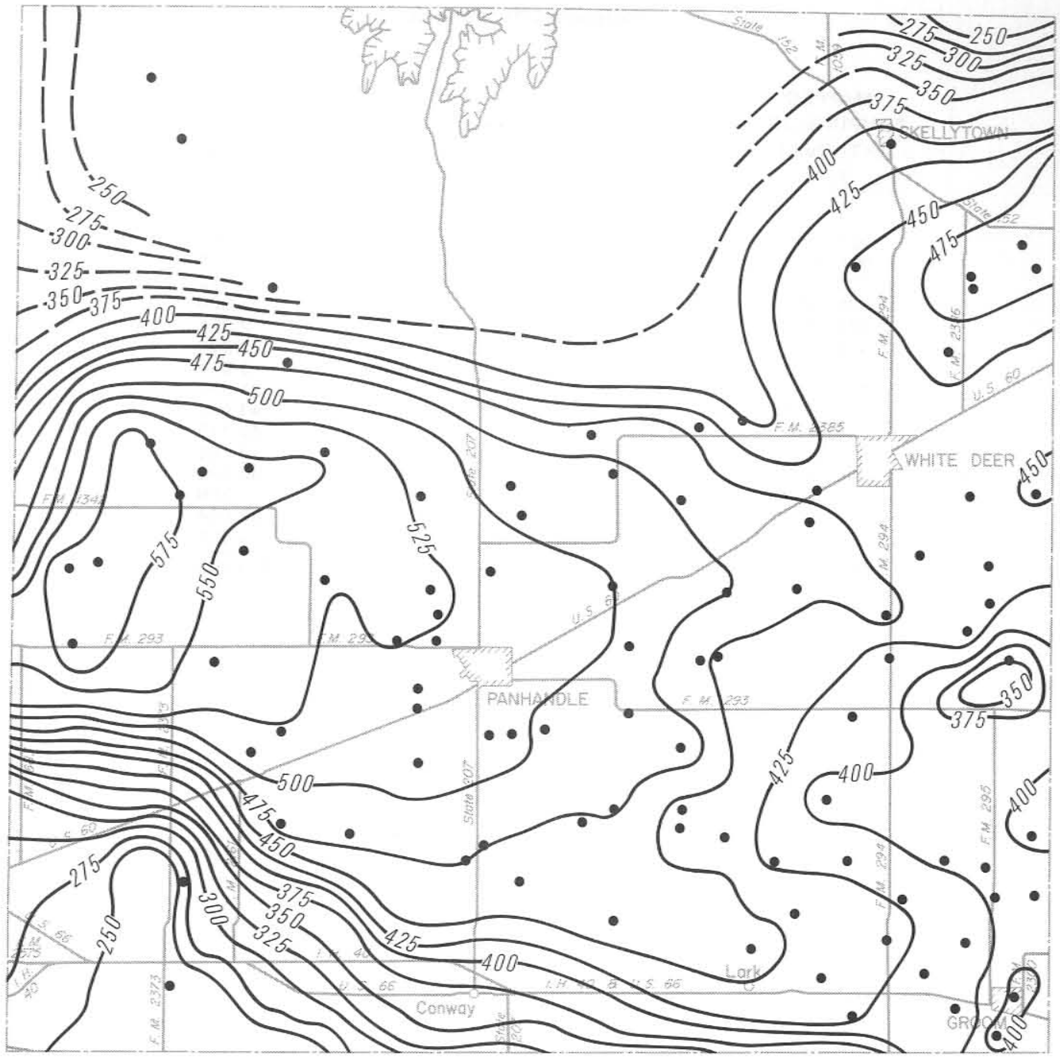
N

1980
Projected Pumping Lifts

1990

Surface Area Corresponding to Mapped Pumping-Lift Intervals

MAPPED PUMPING-LIFT INTERVAL (feet)	SURFACE AREA (acres)
225–250	3,654
250–275	520
275–300	1,562
300–325	1,909
325–350	3,125
350–375	4,166
375–400	17,496
400–425	34,483
425–450	64,596
450–475	49,903
475–500	45,755
500–525	38,196
525–550	28,473
550–575	10,764
575–600	5,903
TOTAL	310,505

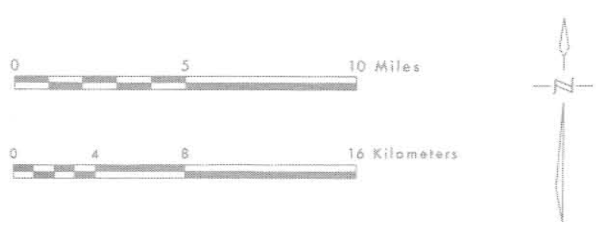


EXPLANATION

•
Well used for control

——200——
Line showing approximate pumping lift, in feet.

Interval is 25 feet (7.62m)

