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LONG-TERM IRRIGATION TRENDS – TEXAS HIGH PLAINS

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ABSTRACT

The Texas High Plains is the most critical groundwater depletion area of the High Plains (Ogallala) Aquifer. The aquifer underlies parts of eight states in the Western Great Plains. Irrigation initially expanded in the central counties of the Texas High Plains during the major drought of the 1930s and peaked during the mid-1970s. Thereafter, continuing groundwater depletion of the Ogallala Aquifer, escalating pumping energy costs, low farm profits, and government set-aside programs stimulated a decline in irrigated area.

The irrigated area in the Texas High Plains declined from a peak of 2.25 million ha (6.0 million acres) in 1974 to 1.62 million ha (4.0 million acres) in 1989. Estimated annual groundwater use declined from 10.0 km^3 (8.1 million ac-ft) in 1974 to 5.6 km^3 (4.5 million ac-ft) in 1989. Although reduction in irrigated area was the major cause of the reduction in groundwater use, improved irrigation systems and water management practices have contributed to reduced water application. Groundwater depletion, which averages about 30% of predevelopment storage, will continue to limit long-term irrigated agriculture. However, continued reduction in irrigated area and adoption of water conservation technology are moderating the rate of groundwater use and water-table decline.

INTRODUCTION

Depletion of the groundwater threatens the long-term stability of irrigated agriculture in major parts of the Central and Southern High Plains. The most critical depletion area occurs in the Texas High Plains. This article documents and assesses the long-term irrigation trends and how these trends may continue into the future. The trends evaluated include the area of irrigated crops grown, estimated groundwater pumped and water application per crop, precipitation influences on water application, total irrigated area and number of irrigation wells, area irrigated in furrow and sprinkler application systems, decline in water-table elevations, yields by the major irrigated and dryland crops, and a brief consideration of some of the technologies influencing irrigation trends.

The primary data sources were county irrigation inventory reports by the Soil Conservation Service (SCS) for the Texas Water Development Board (TWDB Rep. 294, 1986) during 1958, 1964, 1969, 1974, 1979, 1980, 1984, and 1989; annual reports of field crop statistics by the Texas Agricultural Statistics Service (TASS), and annual data on water-table decline and new well permits by Underground Water Conservation Districts. Major parts of the irrigated area are in Water Conservation Districts that regulate well spacing and irrigation runoff that leaves the farm but do not allocate groundwater use for irrigation.

IRRIGATION DEVELOPMENT AND DECLINE

Irrigation from groundwater initially expanded in the Texas High Plains during the mid-1930s and accelerated after World War II and during the major drought of the 1950s. The irrigated crop area since 1935 and number of irrigation wells since 1958 are presented in figure 1. As irrigated crop area has declined since the 1974 inventory, the numbers of irrigation wells pumped have declined to an estimated 81% in 1989. Many old irrigation wells have been replaced or abandoned as irrigated land has declined.

Texas High Plains statistical reports are for a 41-county area that has about 4.3 million ha (10.5 million ac) in cropland and a similar area in grassland. Counties included have partial or total boundaries within the Ogallala Formation, as shown in figure 2. Aquifer storage was

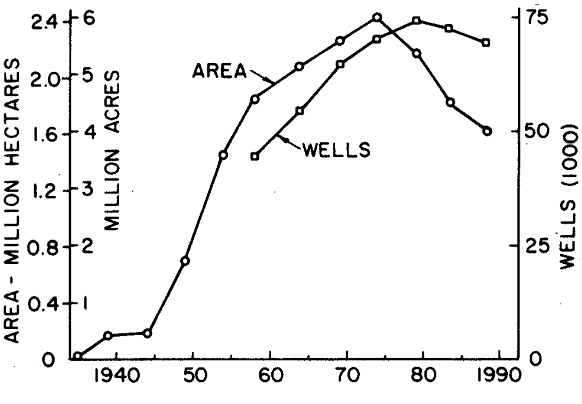

Figure 1–Irrigated crop area and number of irrigation wells for a 41-county area, Texas High Plains. Data sources: U.S. Agricultural census and Texas Agricultural Extension Service prior to 1958 and county irrigation inventories, Soil Conservation Service, since 1958.

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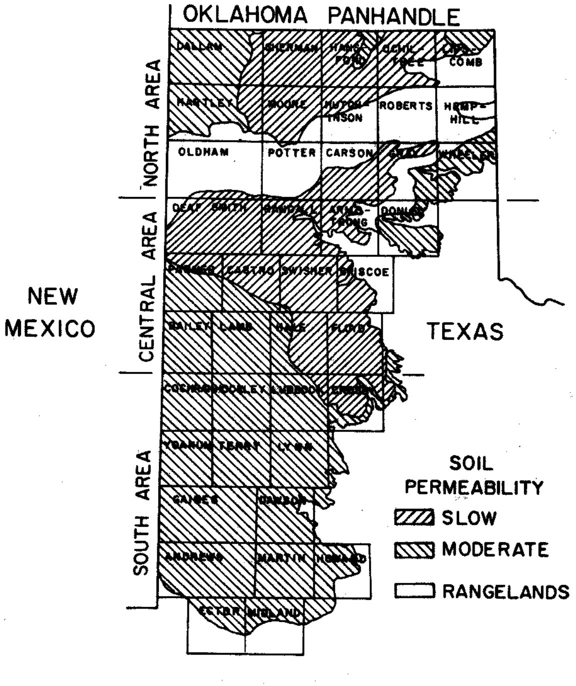


Figure 2–The irrigated area of the Texas High Plains overlaying the Ogallala aquifer divided into the North 15-, Central 12-, and South 14-county areas into the major soil groups of slow and moderate permeability. Data source: Musick et al., 1978.

estimated as 519 km^3 (420.6 million ac-ft) in 1980 with 475 km^3 (384.8 million ac-ft) estimated as recoverable for irrigation (Knowles, 1984). Saturated thickness was less than 6.1 m (20 ft) for 9% of the area, between 6.1 and 30.4 m (20 and 100 ft) for 46%, between 30.4 and 60.8 m (100 and 200 ft) for 27%, between 60.8 and 91.2 m (200 and 300 ft) for 14%, and greater than 91.2 m (300 ft) for 4% of the area.

