A SUCCESSFUL WATER CONSERVATION PROGRAM IN A SEMIARID REGION OF NEBRASKA[1]

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ABSTRACT: Ground water irrigation pumpage of the High Plains Aquifer is controlled at the state level in Texas and Oklahoma but at the regional level in Kansas and Nebraska. Critical declines in the aquifer that threatened the reliability of local public water supply wells prompted Nebraska's Upper Republican Natural Resources District (URNRD) to mandate water restrictions in 1978. Under current regulations, irrigators may not extract more than 1,842 millimeters of water per certified hectare (ha) in any five-year period. Meter monitoring ensures that irrigators comply with restrictions. Farmers now incorporate irrigation scheduling into their cropping practices in order to meet URNRD controls. This study examines whether irrigators are using ground water efficiently while complying with pumpage limits. Crop irrigation requirements (CIR) from 1986 to 1999 were derived from a water balance approach incorporating Penman-Monteith evapotranspiration (ET) calculations from weather data supplied by the High Plains Climate Center automated weather station network. A ratio of average water pumped per well to the CIR was developed to verify irrigation efficiency. Results indicate that irrigation applications were less than CIR during most irrigation seasons. Irrigation efficiency increases can be attributed to crop rotations, favorable growing season precipitation, use of ET estimates to schedule irrigation, and water allocations limited to less than all certified hectares.
(KEY TERMS: crop irrigation requirement; evapotranspiration; irrigation efficiency; natural resources district; pumpage; water conservation.)

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BACKGROUND

The emphasis of this paper is on the efficiency of irrigators pumping from the High Plains or Ogallala Aquifer in southwestern Nebraska, where this aquifer has a history of depletion. The Ogallala Aquifer extends from Texas through Oklahoma and Kansas to as far north as Nebraska, with "fingers" of the aquifer extending into eastern New Mexico and Colorado (Bittinger and Green, 1980; McAda, 1984; Kromm and White, 1985, 1990, 1992). Thirty percent of the ground water pumped for irrigation today in the United States comes from the Ogallala Aquifer, and 80 percent of the ground water pumped from the Ogallala Aquifer goes to irrigated agriculture (Kromm and White, 1990).

Ground water depletion is a critical issue in the High Plains because aquifers provide nearly all the water used by farmers and municipalities. There are very few rivers or lakes, and precipitation is inadequate to support moisture intensive or continuous cultivation. Aquifer depletion threatens the economy of this semiarid area. Irrigated grains are fed to cattle locally, and the cattle are processed regionally; this agribusiness system depends on ground water (Holmes and Petrulis, 1988; Kromm and White, 1990).

Management of ground water in the four states overlying the bulk of the aquifer – Kansas, Nebraska, Oklahoma and Texas – varies from regional to state control. Nebraska's regional natural resource districts cover the entire state and are responsible for regulating ground water pumpage by irrigators. Districts are based on drainage basins. In Kansas, three ground water management districts manage water use from the Ogallala Aquifer in western and central portions of the state, whereas in Oklahoma, ground water restrictions and policies are administered at the state level. Texas, like Oklahoma, has no legislative authority to manage ground water at the local level; however, three underground water conservation districts conduct research and educational programs designed

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to help irrigators conserve water (Kromm and White, 1990).

The objective of this study was to examine the efficiency of Nebraska's URNRD management area irrigators while complying with pumpage limitations. Efficiency in this study means that producers are applying water at a rate equal to or less than what crops require, after accounting for effective precipitation.

Physiographic Setting of the URNRD

Severe ground water shortages in the URNRD have made the ground water management area strategies crucial in maintaining the region's continued vitality. The physical geography within the URNRD ground water management area can be divided into four general land classifications: plains, dissected plains, sand hills, and valleys (Conservation and Survey Division, 1969). The plains are relatively flat uplands with underlying alluvial sands, sandstones, or gravel sands. Dissected plains have been eroded by water and wind, resulting in moderate to steeply sloping lands. Sand hills are comprised of alluvial plains overlying thick deposits of sand or sandstone. Valleys are those areas of low relief along major tributaries. Plains constitute the major land classification within the URNRD, followed by sand hills, dissected plains, and valleys. Five major soil types are found within the URNRD: Keith-Rosebud, Anselmo-Keith, Valentine-Dunday, McCook-Las, and Keith-Colby (Nebraska Natural Resources Commission, 1982). Valentine-Dunday soils are composed of sand to sandy loam and are associated with sand hill areas. They have a relatively high saturated hydraulic conductivity that readily releases soil moisture from the root zone, resulting in a low moisture holding capacity. They are generally poor soils for production agriculture. Anselmo-Keith, Keith-Rosebud, and Keith-Colby soils are composed of silty loam to silty clay loam and are located within the plains and dissected plains regions. McCook-Las soils are sandy to silty loams found within the valley areas. These four soils generally have a lower saturated conductivity than the Valentine-Dunday sands and therefore have a better soil moisture holding capacity, resulting in higher crop productivity. The presence of the Valentine-Dunday soils in the URNRD makes them important to be addressed in developing approaches to conserve ground water.