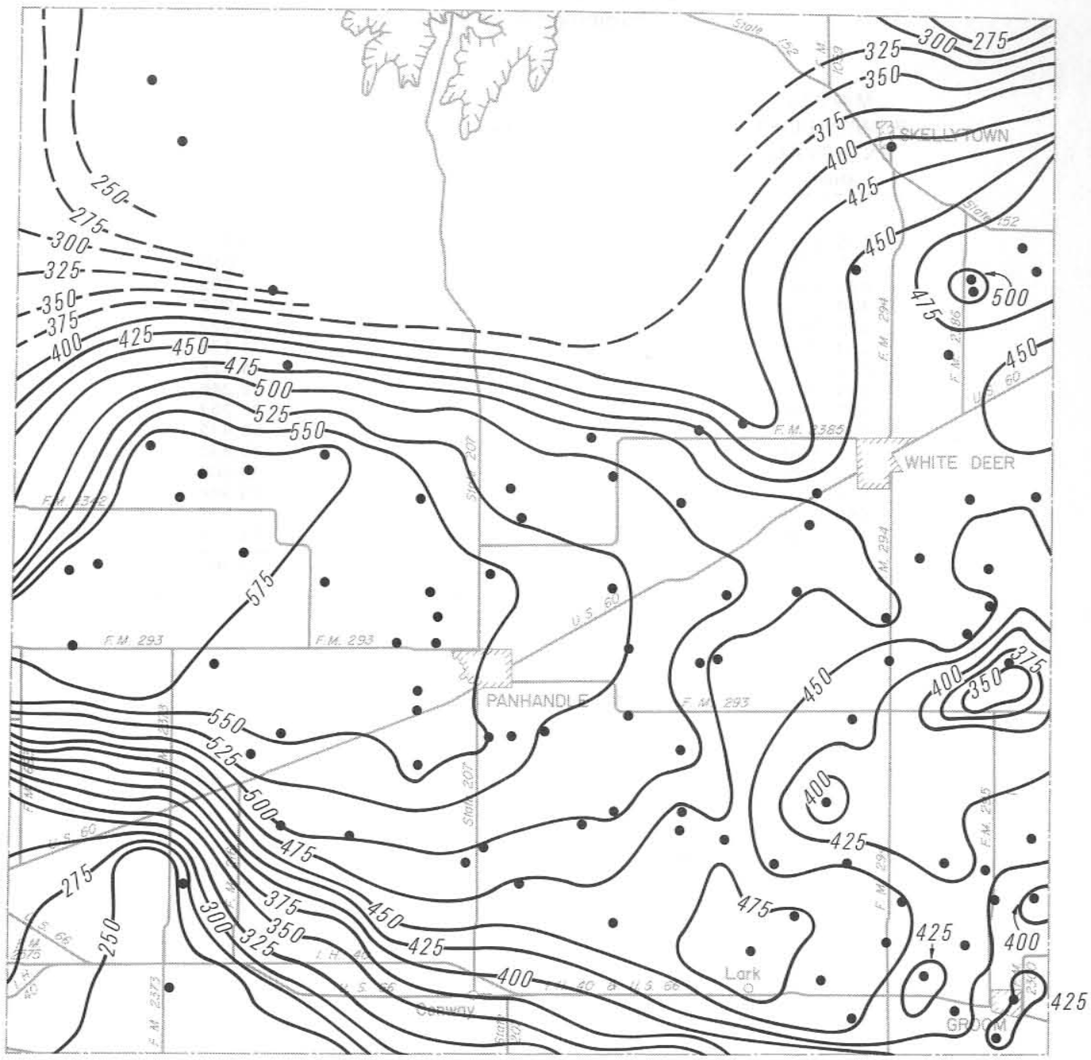


1990
Projected Pumping Lifts

2000

Surface Area Corresponding to Mapped Pumping-Lift Intervals

MAPPED PUMPING-LIFT INTERVAL (feet)	SURFACE AREA (acres)
225–250	3,041
250–275	959
275–300	1,562
300–325	1,909
325–350	2,951
350–375	3,298
375–400	6,014
400–425	21,838
425–450	43,037
450–475	65,775
475–500	39,109
500–525	33,682
525–550	27,258
550–575	36,634
575–600	23,438
TOTAL	310,505



EXPLANATION

•
Well used for control

——200——
Line showing approximate pumping lift, in feet.

Interval is 25 feet (7.62m)

0 5 10 Miles

0 4 8 16 Kilometers

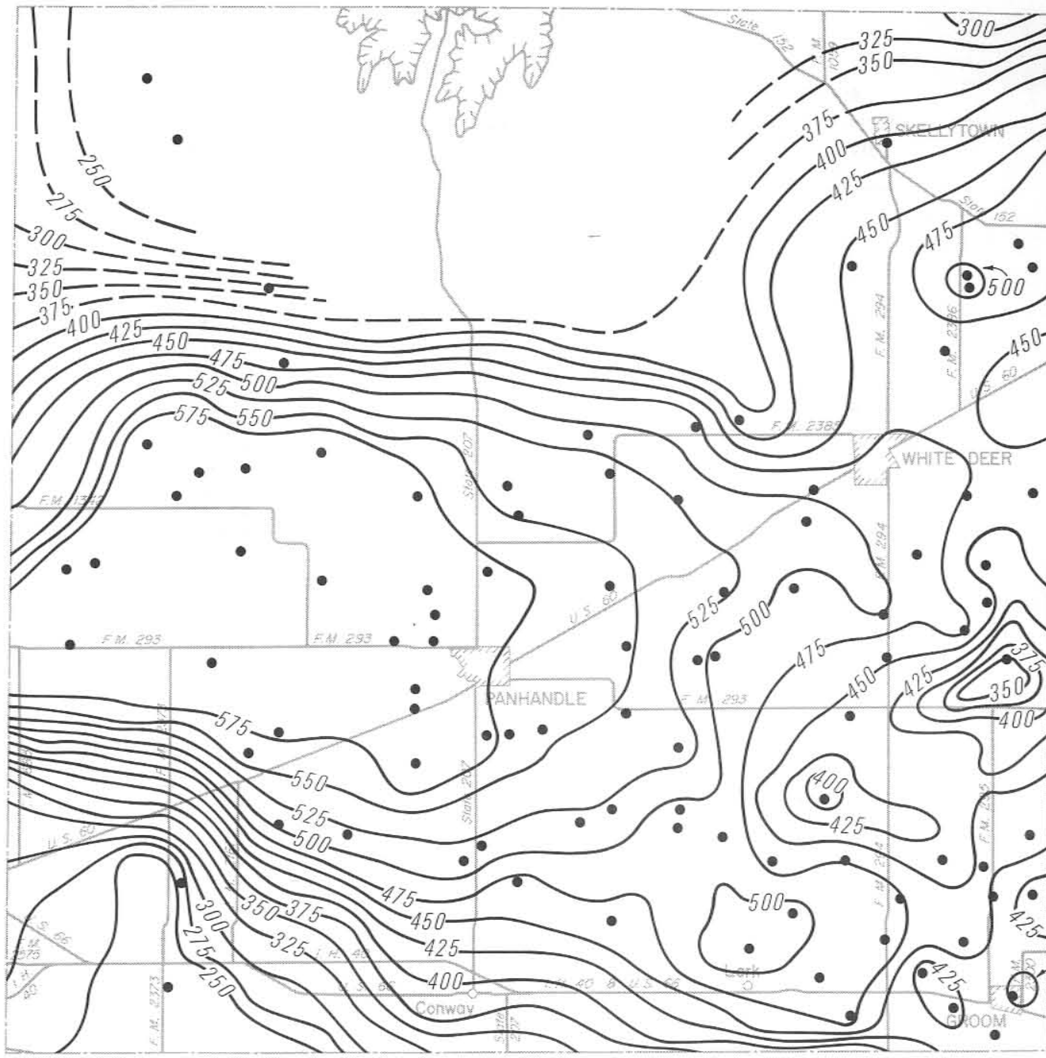
N

2000
Projected Pumping Lifts

2010

Surface Area Corresponding to Mapped Pumping-Lift Intervals

MAPPED PUMPING-LIFT INTERVAL (feet)	SURFACE AREA (acres)
225–250	3,041
250–275	613
275–300	1,909
300–325	1,562
325–350	2,777
350–375	3,125
375–400	4,425
400–425	12,246
425–450	32,357
450–475	53,432
475–500	48,852
500–525	28,800
525–550	28,994
550–575	25,175
575–600	63,197
TOTAL	310,505



EXPLANATION

•
Well used for control

——— 200 ———
Line showing approximate pumping lift, in feet.