The 41-county area was divided into North, Central, and South sub-areas because of major differences in crops, soils, irrigation systems, groundwater storage, and water-table decline. The long-term average monthly precipitation for the three subareas is shown in figure 3.

Irrigation development in the Texas High Plains began when dryland farmers started drilling irrigation wells in the Ogallala aquifer during the major drought of the 1930s when yields of dryland crops were very low and drought relief financial assistance became available. The low dryland yields and the substantial yield response to irrigation led to the dryland crops becoming the major irrigated crops. Grain sorghum and winter wheat became the major irrigated crops in the North area; grain sorghum, wheat, and cotton in the Central area; and cotton and grain sorghum in the South area. In the late 1960s, irrigated corn yields surpassed irrigated grain sorghum yields; and corn expanded during the 1970s to become a major irrigated crop in parts of the North and Central areas having more favorable groundwater storage. In the areas where corn expanded as a major crop, it mostly replaced irrigated grain sorghum.

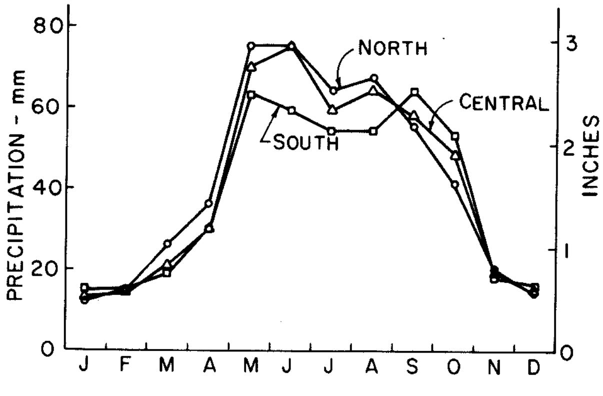


Figure 3–Average 68-yr monthly precipitation for 20 sites in the North area and 16 sites each in the Central and South areas, Texas High Plains.

The rapid irrigation development that began in the late 1940s in the Central and South areas peaked during the 1960s (fig. 4). Rapid development was delayed about one decade in the North area because of deeper groundwater storage and peaked in the late 1970s. Development was most intense in parts of the Central and South areas having shallow depth to groundwater and moderate to high well yields. The peaking of the total development in the mid-1970s and the subsequent decline is associated with the decline in water-table elevations and well yields, greatly increased pumping energy costs, and low profits from irrigated field crop production (Lansford et al., 1987).

The irrigated area in furrow and sprinkler systems for inventory years during 1958-89 is shown in figure 5. Irrigation initially developed primarily using graded

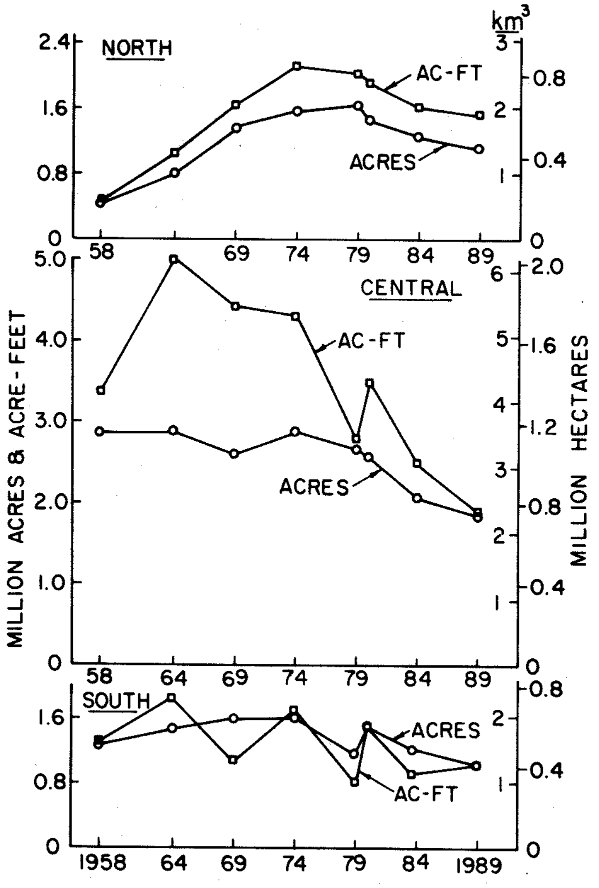


Figure 4–Irrigated crop area and estimated groundwater pumped for the eight irrigation inventory years, 1958-89, North, Central, and South areas of the Texas High Plains.

