SATURATED-THICKNESS CHANGES

The map on this sheet illustrates the areal extent of saturated-thickness changes (in percent) that occurred from predevelopment to 1980 in the High Plains aquifer. The map was constructed by superimposing the 1980 saturated-thickness map (Weeks and Gutentag, 1981), and the predevelopment to 1980 water-level-change map (Sheet 1, this report), and calculating the percentage change in saturated thickness. Each saturated-thickness-change interval on the map shows the range of change that predominates in that area. Because of map scale, it is not possible to show small areas within each interval where saturated-thickness change may be more or less than that indicated.

The saturated-thickness-change map depicts areas of change in available water supply caused by pumpage. This map appears similar in some areas to the water-level-change map shown on Sheet 1 of this report. However, an area of large water-level change may not be shown on this map if the original saturated thickness was large and the change did not significantly alter the saturated thickness. Conversely, areas with small water-level changes may have a large percentage change in saturated thickness because of small predevelopment saturated thickness. For example, a water-level decline of 10 feet in an area where the predevelopment saturated thickness was 200 feet represents a change in saturated thickness of only 5 percent. However, a decline of 10 feet in an area where the original saturated thickness was 30 feet represents a change of 33 percent. Changes in saturated thickness are important because large changes in saturated thickness may be directly related to changes in well yield. Decreased well yields have been reported in parts of southwestern Kansas where saturated thickness has decreased 30 percent or more (Pabst and Gutentag, 1979, p. 5).

Two areas with significant increases in saturated thickness (greater than 10 percent) occur in Nebraska. These two areas are in Gosper, Kearney, and Phelps Counties; and Lincoln County. In each of these areas, recharge to the High Plains aquifer from surface-water irrigation projects has resulted in more than 10 percent increase in the saturated thickness of the aquifer. Increases in saturated thickness of more than 10 percent also occur in Logan County, Colorado; Kingman and Kiowa Counties, Kansas; Cimarron County, Oklahoma; and Dallam, Dawson, and Lynn Counties, Texas. These increases are the result of small water-level rises in areas with little saturated thickness (less than 100 feet, Weeks and Gutentag, 1981). Small rises in water levels in areas with thin saturated thickness result in significant percentage increases in saturated thickness.

Areas of significant decreases in saturated thickness generally are found where the aquifer has been pumped for irrigation for a long period of time. Large scale irrigation development began south of the Canadian River in the southern High Plains of Texas and New Mexico during the 1930's. Areas of more than 25 percent decrease in saturated thickness have occurred since the 1930's in nearly one-half of the southern High Plains. Areas of more than 50 percent decrease in saturated thickness occur in parts of Briscoe, Castro, Crosby, Deaf Smith, Floyd, Hale, Lubbock, Parmer, and Swisher Counties, Texas. Smaller areas of more than 50 percent decrease in saturated thickness are found in Curry and Roosevelt Counties, New Mexico, and in the southern-most part of the High Plains in Martin County, Texas.

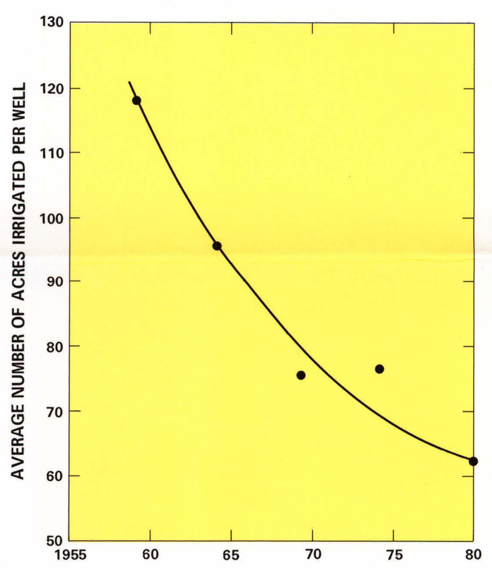
Between the Canadian River and the Kansas-Oklahoma State line, decreases in saturated thickness of 25 to 50 percent have occurred. Saturated thickness has decreased more than 25 percent in Dallam, Hansford, Hutchinson, Moore, Ochiltree, and Sherman Counties, Texas, and Beaver, Cimarron, and Texas Counties, Oklahoma. Irrigation began in this area during the 1940's. Although the saturated thickness in most of this area is 200 to 400 feet (Weeks and Gutentag, 1981), saturated thickness has decreased from 25 to 50 percent because of intensive irrigation.