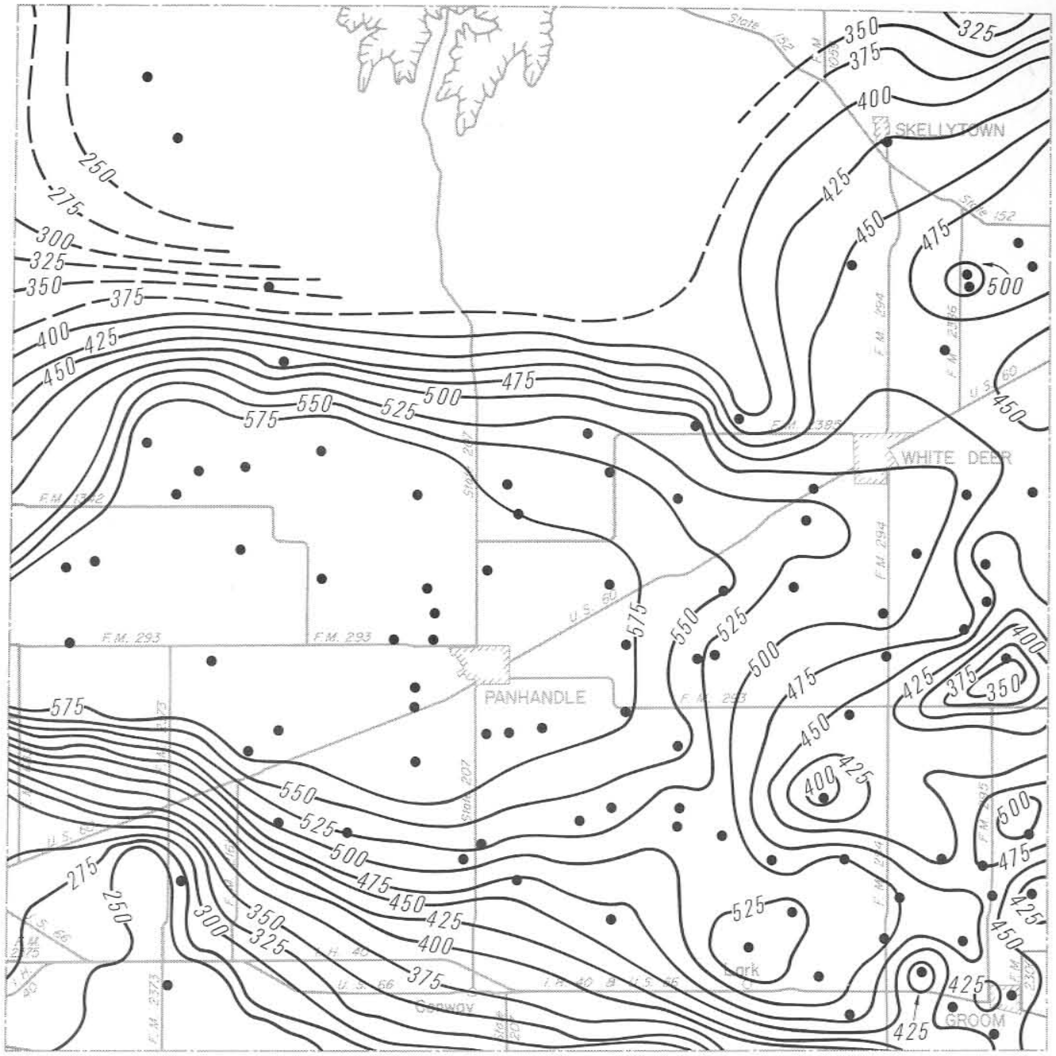
Interval is 25 feet (7.62m)

2010
Projected Pumping Lifts

2020

Surface Area Corresponding to Mapped Pumping-Lift Intervals

MAPPED PUMPING-LIFT INTERVAL (feet)	SURFACE AREA (acres)
225–250	3,041
250–275	612
275–300	1,736
300–325	1,736
325–350	2,083
350–375	3,472
375–400	4,078
400–425	9,393
425–450	25,633
450–475	46,327
475–500	40,719
500–525	37,296
525–550	22,744
550–575	23,959
575–600	87,676
TOTAL	310,505

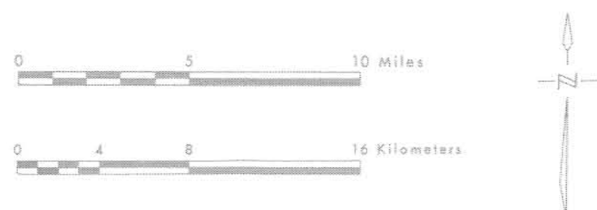


EXPLANATION

• Well used for control

——200—— Line showing approximate pumping lift, in feet.