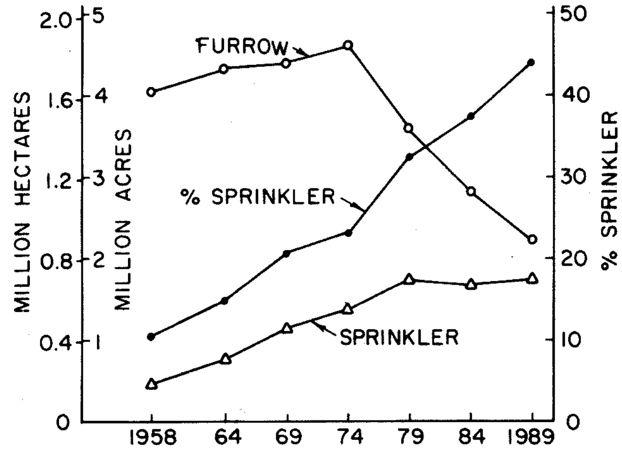


Figure 5–Crop area in furrow and sprinkler irrigation systems and percent of crop area sprinkler irrigated, 1958-89, Texas High Plains.

furrows as water application systems. The period of major expansion led to both furrow and sprinkler systems developing on the moderately permeable soil areas. For the most part, only furrow application systems developed on the slowly permeable soils which comprised 41% of the irrigated area in 1984 (Musick et al., 1988). In 1984, sprinkler irrigation was practiced on 0.6 million ha (1.47 million ac) of moderately permeable soils and 60 000 ha (147,000 ac) of slowly permeable soils. During the 1974 through 1989 period of irrigation decline, furrow irrigated area declined from 1.86 to 0.90 million ha (4.60 to 2.23 million ac) or 52%. Sprinkler irrigated area declined by 30% in the South area and increased by 86% in the Central and North areas and totaled 0.71 million ha (1.75 million ac) or 44% of total irrigated crop area in 1989.

The decline in furrow irrigation is associated with relatively low application efficiencies, primarily associated with deep percolation losses on moderately permeable soils. Furrow application efficiencies, estimated in the 1984 irrigation inventory by counties, averaged 58% for moderately permeable soils and 72% for slowly permeable soils without considering reuse of tailwater runoff (Musick et al., 1988). Application efficiencies for 223 center pivot sprinkler irrigation tests by the SCS in the early 1980s averaged 83%.

Although sustained periods of low farm profits are a major problem in maintaining irrigated area, the more significant long-range problem is the continuing depletion of groundwater storage. By 1980, Gutentag et al. (1984) reported that groundwater storage estimates in the High Plains Aquifer (parts of eight states) had declined by about 205 million km^3 (166 million ac-ft). About 141 million km^3 (114 million ac-ft) of depletion occurred in the Texas High Plains and 36 km^3 (29 million ac-ft) occurred in Western Kansas. The decline in the Texas High Plains by 1989 is estimated to average about 30% of predevelopment storage with parts of some counties exceeding 50%. About 95% of the storage depletion was attributed to irrigation pumping (Gutentag et al., 1984).

Estimated groundwater application to irrigated crops during the 1958-89 inventory years averaged 7.7 km^3 (6.22 million ac-ft). The estimates through 1980 (8.3 km^3 or 6.72 million ac-ft) are similar to independent estimates reported by Gutentag et al. (1984), which averaged 8.4 km^3 (6.8 million ac-ft) for the 6 yr in which the U.S. Census of Agriculture data were taken from 1954 through 1978. The estimates of irrigation pumping substantially exceed estimates of depletion of predevelopment storage. The difference is probably associated with natural recharge, particularly during the wetter seasons, and with groundwater recharge occurring as return flow from deep percolation losses on irrigated land. Gutentag et al. (1984) reviewed published estimates of natural groundwater recharge that ranged from 0.4% to 2.5% of mean annual precipitation in counties having predominantly slowly permeable soils and 5% in counties having moderately permeable soils. Recharge of storm runoff to playas is substantial. Wood and Osterkamp (1984) estimated recharge of runoff reaching playas as high as 80%. Recharge occurs primarily through an annulus of higher permeability soil surrounding the playa floor since percolation rates are very low through the swelling clays of the playa floor.

The decline in irrigated area, along with the improvements in irrigation systems and management practices, has resulted in a decrease of water-table decline rates with time. The trends in water-table decline are illustrated in figure 6 for parts of the North, Central, and South areas in Underground Water Conservation Districts. The rise in the water table in the South area in recent years and the major slowing of the decline in the Central and North areas suggest potential for approaching stability of groundwater storage as the decline in irrigated area and adoption of water conservation technologies continue. However, another long-term drought, such as occurred during the 1950s, would likely accelerate depletion while reducing natural recharge. Although groundwater depletion has long been recognized as a major long-range problem that will eventually cause a substantial return to dryland cropping, Musick (1989) projected a stabilization phase to develop about the year 2000. This projection involves a

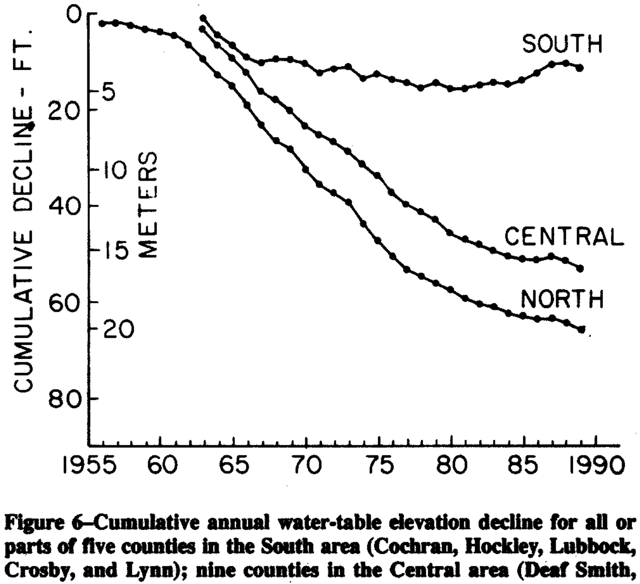


Figure 6–Cumulative annual water-table elevation decline for all or parts of five counties in the South area (Cochran, Hockley, Lubbock, Crosby, and Lynn); nine counties in the Central area (Deaf Smith, Randall, Armstrong, Parmer, Castro, Bailey, Lamb, Hale, and Floyd); and seven counties in the North area (Hansford, Hartley, Hutchinson, Lipscomb, Moore, Ochiltree, and Sherman). Data sources: South and Central areas, High Plains Underground Water Conservation District No. 1 (Gestes, 1988); North area, North Plains Underground Water Conservation District No. 2, Dumas, TX.

reduction of irrigated area to about 50% and groundwater use to about 40% of the 1974 development peak.