Intensive irrigation also began in the 1940's in Kansas south of the Smoky Hill River. The earliest irrigation development in the area was in the vicinity of Ulysses in Grant County (McLaughlin, 1946, p. 73). Today, most of southwestern Kansas is irrigated by wells pumping water from the High Plains aquifer. Water levels have declined due to pumping, and in many areas there has been more than 50 percent decrease in saturated thickness.

In the area north of the Smoky Hill River, most of the irrigation development has taken place since 1960. Development was considerably earlier along the Platte River in Nebraska, but these wells draw much of their water from recharge to the aquifer from the Platte River. North of the Smoky Hill River, there are only very small areas of more than 25 percent decrease in saturated thickness caused by local pumpage. A large area of 10 to 25 percent decrease in saturated thickness occurs in large parts of Kit Carson and Yuma Counties, Colorado, and Cheyenne and Sherman Counties, Kansas, and a smaller area in Clay and Fillmore Counties, Nebraska. In these areas, irrigation pumpage is beginning to significantly reduce saturated thickness of the aquifer.

Changes in saturated thickness shown on the map are summarized by State in the accompanying table, which indicates that a significant (greater than 10 percent) increase in saturated thickness, mostly in Nebraska, has occurred in only 1 percent of the area, or about 1,700 square miles (1.1 million acres). There has been no significant (less than 10 percent) change in saturated thickness in 74 percent of the area, or 129,000 square miles (82 million acres). Significant decreases (more than 10 percent) in saturated thickness have occurred in 25 percent of the area, or about 44,000 square miles (28 million acres); saturated thickness has decreased more than 25 percent in 14,000 square miles (9 million acres). About 5 percent of the predevelopment volume of saturated aquifer material has been dewatered. However in New Mexico, 16 percent of the original volume has been dewatered and in Texas, 23 percent has been dewatered. No significant regional changes in saturated thickness of the High Plains aquifer have occurred in South Dakota or Wyoming.

In Texas, more than 10 percent decrease in saturated thickness has occurred in 74 percent, or 26,000 square miles (17 million acres), of the High Plains aquifer. Also, more than 25 percent decrease in saturated thickness has occurred in 29 percent of the aquifer, and more than 50 percent decrease in saturated thickness since predevelopment has occurred in 8 percent of the aquifer. Saturated thickness has decreased more than 50 percent in large parts of Castro, Crosby, Floyd, Hale, Lubbock, Parmer, and Swisher Counties, Texas. The impact of this depletion of the aquifer is illustrated by the following graph, which shows the decrease in the average number of acres irrigated by the wells in these seven Texas counties. Each data point on the graph is the average for all seven counties for each year of data.



The average number of acres irrigated per well in these 7 counties has decreased from 118 in 1958 to 62 in 1980. This decrease in acres irrigated per well is the result of decreasing well yields caused by declining water levels and decreasing saturated thickness in the aquifer. From 1958 to 1980, the number of irrigated acres in the 7 counties decreased from 2.5 million to 1.9 million, and the number of wells increased from about 21,000 to 30,000. The declining ground-water supply and increased pumping lifts in these seven counties have undoubtedly caused significant increases in farm-operation expenses. Similar impacts can be expected as ground-water development continues in other areas of the High Plains.

SELECTED REFERENCES

Bonnen, C. A., McArthur, W. C., Magee, A. C., and Hughes, W. F., 1952, Use of irrigation water on the High Plains: Texas Agricultural Experiment Station Bulletin 756, 43 p.

Borman, R. G., and Major, T. J., 1977, Water-level changes in the northern High Plains of Colorado, 1964 to 1976 and 1972 to 1976: U.S. Geological Survey Water-Resources Investigations 77-42, 1 sheet.

Gammon, S. W., and Muse, W. R., 1966, Water-level data from observation wells in the southern High Plains of Texas: Texas Water Development Board Report 21, 537 p.

Green, D. E., 1973, Land of the underground rain: Irrigation on the Texas High Plains, 1910-1970: Austin, Texas, University of Texas Press, 295 p.

Gutentag, E. D., and Weeks, J. B., 1980, Water table in the High Plains aquifer in 1978 in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Hydrologic Investigations Atlas 642.