Interval is 25 feet (7.62m)



2020

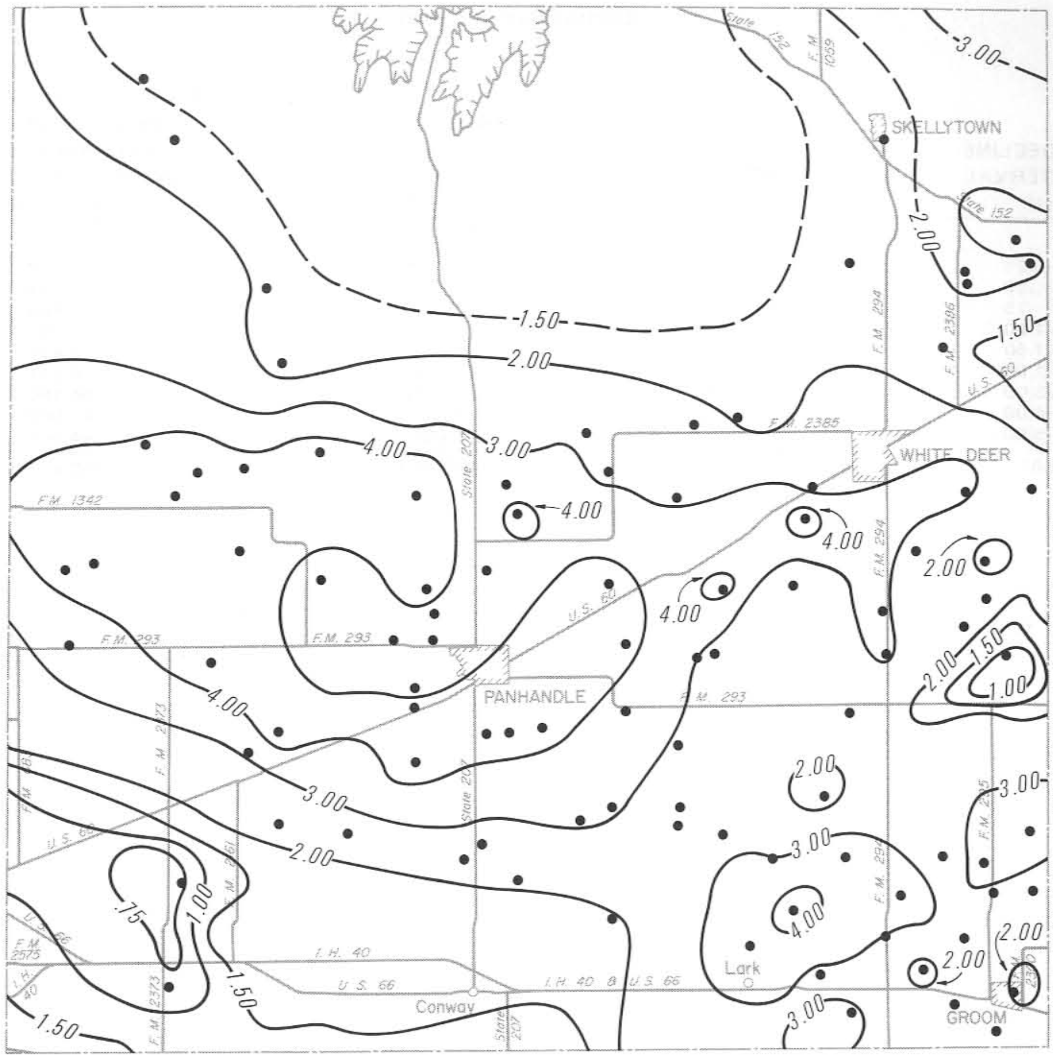
Projected Pumping Lifts

PUMPAGE FROM THE OGALLALA AQUIFER

1974

Pumpage Corresponding to Mapped Decline-Rate Intervals

MAPPED DECLINE-RATE INTERVAL (feet)	SURFACE AREA (acres)	STORAGE CAPACITY OF DEWATERED SECTION (acre-feet)	ESTIMATED PUMPAGE RATE, INCLUDING NATURAL RECHARGE AND IRRIGATION RECIRCULATION (acre-feet per year)
0.00–0.25	0	0	0
.25– .50	520	28	54
.50– .75	868	87	136
.75–1.00	1,862	249	356
1.00–1.50	7,801	1,533	2,044
1.50–2.00	39,671	10,601	13,480
2.00–3.00	115,891	44,280	54,020
3.00–4.00	87,291	46,378	55,016
4.00–5.00	55,385	34,960	40,994
TOTAL	309,289	138,116	166,100

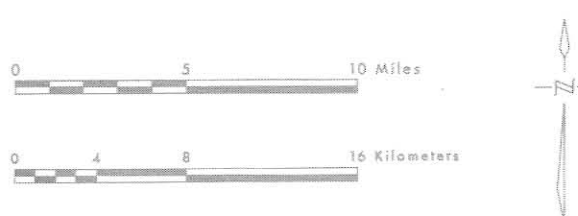


EXPLANATION

•
Well used for control

——1.25——
Line showing approximate rate of decline in water level, in feet per year.