The decline in irrigation is difficult to accurately predict and is best approached by economic model studies such as Hughes and Harman (1968), High Plains Associates (1984), and Ellis et al. (1985). Detailed economic study was beyond the scope of this assessment. Lansford et al. (1987) describes some of the adjustments to changing economic conditions since 1970.

The favorable farm prices in relation to cost of production in the early to mid-1970s resulted in a continuation of the drilling of new wells and some further expansion in irrigated area in the North counties. The number of irrigation wells in the 41-county area increased in a linear relationship with time from 44,180 in 1958 to 70,700 in 1974 (fig. 1). The rate of increase slowed after 1974, with 73,710 reported in 1979. With the high cost of replacement wells, the moderately low pumping rates frequently attained, and the less favorable farm economics during the 1979-89 period, the estimated number of wells declined to 69,600 by 1989 (56,300 estimated as in use). The number of pumped wells will likely continue to decline as wells and pumping equipment continue to age. Replacement of abandoned and low efficiency units has been very low since the early 1980s and will continue to be limited (fig. 7).

CROP AREA

During the 1958-89 period, the irrigated area in the major crops averaged 30.6% in cotton, 28.0% in grain sorghum, 19.3% in winter wheat, and 9.4% in corn for grain (Table 1). These four crops accounted for 87% of the area irrigated during 1958-89 and 84% in 1989. Grain sorghum, wheat, and cotton are grown both as irrigated and dryland crops, while corn is grown only under irrigation. The percentage of harvested crop area that was irrigated was compared for a 6-yr period through 1974 with a similar period after 1981. Irrigated grain sorghum declined from 61 to 45% of the total production area, irrigated wheat declined from 41 to 37%, and irrigated cotton declined from 65 to 49%.

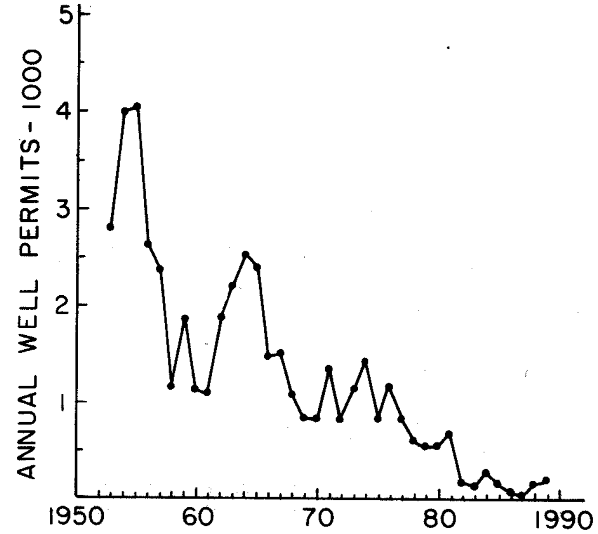


Figure 7–Annual irrigation well permits for all or parts of 14 counties in the High Plains Underground Water Conservation District No. 1, Lubbock, TX, 1953-89.

Minor crops irrigated during the 32-yr period averaged 3.3% of the irrigated area in forage-silage (mostly corn silage after the cattle feedlot industry developed in the 1960s), 2.3% in soybeans, 1.7% in alfalfa, 1.1% in other permanent hay-pasture, 1.1% in barley and oats, and 1.5% in vegetables including Irish potatoes (Table 1). Other crops (sugarbeets, pecans, peanuts, vineyards, and castor beans until the 1960s, sunflowers after the 1960s, and farm windbreaks) accounted for 1.7% of the total area irrigated.

The decline phase in irrigated area became evident from inventory data in 1979, which indicated a decline of 229 000 ha (565,000 ac) since 1974. A repeat inventory of the High Plains counties in 1980 (reported in Appendix data in Texas Dept. Water Resources Rep. 263, 1981) confirmed the decline indicated by the 1979 inventory. Subsequent

TABLE 1. Average crop area irrigated and estimated groundwater applied for 1989 and average for eight inventory years, 1958 to 1989

Crop	North		Central		South		41-county		Applied	
	ha	Ac	ha	Ac	ha	Ac	ha	Ac	mm	In
	(1000)		(1000)		(1000)		(1000)			
1989 Inventory										
Cotton	0.4	0.9	178.9	441.8	332.9	822.2	512.2	1264.9	259	10.2
Grain sorghum	106.0	261.8	109.7	270.9	42.4	104.7	258.1	637.4	348	13.7
Corn	81.4	201.0	150.0	370.4	2.4	6.0	233.8	577.4	587	23.1
Winter wheat	210.0	518.6	147.5	364.2	10.2	25.2	367.7	908.0	287	11.3
Barley-oats	6.0	14.7	7.6	18.8	0.4	1.1	14.0	34.6	284	11.2
Forage-silage	29.8	73.5	20.0	49.5	1.1	2.6	50.9	125.6	325	12.8
Alfalfa	7.7	18.9	14.9	36.7	4.9	12.2	27.5	67.8	538	21.2
Other hay-pasture	5.7	14.1	6.1	15.0	0.9	2.2	12.7	31.3	300	11.8
Sugar beets	0.1	0.3	15.7	38.7	0.0	0.0	15.8	39.0	386	15.2
Soybeans	5.7	14.0	64.5	159.2	3.5	8.6	73.7	181.8	384	15.1
Other oil seeds	1.5	3.6	16.1	39.9	1.3	3.1	18.9	46.6	218	8.6
Irish potatoes	0.4	1.0	5.9	14.6	1.2	3.0	7.5	18.6	386	15.2
Other vegetables	1.1	2.8	9.5	23.5	4.0	10.0	14.6	36.3	445	17.5
Peanuts	0.0	0.1	2.8	6.9	8.6	21.2	11.4	28.2	617	24.3
Pecans	0.0	0.0	0.2	0.5	1.7	4.2	1.9	4.7	401	15.8
Vineyards	0.0	0.0	0.2	0.5	1.0	2.4	1.2	2.9	249	9.8