Hart, D. L., Jr., Hoffman, G. L. and Goemaat, R. L., 1976, Geohydrology of the Oklahoma Panhandle, Beaver, Cimarron, and Texas Counties: U.S. Geological Survey Water-Resources Investigations 25-75, 62 p.

Hughes, W. F., and Magee, A. C., 1960, Some economic effects of adjusting to a changing water supply: Texas Agricultural Experiment Station Bulletin 966, 27 p.

Johnson, M. S., and Pederson, D. T., 1980, Groundwater levels in Nebraska, 1979: University of Nebraska, Conservation and Survey Division, Nebraska Water Supply Paper no. 50, 65 p.

McCall, K. D., 1944, Growth of irrigation in Scott County, Kansas: Kansas State Board of Agriculture Report, v. 63, no. 262, p. 1-31.

McLaughlin, T. G., 1946, Geology and ground-water resources of Grant, Haskell, and Stevens Counties, Kansas: Kansas Geological Survey Bulletin 61, 221 p.

Pabst, M. E., and Jenkins, E. D., 1976, Water-level changes in northwestern Kansas 1950-76: Kansas Geological Survey Journal, December 1976, 20 p.

Pabst, M. E., and Gutentag, E. D., 1977, Water-level changes in west-central Kansas, 1950-77: Kansas Geological Survey Journal, October 1977, 18 p.

______1979, Water-level changes in southwestern Kansas, 1940-78: Kansas Geological Survey Journal, May 1979, 29 p.

Waite, H. A., 1947, Geology and ground-water resources of Scott County, Kansas: Kansas Geological Survey Bulletin 66, 216 p.

Weeks, J. B., 1978, Plan of study for the High Plains regional aquifer-system analysis in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Water-Resources Investigations 78-70, 28 p.

Weeks, J. B., and Gutentag, E. D., 1981, Bedrock geology, altitude of base, and 1980 saturated thickness of the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Hydrologic Investigations Atlas 648.

White, W. N., Broadhurst, W. L., and Lang, J. W., 1946, Ground water in the High Plains of Texas: U.S. Geological Survey Water-Supply Paper 889F, p. 381-420.