Interval is variable

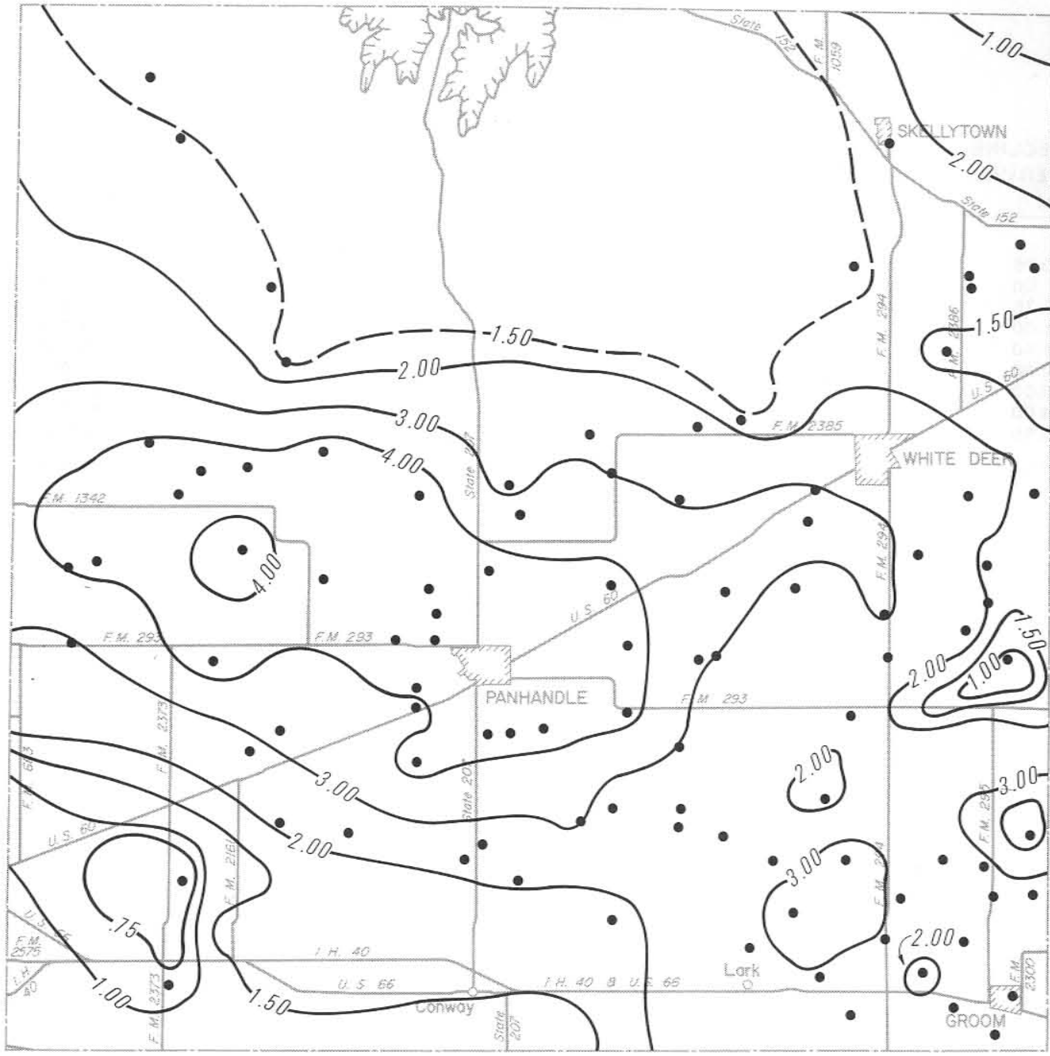


1974
Estimated Rates of Water-Level Decline

1980

Pumpage Corresponding to Mapped Decline-Rate Intervals

MAPPED DECLINE-RATE INTERVAL (feet)	SURFACE AREA (acres)	STORAGE CAPACITY OF DEWATERED SECTION (acre-feet)	ESTIMATED PUMPAGE RATE, INCLUDING NATURAL RECHARGE AND IRRIGATION RECIRCULATION (acre-feet per year)
0.00–0.25	0	0	0
.25– .50	698	44	77
.50– .75	1,016	102	159
.75–1.00	2,059	275	397
1.00–1.50	12,989	2,580	3,433
1.50–2.00	47,485	12,507	15,934
2.00–3.00	117,232	44,342	54,150
3.00–4.00	67,911	35,323	41,968
4.00–5.00	59,899	38,017	44,564
TOTAL	309,289	133,190	160,682

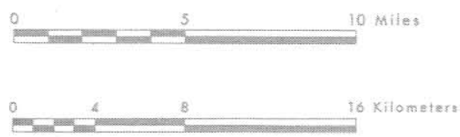


EXPLANATION

•
Well used for control

——— 1.25 ———
Line showing approximate rate of decline in water level, in feet per year.

Interval is variable

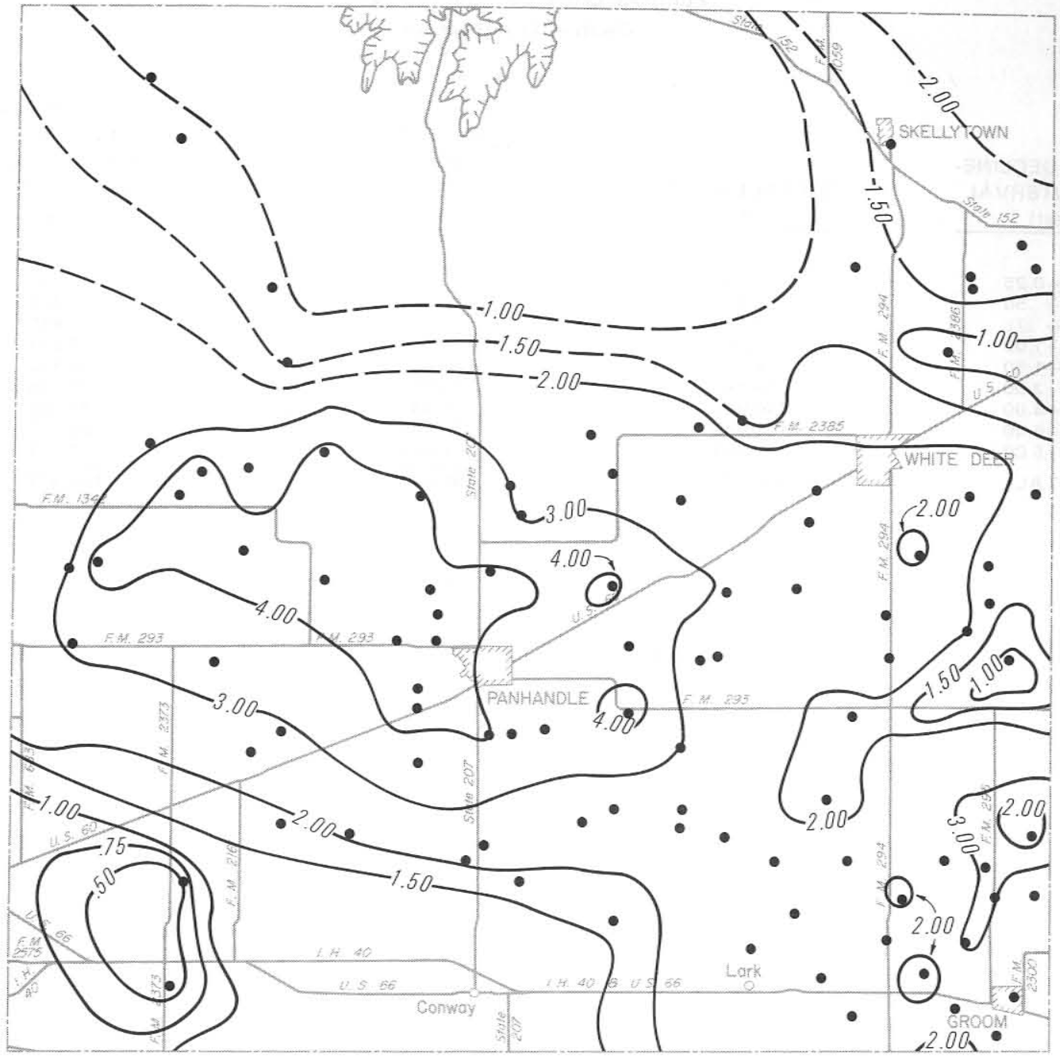


1980
Projected Rates of Water-Level Decline

1990

Pumpage Corresponding to Mapped Decline-Rate Intervals

MAPPED DECLINE-RATE INTERVAL (feet)	SURFACE AREA (acres)	STORAGE CAPACITY OF DEWATERED SECTION (acre-feet)	ESTIMATED PUMPAGE RATE, INCLUDING NATURAL RECHARGE AND IRRIGATION RECIRCULATION (acre-feet per year)
0.00–0.25	176	7	11
.25– .50	868	51	96
.50– .75	1,537	142	227
.75–1.00	5,483	739	1,064
1.00–1.50	24,060	4,635	6,201
1.50–2.00	54,118	14,124	18,017
2.00–3.00	125,396	47,424	57,913
3.00–4.00	65,358	34,707	41,173
4.00–5.00	32,293	20,201	23,702
TOTAL	309,289	122,030	148,404