TABLE 1. Average crop area irrigated and estimated groundwater applied for 1989 and average for eight inventory years, 1958 to 1989 (continued)

Crop	North		Central		South		41-county		Average applied	
	ha	Ac	ha	Ac	ha	Ac	ha	Ac	mm	In
	(1000)		(1000)		(1000)		(1000)			
1958-89 Inventory										
Cotton	1.1	2.8	249.3	615.7	382.3	944.2	632.7	1562.7	307	12.1
Grain sorghum	180.6	446.0	288.8	713.3	111.5	275.3	580.9	1434.6	417	16.4
Corn	57.8	142.8	135.3	334.1	1.3	3.3	194.4	480.2	554	21.8
Winter wheat	203.1	501.7	183.5	453.2	13.8	34.1	400.4	989.0	312	12.3
Barley-oats	5.5	13.7	14.5	35.8	2.3	5.6	22.3	55.1	287	11.3
Forage-silage	24.6	60.7	38.9	96.0	5.3	13.2	68.8	169.9	343	13.5
Alfalfa	7.6	18.8	18.2	45.0	8.7	21.6	34.5	85.4	627	24.7
Other hay-pasture	3.8	9.4	13.5	33.4	6.2	15.3	23.5	58.1	348	13.7
Sugar beets	0.7	1.8	8.6	21.3	0.0	0.0	9.3	23.1	554	21.8
Soybeans	3.4	8.4	41.8	103.3	3.2	7.9	48.4	119.6	389	15.3
Other oil seeds	0.7	1.8	7.2	17.8	1.7	4.1	9.6	23.7	259	10.2
Irish potatoes	0.2	0.4	5.5	13.5	0.8	1.9	6.5	15.8	549	21.6
Other vegetables	0.3	0.7	11.0	27.1	3.2	7.9	14.5	35.7	467	18.4
Peanuts	0.1	0.3	0.5	1.3	3.5	8.6	4.1	10.2	516	20.3
Pecans	0.0	0.0	0.2	0.4	0.8	2.0	1.0	2.4	533	21.0
Vineyards	0.0	0.0	0.2	0.4	0.5	1.3	0.7	1.7	310	12.2

inventories indicated the decline phase has continued through 1989 and was projected by Musick (1989) to continue to about the year 2000, considering a continuation of farm policies which reduce levels of price support and increase dependence on the market. The North, Central, and South area distribution of the total irrigated crop area decline was 87 800 (217,000 ac), 209 300 (517,000 ac), and 114 200 ha (282,000 ac), respectively, as the total irrigated area declined from 2.45 to 1.62 million ha (6.04 to 4.01 million ac) (fig. 4).

The major change in the Central area was the dramatic decline in irrigated grain sorghum between 1964 and 1979 (522 000 to 84 000 ha or 1.29 million to 208,000 ac). The expansion of irrigated corn area compensated for about 60% of the decline in irrigated grain sorghum. Considering the higher groundwater use for corn (Table 1), the shift from grain sorghum to corn was mostly a shift in water use to a crop with higher water requirements and yields with profits favoring the higher yields obtained with corn. The expansion peak in corn occurred during 1976-77 at 486 000 ha (1.19 million ac) (TASS annual reports); by the 1979 inventory, a substantial decline in irrigated corn area had already occurred. The irrigated area of corn in 1989 was 49% of the peak irrigated area in 1976-77.

The trend to managing reduced water application, along with adoption of the higher yielding semidwarf wheat varieties that began about 1979 (Musick et al., 1984), resulted in some expansion of irrigated wheat in association with the decline in irrigated corn area and earlier decline in irrigated grain sorghum area. Since 1974, the irrigated cotton area has declined by 16% in the Central area and 20% in the South area. Substantial year-to-year variations in irrigated cotton area has occurred due to variations in weather and farm programs (Lansford et al., 1987).

The most significant trend in the South area was the major decline in irrigated sorghum from 232 000 ha (572,000 ac) in 1969 to 32 500 ha (80,300 ac) in 1979 and the increase in irrigated cotton area that accounted for 30% of the decline in irrigated sorghum area. Very little irrigated corn (1.0% of the total corn area in 1989) and wheat (2.8% of the total irrigated wheat area in 1989) have been grown in the South area because of more restrictive water supplies and more favorable profits from irrigated cotton.

GROUNDWATER APPLICATION

Estimated groundwater application for irrigated crop production increased from 6.4 km^3 (5.17 million ac-ft) in 1958 to irrigate 1.84 million ha (4.55 million ac) to a peak of 10.0 km^3 (8.13 million ac-ft) in 1974 to irrigate 2.45 million ha (6.05 million ac). Gutentag et al. (1984) reported similar estimates during this period and provided earlier estimates of 2.0 km^3 (1.6 million ac-ft) in 1949 and 3.6 km^3 (2.9 million ac-ft) in 1954. The peak in irrigated area (1974 data) represented a period of favorable commodity prices and comparatively low pumping energy and other production costs. By 1989, groundwater applied had declined to 6.2 km^3 (4.50 million ac-ft) to irrigate 1.84 million ha (4.01 million ac).

The average estimated groundwater applied for the eight inventory years (1958-89) and for 1989 are presented for the 16 inventory crops and crop categories in Table 1. The estimated groundwater applied for the eight inventory years during 1958 through 1989 ranged from 467 to 315 mm (18.4 to 12.4 in.) and averaged 369 mm (14.5 in.). On a subarea basis, application averaged 389 mm (15.3 in.) in the North area, 399 mm (15.7 in.) in the Central area, and 288 mm (11.3 in.) in the South area. These data indicate similar overall groundwater use patterns in the North and Central areas and a lower use in the South area because of the predominance of irrigated cotton and limited remaining groundwater supplies.