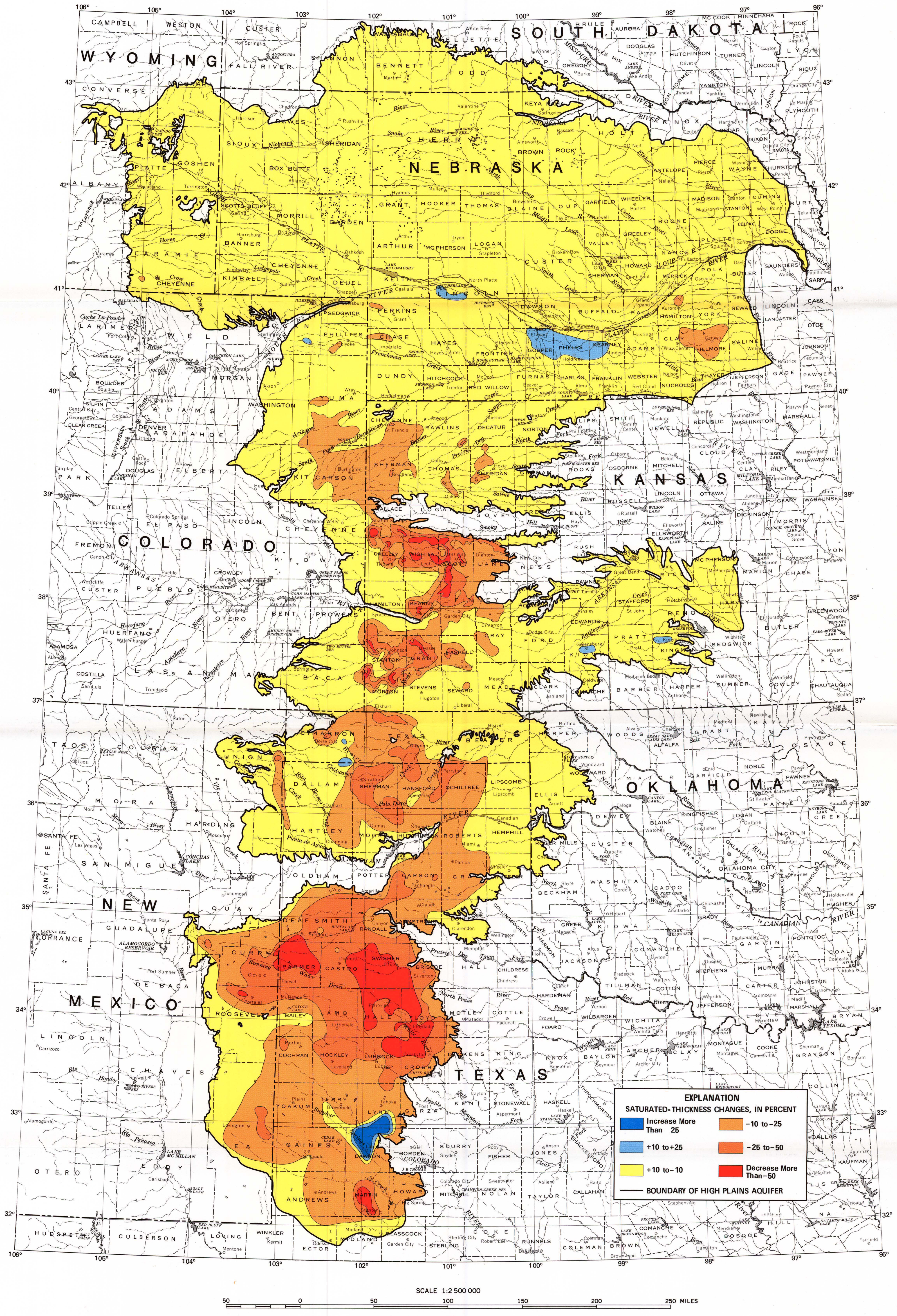
CONVERSION FACTORS

Multiply inch-pound units	*By*	*To obtain SI units*
foot	0.3048	meter
mile	1.609	kilometer
acre	0.4047	square hectometer
acre-foot	1,233	cubic meter
square mile	2.590	square kilometer
gallon per minute	0.06309	liter per second

DISTRIBUTION OF SATURATED-THICKNESS CHANGES AND VOLUME OF AQUIFER DEWATERED, HIGH PLAINS AQUIFER, PREDEVELOPMENT TO 1980

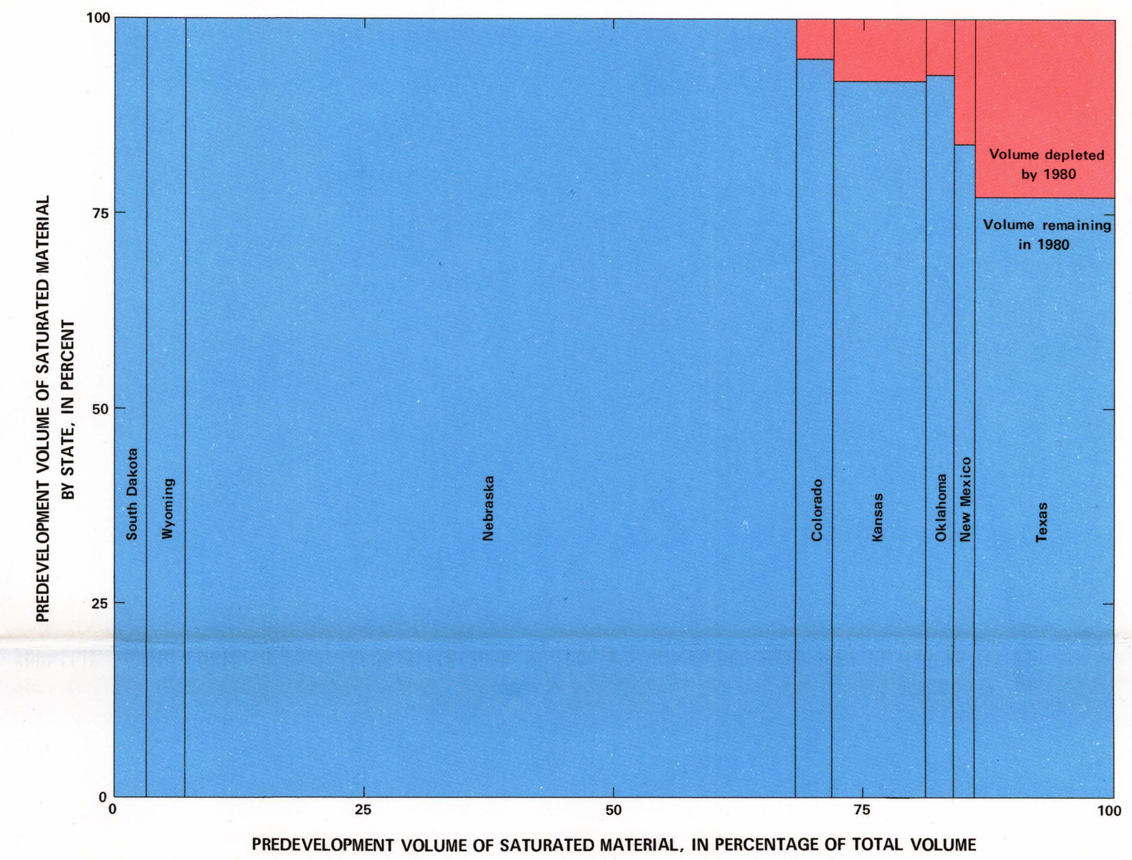
State	Area of High Plains aquifer within State[1] (square miles)	Percentage of area within each saturated-thickness change interval						Volume of aquifer material dewatered, in percent
		+25 to +50	+10 to +25	-10 to +10	-10 to -25	-25 to -50	-50 to -75	
Colorado------	14,900	-	-	86	14	--	--	5
Kansas--------	30,500	-	-	74	17	7	2	8
Nebraska------	63,650	-	1	98	1	--	--	--
New Mexico----	9,450	-	-	55	34	10	1	16
Oklahoma------	7,350	-	1	74	21	4	--	7
South Dakota--	4,750	-	-	--	--	--	--	--
Texas---------	35,450	1	-	25	45	21	8	23
Wyoming-------	8,000	-	-	--	--	--	--	--
TOTAL-----	174,050	-	1	74	17	6	2	5