EXPLANATION

• Well used for control

——— 1.25 ———
Line showing approximate rate of decline in water level, in feet per year.

Interval is variable

0 5 10 Miles

0 4 8 16 Kilometers

N

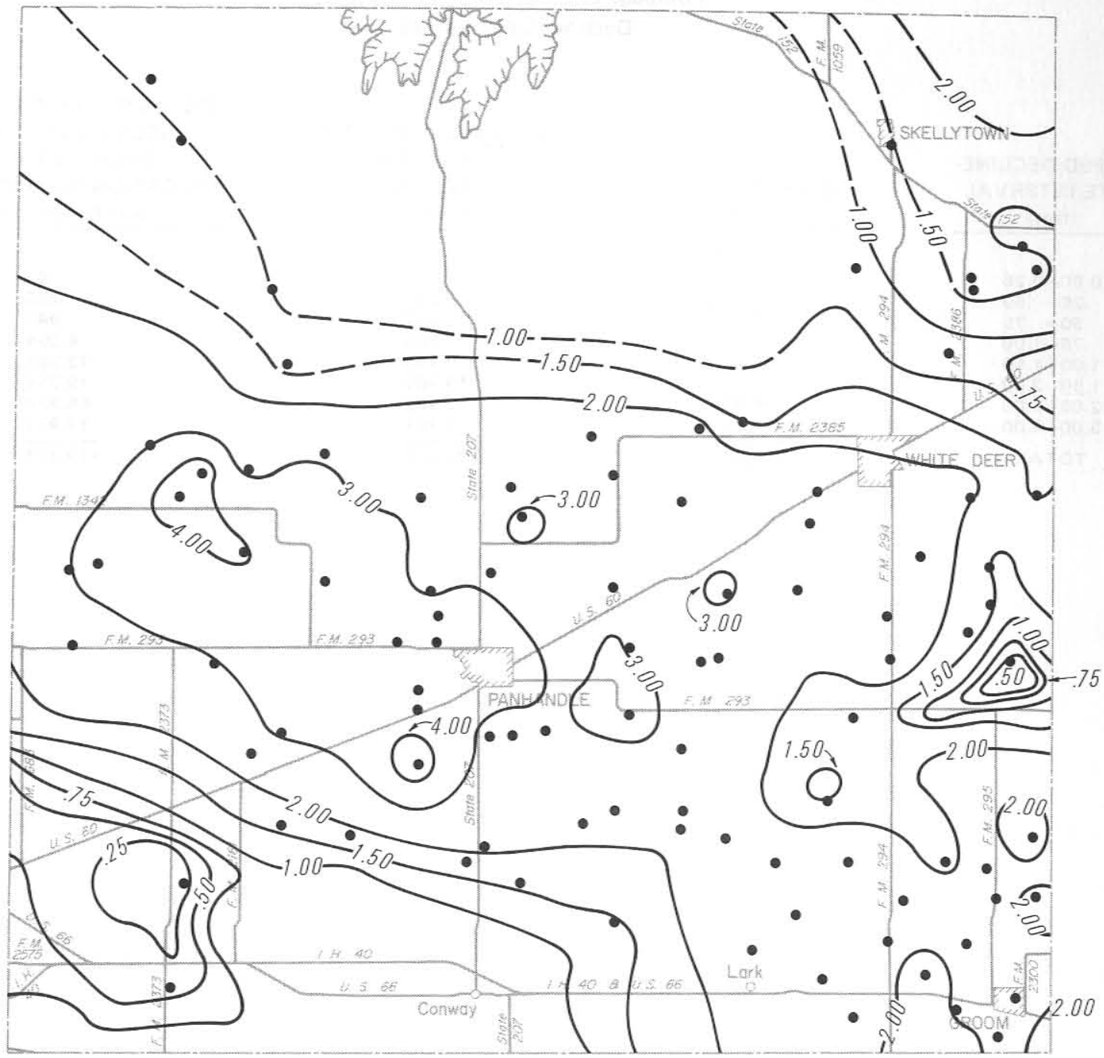
1990

Projected Rates of Water-Level Decline

2000

Pumpage Corresponding to Mapped Decline-Rate Intervals

MAPPED DECLINE-RATE INTERVAL (feet)	SURFACE AREA (acres)	STORAGE CAPACITY OF DEWATERED SECTION (acre-feet)	ESTIMATED PUMPAGE RATE, INCLUDING NATURAL RECHARGE AND IRRIGATION RECIRCULATION (acre-feet per year)
0.00–0.25	347	11	29
.25– .50	2,208	125	239
.50– .75	4,118	387	615
.75–1.00	13,408	1,786	2,574
1.00–1.50	34,523	6,627	8,872
1.50–2.00	54,542	14,251	18,176
2.00–3.00	146,602	55,441	67,705
3.00–4.00	50,243	25,195	30,017
4.00–5.00	2,951	1,814	2,131
TOTAL	308,942	105,637	130,358

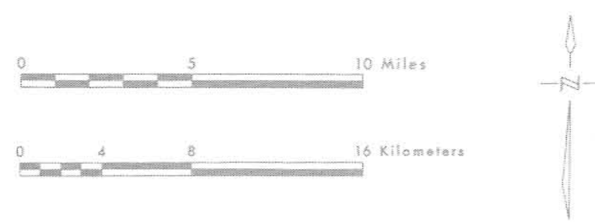


EXPLANATION

•
Well used for control

——1.25——
Line showing approximate rate of decline in water level, in feet per year.