Seasonal variations in precipitation and drought occurrence had some effect on the area irrigated and estimated groundwater applied. Drought has been a stimulus for expending the area irrigated and increasing water application. Water application for cotton was much more sensitive to precipitation than for corn, grain sorghum, and winter wheat. The most significant water application relationships with precipitation, using linear regression of average monthly data for the three areas, were April through August for cotton and June through August for grain sorghum (fig. 8). Preplant irrigation compared with seasonal irrigation is much more significant for cotton than for grain sorghum, and the best relationship for cotton included the preplant irrigation period of April and May. The linear regression slopes indicate that deficits in precipitation are normally fully compensated by increased water application for cotton and about one-half for grain sorghum. Also, the relationship indicates that as precipitation increases, less groundwater is pumped. Relationships for corn were less significant because of an increased water application trend over time for increased yields. Winter wheat is grown in drier parts of the year, and water application was less affected and poorly related to precipitation.

When compared with the full development inventory year of 1974, the decline in estimated total groundwater applied by 1989 averaged 45%; 27% in the North area, 56% in the Central area, and 38% in the South area, figure 4. The reduction in the North and South areas was mostly associated with the reduction in irrigated area, while both the reduction in irrigated area and the application depth contributed to the decline in groundwater use in the Central area.

Major interest developed in adoption of water conservation practices during the several years of energy cost escalation following the OPEC oil embargo in 1973. Estimated depth of groundwater applied for crops for the three inventory years of 1964, 1969, and 1974, (which reflects the full development period and low pumping energy costs) were compared with the average applied during the three inventory years of 1979, 1984, and 1989 (which represents a period of much higher energy costs and use of more efficient application systems such as expansion in sprinkler irrigation). Both periods included above- and below-normal precipitation seasons. Average water application depth decreased 35% for cotton, 18% for grain sorghum, and 19% for winter wheat, and averaged 15% less for all other crops except for corn which increased 17%. Crops that showed no significant time trend in water application were alfalfa, soybeans, Irish potatoes, other vegetables, and peanuts. Water application and the yield data examined for the major crops suggest that limited irrigation is practiced for cotton, winter wheat, grain sorghum, barley-oats, forage-silage, hay-pasture, sugarbeets, sunflowers, and vineyards. Average water application for all crop categories is presented in Table 1. In counties where grain sorghum is the primary crop, it is mostly grown under adequate irrigation for relatively high yields. In counties where it is a secondary crop to corn or cotton, it is widely grown under limited irrigation.

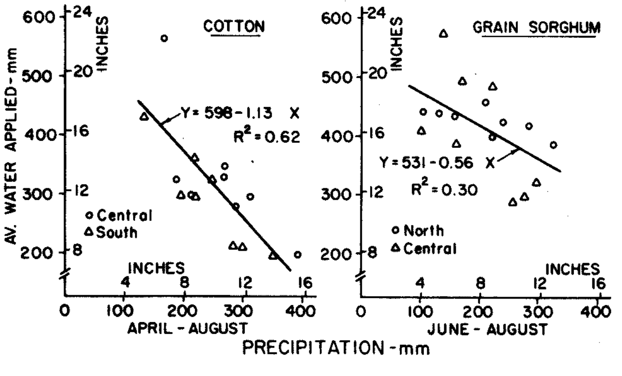


Figure 8–Effect of precipitation (and drought) on estimated groundwater applied in the Central and South areas for cotton and the North and Central areas for grain sorghum. Precipitation data were averaged for 20 sites in the North area and 16 sites each in the Central and South areas, and best-fit relationships found represent the preplant plus seasonal irrigation periods (April-August) for cotton and seasonal (June-August) for sorghum.