[1]Areas revised from those previously published (Gutentag and Weeks, 1980, and Weeks and Gutentag, 1981); 1.6 percent change in total area.



PREDEVELOPMENT TO 1980 SATURATED-THICKNESS CHANGES

PREDEVELOPMENT AND 1980 SATURATED VOLUME OF AQUIFER MATERIAL

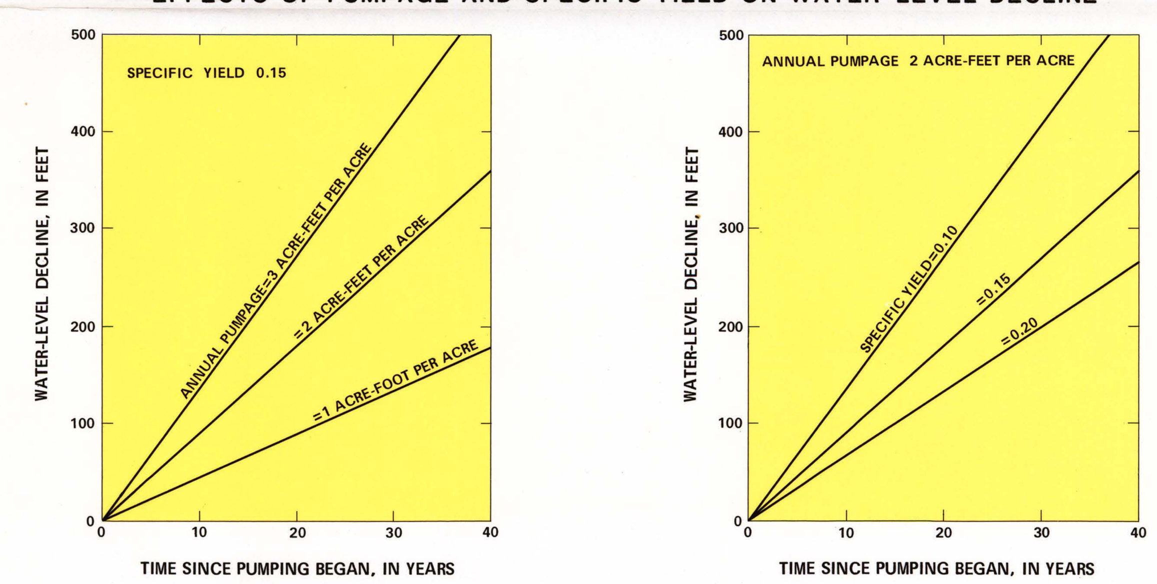


The predevelopment and 1980 volume of saturated material, in percent, is illustrated by State in the above bar graph. The width of the bars represents the proportion of saturated aquifer material in each state prior to development. For example, prior to development, about 3 percent of the saturated material in the High Plains aquifer occurred in Colorado and about 61 percent occurred in Nebraska. The height of the bars (shown in blue) represents the proportion of the original volume of saturated material in each State that remained in 1980. The upper area on certain bars (shown in red) represents the volume dewatered from predevelopment to 1980. For example, in Texas, approximately 77 percent of the original volume of saturated material remains and 23 percent has been depleted.