Interval is variable

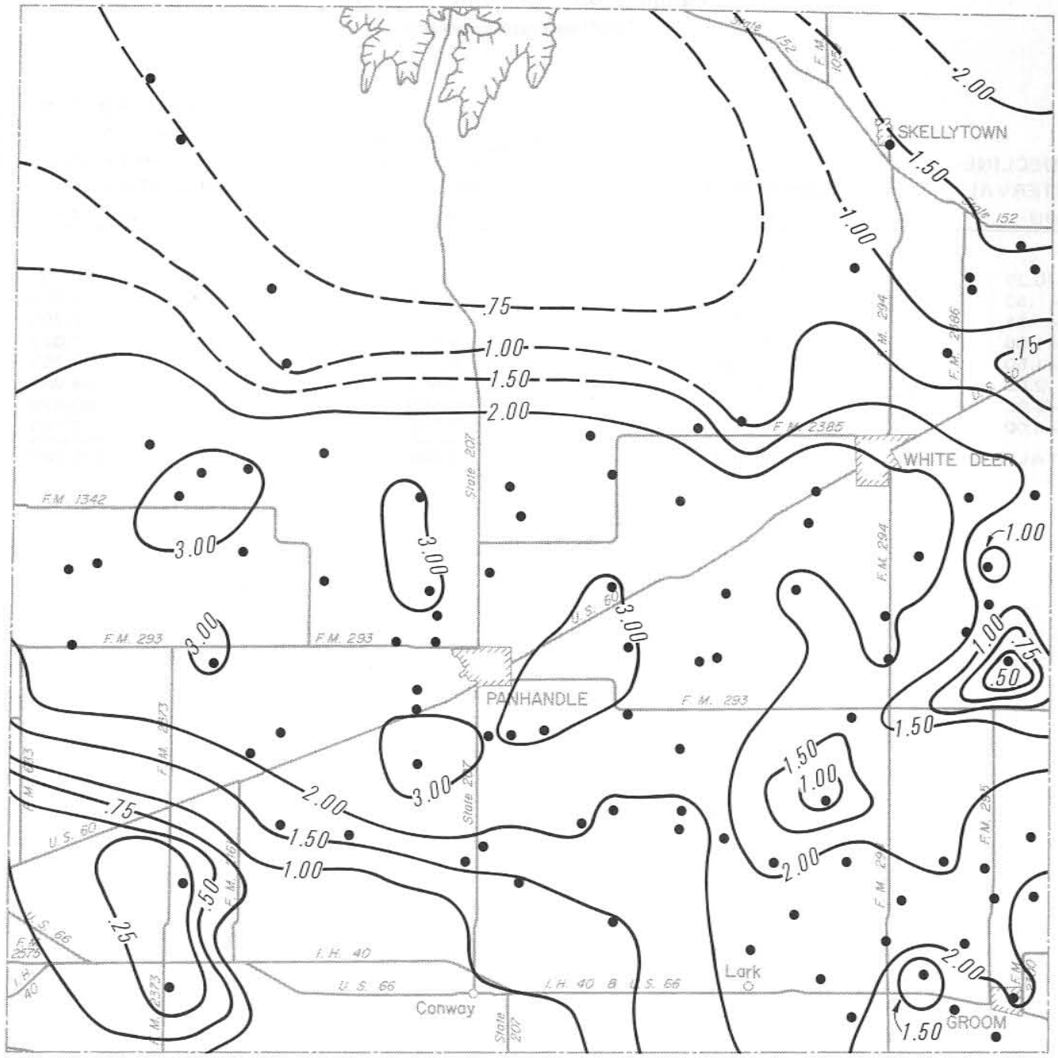


2000
Projected Rates of Water-Level Decline

2010

Pumpage Corresponding to Mapped Decline-Rate Intervals

MAPPED DECLINE-RATE INTERVAL (feet)	SURFACE AREA (acres)	STORAGE CAPACITY OF DEWATERED SECTION (acre-feet)	ESTIMATED PUMPAGE RATE, INCLUDING NATURAL RECHARGE AND IRRIGATION RECIRCULATION (acre-feet per year)
0.00–0.25	1,041	29	80
.25– .50	3,423	207	385
.50– .75	6,201	597	941
.75–1.00	22,207	2,955	4,264
1.00–1.50	48,128	9,159	12,281
1.50–2.00	58,463	15,485	19,714
2.00–3.00	146,388	56,482	68,839
3.00–4.00	23,091	10,781	12,917
TOTAL	308,942	95,695	119,421

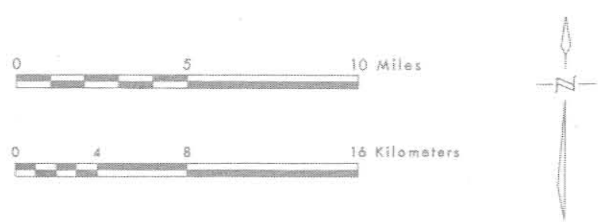


EXPLANATION

•
Well used for control

——1.25——
Line showing approximate rate of decline in water level, in feet per year.