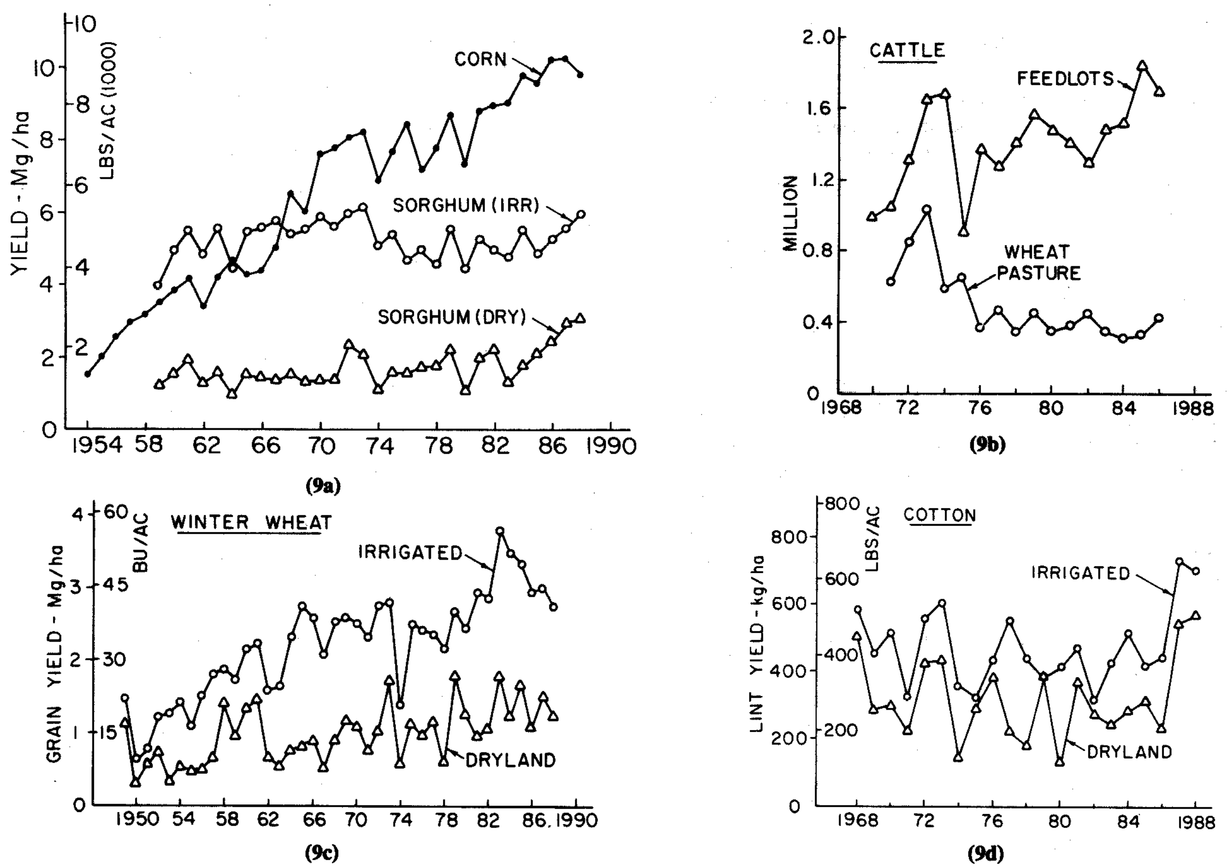
CROP YIELDS

Average yields based on harvested area were available for differing periods of record through 1988 for corn, grain sorghum, wheat, and cotton (TASS annual reports). Irrigated and dryland yields are presented for grain sorghum since 1958, for wheat since 1949, and for cotton since 1968. Irrigated yields are presented for corn since 1954 (fig. 9). Irrigated and dryland yields were compared for the common period of 1968-88. Grain sorghum yields averaged 5.30 and 1.81 Mg/ha (4,730 and 1,610 lbs/ac), respectively; wheat yields averaged 2.74 and 1.18 Mg/ha (40.8 and 17.5 bu/ac), respectively; and cotton yields averaged 471 and 326 kg/ha, (420 and 291 lbs/ac), respectively. Corn is grown only as an irrigated crop, and yields averaged 8.34 Mg/ha (7,450 lbs/ac or 133 bu/ac).

Dramatic yield increases have occurred over time for both irrigated corn and wheat. Grain sorghum hybrids were fully adopted by 1961, and their adoption resulted in increased irrigated yields by 20 to 25%. This effect of hybrid adoption is illustrated in figure 9 by the yield increase after 1959. After about 1973, irrigated grain sorghum experienced some yield decline which was associated with replacement of full season, high yield potential hybrids with corn in the favorable groundwater areas and the trend for grain sorghum to become a secondary crop in much of the area.

Irrigated corn yields were lower than irrigated grain sorghum yields through 1967. During this period, irrigated corn was a minor crop compared with irrigated grain sorghum and did not exceed 22 000 ha (54,000 ac) per year. As the expansion trend in irrigated corn began in the late 1960s, yields continued to increase due to use of improved hybrids and increased use of irrigation water, fertilizers, and other production inputs.

Cotton has a limited length of growing season in the Texas High Plains in relation to irrigated yield potential. Since 1968, both irrigated and dryland yields have declined. Regression analysis of yields through 1986 indicated an average annual decline of 3.9 kg/ha (3.5 lbs/ac) for irrigated yields and 6.2 kg/ha (5.5 lbs/ac) for dryland yields. The yield decline was attributed primarily to reduction in irrigation and fertilizer applications by Wanjura and Barker (1988). However, the high yields in 1987 and 1988 suggests a strong climatic influence that can affect yield trends.



(9a)

(9b)

(9c)

(9d)

Figure 9–Long-term average annual yields by irrigated corn irrigated and dryland grain sorghum, winter wheat, and feedlot stocker cattle numbers 1 January of each year on wheat pasture (mostly irrigated) and in feed lots, Texas High Plains. Data source: annual reports, Texas Agricultural Statistics Service, Austin, TX.

SIGNIFICANT CONTINUING TRENDS

The 33% reduction in irrigated crop area that occurred between 1974 and 1989 is likely to continue at a slower pace. Many of the irrigation facilities are aging and replacement wells are inadequate to maintain existing water supplies. As water-table levels continue to decline, but at a slower rate, increased emphasis is being placed on water conservation practices that increase application efficiencies and reduce system losses. Probably the most significant development for water conservation is the continuing trend in reducing irrigated area in less efficient furrow systems on moderately permeable soils and continued expanded use of center pivot sprinkler systems. Two significant technology trends are the adoption of surge-flow application to graded furrows, particularly on the moderately permeable soils, and LEPA (Low Energy Precision Applicator) sprinkler systems (about 300 systems were operational on center pivots by 1989). Recently, pumping energy costs appear to have plateaued, and natural gas costs have even declined slightly; thus, a period of relatively stable energy prices may continue for some time. Also, commodity prices and farm profits have stabilized and even risen somewhat in very recent years. These slight changes to more favorable economic conditions are not sufficient to stimulate expansion in irrigated area, and rapid expansion is unlikely to occur in the near future unless production declines dramatically in other areas, and prices increase dramatically.

The decline in irrigated area will continue to be most evident in the major field crops that are also grown widely in the Great Plains without irrigation. Specialty-crop irrigation is influenced by the development of markets that relate to timing of production and/or quality factors that influence competitive markets. The importance of crops such as vegetables, peanuts, pecans, and grapes for wine will likely continue. Although irrigated specialty crops are very significant to the growers, they are and will likely continue to be minor crops to the total irrigated area.