The area of each blue bar is proportional to the 1980 volume of saturated aquifer material in that state. The volume of saturated material in Nebraska is about 7 times the volume in Kansas, and about 20 times the volume in Colorado. The entire blue area of the graph shows that 95 percent of the original volume of the High Plains aquifer remained saturated during 1980. The red area shows that 5 percent of the aquifer material has been dewatered.

Although net depletion of the High Plains aquifer seems small (5 percent), it has significantly affected ground-water supplies in local areas. As shown in the table on this sheet, saturated thickness has decreased more than 25 percent in an area of 14,000 square miles (8 percent of the area of the High Plains aquifer). Also, saturated thickness has decreased more than 50 percent in an area of 3,500 square miles (2 percent of the area of the aquifer). Decreases in saturated thickness reduce well yields and increase pumping costs.

EFFECTS OF PUMPAGE AND SPECIFIC YIELD ON WATER-LEVEL DECLINE



The above graphs show a theoretical relationship between average annual pumpage, specific yield, and water-level decline in an area of irrigated cropland. The purpose of these graphs is to illustrate the relationship between pumpage, specific yield, and water-level decline; they are not meant to illustrate typical rates of water-level decline. Pumpage and specific yield are the two major factors that affect the rate of water-level decline in a uniformly developed well field. Specific yield is defined as the ratio of: (1) Volume of water which the saturated rock will yield to gravity drainage, to (2) volume of saturated rock. Specific yield multiplied by volume of saturated aquifer material is equal to volume of drainable water in the aquifer.

The graph on the left shows the effect of pumpage on water-level decline assuming a constant specific yield of 0.15. The graph on the right shows the effect of specific yield on water-level decline assuming constant annual pumpage of 2 acre-feet per acre. A change in either pumpage or specific yield will make a large difference in the rate of water-level decline (slope of the line): Doubling annual pumpage doubles the rate of water-level decline, and halving the specific yield also doubles the rate of water-level decline.

In developing these graphs, it was assumed that wells were uniformly spaced; 75 percent of the total area was irrigated; and 10 percent of the pumped water returned to the aquifer (90 percent consumed) after it was applied to the irrigated area. These assumptions are representative of areas in the High Plains irrigated by center-pivot systems without irrigating the corners. For example, if center pivots are to apply 2 acre-feet per irrigated acre of each quarter section (0.25 square mile), then the net annual withdrawal from the aquifer is 1.35 (2 x 75 percent x 90 percent) acre-feet per acre of surface area. Using a specific yield of 0.15, the water-level decline after pumping 2 acre-feet per irrigated acre for 20 years would be 180 feet as shown on the graphs.

The rates of water-level decline shown in these graphs do not represent typical rates of water-level decline in the High Plains aquifer, because recharge from precipitation is ignored and wells are not uniformly spaced throughout large areas. However, these rates of decline may be observed in small highly developed areas, where irrigated acreage approaches 75 percent of the total area. For example, the hydrograph from Floyd County, Texas, on sheet 1 shows 200 feet of water-level decline in 40 years. From the graph on the left with a specific yield of 0.15, 200 feet of decline in 40 years will result from annual pumpage of slightly more than 1 acre-foot per acre irrigated.

Base from U. S. Geological Survey
United States base map, 1972

INTERIOR—GEOLOGICAL SURVEY, RESTON, VA.—1980—W81513

WATER-LEVEL AND SATURATED-THICKNESS CHANGES, PREDEVELOPMENT TO 1980, IN THE HIGH PLAINS AQUIFER IN PARTS OF COLORADO, KANSAS, NEBRASKA, NEW MEXICO, OKLAHOMA, SOUTH DAKOTA, TEXAS, AND WYOMING

By
Richard R. Luckey, Edwin D. Gutentag, and John B. Weeks
1981

For sale by Branch of Distribution, U.S. Geological Survey, Box 25286, Federal Center, Denver, CO 80225