Interval is variable

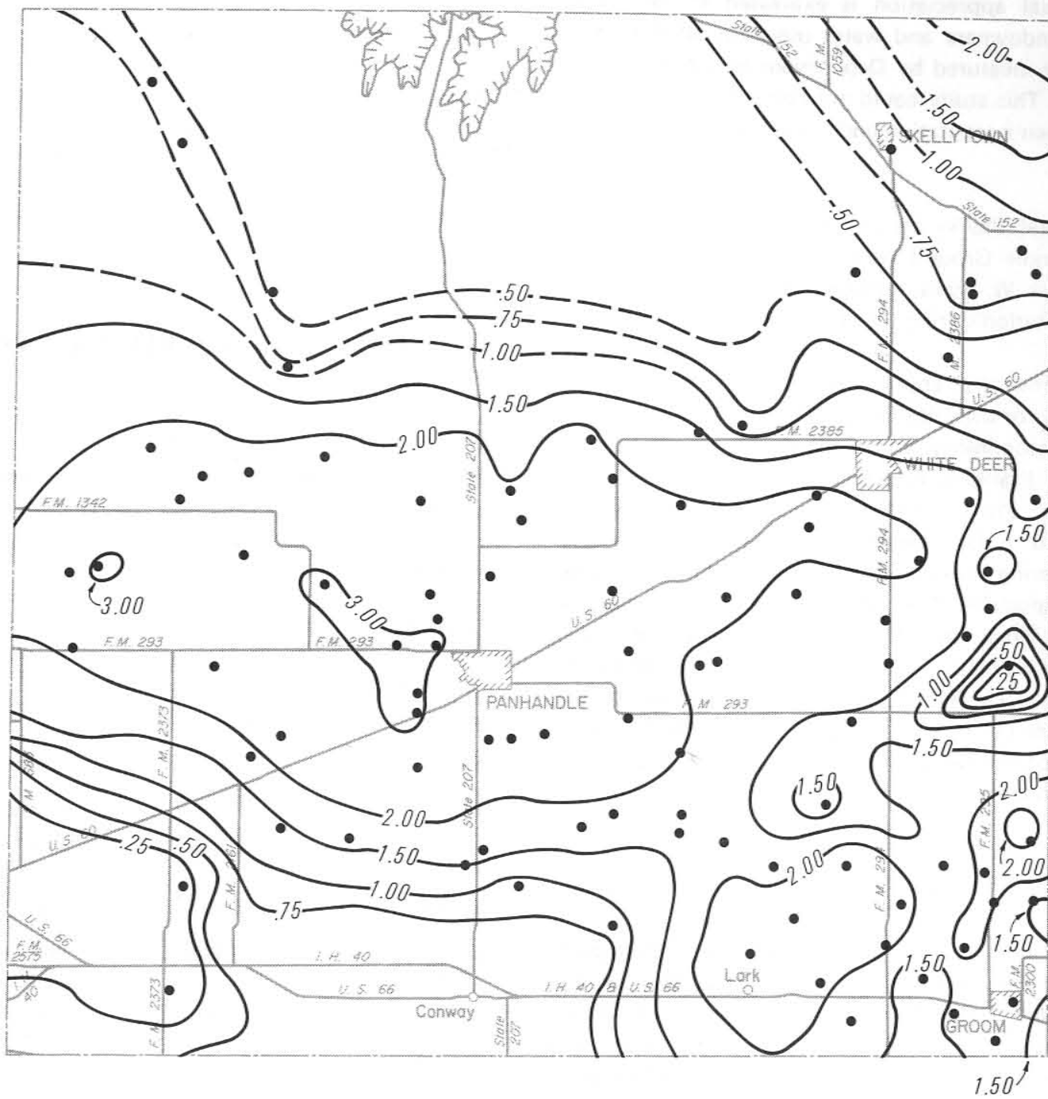


2010
Projected Rates of Water-Level Decline

2020

Pumpage Corresponding to Mapped Decline-Rate Intervals

MAPPED DECLINE-RATE INTERVAL (feet)	SURFACE AREA (acres)	STORAGE CAPACITY OF DEWATERED SECTION (acre-feet)	ESTIMATED PUMPAGE RATE, INCLUDING NATURAL RECHARGE AND IRRIGATION RECIRCULATION (acre-feet per year)
0.00–0.25	2,729	73	203
.25– .50	11,236	696	1,280
.50– .75	17,904	1,708	2,700
.75–1.00	26,492	3,466	5,027
1.00–1.50	45,799	8,776	11,753
1.50–2.00	74,590	19,602	24,981
2.00–3.00	125,727	46,558	56,976
3.00–4.00	4,340	1,970	2,366
TOTAL	308,817	82,849	105,286



EXPLANATION

•
Well used for control

——— 1.25 ———
Line showing approximate rate of decline in water level, in feet per year.

Interval is variable

0 5 10 Miles

0 4 8 16 Kilometers

N

2020
Projected Rates of Water-Level Decline

ACKNOWLEDGEMENTS

Special appreciation is expressed to the Carson County landowners and water users for allowing their wells to be measured by Department and Water District personnel. This study could not have been accomplished without their cooperation and the records obtained from their wells.

Special thanks are also expressed to the staff of the Panhandle Ground Water Conservation District No. 3, Mr. Felix W. Ryals, manager, for providing records and consultation during the study.

Additionally, appreciation is expressed to several individuals for consultation and for review and comment on the methodology and techniques employed in this study: Mr. Frank A. Rayner, former general manager of the High Plains Underground Water Conservation District No. 1; Dr. Donald Reddell, associate professor of Engineering, Texas A&M University; Mr. Leon New, irrigation specialist, Texas Agriculture Extension Service, Lubbock, Texas; Mr. Shelby Newman, superintendent, Texas Agricultural Experiment Station, Stephenville, Texas; Dr. C. C. Reeves, Jr., professor of Geosciences, Texas Tech University; and Dr. James Osborn, former chairman of the Department of Agricultural Economics, Texas Tech University.

STAFF INVOLVEMENT

This report is one of a series of county reports being published under the title "Analytical Study of the Ogallala Aquifer." Former staff member A. Wayne Wyatt was instrumental in initiating the study and coauthored a number of the previously published reports of this series.

The Carson County report was prepared under the supervision of Bernard B. Baker, head of the Ground Water Data Unit in the Texas Department of Water Resources' Data Collection and Evaluation Section, Dr. Tommy R. Knowles, chief. Numerous staff members of this Section assisted the authors in assembling and evaluating data and information. Overall technical supervision of the Ogallala study is exercised by C. R. Baskin, director, Data and Engineering Services Division. The Department's Information Systems and Services Office, David L. Ferguson, director, provided automated data processing and computational services, and prepared the manuscript copy of tabular and graphical displays.

METRIC CONVERSIONS TABLE

For those readers interested in using the International System (SI) of Units, the metric equivalents of English units of measurement have been given in parenthesis in the text. The English units used in tables of this report may be converted to metric units by the following conversion factors:

MULTIPLY ENGLISH UNITS	BY	TO OBTAIN SI UNITS
inches	2.540	centimeters (cm)
feet	.3048	meters (m)
miles	1.609	kilometers (km)
square miles	2.590	square kilometers (km^2)
gallons	3.785	liters (l)
gallons per minute	.06309	liters per second (l/s)
gallons per minute per foot	.207	liters per second per meter ([l/s]/m)
acre-feet	1,233.	cubic meters (m^3)
acre-feet	1.233×10^{-6}	cubic kilometers (km^3)
million acre-feet	1.233	cubic kilometers (km^3)

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