Cash receipts from livestock approach that from field crops in the Texas High Plains (Lansford et al., 1987). Cattle numbers in feedlots on 1 January increased from 988,000 in 1970 to about 1.4 to 1.7 million in the 1980s (fig. 9). Feedlot stocker cattle on irrigated and dryland wheat pasture (1 January of each year) declined from an annual average of 775,000 during 1971 through 1975 to an average of 386,000 from 1976 through 1986. No data are available since 1986.

The 1971 through 1975 period represents five consecutive years of above-normal fall precipitation for 36 precipitation sites located within the wheat production region of the Texas High Plains. The high numbers of feedlot stocker cattle on wheat pasture during this period is believed to be associated with favorable grazing conditions on both irrigated and dryland wheat. The major decline correlated with a shift to below-normal fall precipitation, increased grain prices which shifted some water application from fall grazing to spring grain production, and the effect increased pumping energy costs on limiting fall irrigation for grazing. Irrigated wheat has averaged 40% of the total wheat area harvested for grain and will continue to be important for producing forage for grazing stocker cattle. Also, irrigation will continue in importance for feed grain production to support the fat cattle feedlot industry.

The expansion of sprinkler irrigation as a percentage of the total irrigated area (44% in 1989) will continue to increase the overall water application efficiencies of irrigation systems, particularly as the decline in area irrigated by less efficient furrow systems continues. Research has led to development of practices for reducing water application in the Texas High Plains. These were reviewed by Musick and Walker (1987) as: (1) graded furrow management to reduce tailwater runoff; (2) reduction in graded furrow water intake by using wide-spaced furrows; (3) limited but increasing use of tractor wheel compaction of furrows to reduce excessive water intake; (4) use of surge-flow application to graded furrows; (5) reducing or eliminating the normally large preplant irrigation to graded furrows; and (6) applying fewer but more timely irrigations to the drought-tolerant crops in relation to critical stages of plant development for water stress. Under some management techniques such as the Limited Irrigation-Dryland (LID) system, reduced water application enhances irrigated yield response to rainfall by managing irrigated graded furrow fields without tailwater runoff and using a lower field dryland section containing furrow dams to prevent storm runoff (Stewart et al., 1983). Adoption of practices such as these will continue to increase and contribute to overall improvements in irrigation efficiencies for crop production.

The continued reduction in irrigated area and adoption of water conservation technology will further moderate the rate of groundwater use and contribute to sustainability of water-table levels in much of the Texas High Plains.

REFERENCES

Ellis, J.R., R.D. Lacewell and D.R. Reneau. 1985. Economic implications of water related technologies for agriculture, Texas High Plains. Texas Agric. Exp. Stn. MP-1577.

Gutentag, E.D., F.J. Heimes, N.C. Krothe, R.R. Luckey and J.B. Weeks. 1984. Geohydrology of the High Plains Aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. U.S. Geol. Survey Prof. Paper 1400-B, Washington, DC: U.S. GPO.

High Plains Associates. 1982. Six-state High Plains Ogallala Aquifer regional resources study. A report to the U.S. Dept. of Commerce and the High Plains Study Council, Austin, TX.

Hughes, W.F. and W L. Harman. 1969. Projected economic life of water resources, Subdivision No. 1, High Plains underground water reservoir. Texas Agric. Exp. Stn. Tech. Monograph No. 6.

Knowles, T.R. 1984. Assessment of ground-water resources of the Texas High Plains. *Proc. Ogallala Symp. II*, 217-237.

Lansford, V., W.L. Harman and J.T. Musick. 1987. The Texas High Plains: Adjustments to changing economic and resource conditions, 1970-85. Texas Agric. Exp. Stn. MP-1637.

Luckey, R.R., E.D. Gutentag and J.B. Weeks. 1981. 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. USGS, Dept. of Interior Atlas HA-542.

Musick, J.T., D.A. Dusek and A.C. Mathers. 1984. Irrigation water management of winter wheat. ASAE Paper No. 84-2094. St. Joseph, MI: ASAE.

Musick, J.T. and J.D. Walker. 1987. Irrigation practices for reduced water application - Texas High Plains. *Applied Engineering in Agriculture* 3(2): 190-195.

Musick, J.T., F.B. Pringle and J.D. Walker. 1988. Sprinkler and furrow irrigation trends, Texas High Plains. *Applied Engineering in Agriculture* 4(1):46-52.

Musick, J.T. 1989. Sustainability of low input limited irrigation-Southern Plains. ASAE Paper No. 89-2639. St. Joseph, MI: ASAE.

Stewart, B.A., J.T. Musick and D.A. Dusek. 1983. Yield and water use efficiency of grain sorghum in a limited irrigation-dryland farming system. *Agronomy Journal* 75: 629-634.

Texas Agricultural Statistics Service, Texas Dept. of Agriculture. Annual Reports of Texas Field Crop Statistics. Austin, TX.

Texas Department of Water Resources. 1981. Inventories of irrigation in Texas, 1958, 1964, 1969, 1974, and 1979. Rep. 263.

Texas Water Development Board. 1986. Surveys of irrigation in Texas, 1958, 1964, 1969, 1974, 1979, and 1984. Rep. 294.

Wanjura, D.F. and G.L. Barker. 1988. Simulation analysis of declining cotton yields. *Agric. Systems* 27(2): 81-98.

Weeks, J.B. 1986. High Plains regional aquifer-system study. In Regional Aquifer-System Analysis Program of the Geologic Survey Summary of Projects, 1978-84, ed. Ren Jen Sun, USGS Circ. 1002.

Wood, W.W. and W.R. Osterkamp. 1984. Recharge to the Ogallala Aquifer from playa lake basins on the Llano Estacado. *Proc. Ogallala Aquifer Symp. II*, 337-349.