With a few exceptions, the High Plains region is devoid of significant surface water resources. Enders Reservoir, with a surface area of 385 ha, is the largest reservoir within the URNRD (NDNR, 1998). The Republican and Frenchman Rivers are the largest streams within the URNRD. Several comparatively small tributaries flow into these rivers, but other creeks and streams in the URNRD are intermittent in nature.

According to the Koppen classification system (Oliver and Fairbridge, 1987), the URNRD is considered a cold steppe environment. By classification, annual evaporation exceeds precipitation, and average annual temperatures in such areas typically fall below 17.8°C. The normal annual precipitation for 1961 through 1990 in the URNRD ranged from 451 mm at Haigler to 486 mm at Imperial (National Oceanic and Atmospheric Administration, 1992). Growing season (April through September) precipitation averages 356 to 381 mm at the same locations, respectively. About half the precipitation from October through March falls in the form of snow and provides a nearly negligible contribution to soil water reserves. With data from all recording stations taken together, the 1961 through 1990 normal annual temperature for the URNRD is 10.6°C (National Oceanic and Atmospheric Administration, 1992). Average daily temperatures range from 24.6°C in July to -3.3°C in January. Average daily high temperatures range in July are from 32.6°C at Imperial to 33.8°C at Madrid, and average daily maximum and minimum temperatures in January are 4.2°C and -10.1°C at Imperial. Madrid has January average maximum and minimum temperatures of 3.9°C and -10.8°C, respectively. Overall, the URNRD's relatively high growing season temperatures, which are conducive to high evapotranspiration, and its low growing season precipitation accentuate the water demand for crop irrigation. These conditions need to be considered in any programs to conserve ground water.

The URNRD lies over the western extent of the Ogallala Aquifer. Throughout most of western Dundy and Chase counties, the depth to ground water is less than 15.2 meters (m). Ground water in storage within the management control area has average saturated thicknesses from 12.2 to 15.2 m (Steele and Wigley, 1991).

There are nearly 689,000 ha within the URNRD management control area. Approximately 16,000 ha are dedicated to gravity irrigation and 159,000 ha to center pivot irrigation (Peckenpaugh *et al.,* 1995). A total of 1,449 registered irrigation wells are located in Chase County, 1,037 irrigation wells in Dundy County, and 932 irrigation wells in Perkins County (USGS, 2001). High irrigation demands within the URNRD resulted in significant ground water level declines since predevelopment. As of 2000, ground water declines of up to 3.28 m occurred below 105,348 ha within the management area (USGS, 2001). Across an additional 214,878 ha, declines from 3.28 to 4.57 m were experienced. Across another 157,837 ha, declines were from 4.57 to 6.56 m. Across another 53,052 ha, declines were from 6.56 to 7.62 m. Finally, another 14,789 ha experienced declines greater than 7.62 m (USGS, 2001).

Regulatory Activities Relating to Ground Water Irrigation

This section covers how the URNRD dealt from a regulatory perspective with the ground water table declines discussed in the previous section. Nebraska's system for management of natural resources relies, in part, upon local natural resources districts (NRDs) (Figure 1), uniquely created by the merger of 154 special purpose districts in 1972 (Jenkins, 1975). Twenty-three NRDs now exist covering the entire state. An elected board of directors independently governs each. NRD programs are largely tax supported, and each NRD employs a full time professional staff (J. M. Jess, 1999, personal communication).

From their beginning, NRD responsibilities included development, preservation, and protection of soil and water resources, recreation, and wildlife management. The specific role of the NRDs in ground water management was outlined by the Nebraska Legislature in 1975. Initial ground water management objectives were quantitative in nature and intended as a means to sustain beneficial uses (J. M. Jess, 1999, personal communication). Since 1982, a series of legislative enactments expanded NRD responsibilities. In both educational activities and regulatory programs, the attention of many NRDs is now directed toward ground water quantity, ground water quality, and conjunctive uses, where surface water and ground water resources are known to have a hydraulic connection. Regulatory tools particularly relevant to the protection of ground water quantity include volumetric allocation limits for each water user, restrictive spacing for new wells, and moratoriums prohibiting construction of additional wells (J. M. Jess, 1999, personal communication).

The majority of the state's NRDs have created ground water management areas to regionally regulate ground water quantity, ground water quality, and conjunctive uses, where surface water and ground water resources are known to have a hydraulic connection. Because of ground water quality concerns, especially increasing nitrate concentrations, most management areas have been established to reduce nonpoint source contamination. Two designated areas, however, are managed to address ground water depletion and declining water levels. For several NRDs, future attention is expected to focus upon resolution of conflicts stemming from competing and currently unregulated ground water uses and surface water sources that are believed to be hydraulically interrelated. URNRD (Figure 1) was the first NRD in Nebraska to actively manage ground water. Its efforts began in 1978. Management efforts are directed toward stabilizing the saturated water thickness of the Ogallala (High Plains) aquifer underlying the NRD management area (J. M. Jess, 1999, personal communication). The Upper Big Blue NRD (UBBNRD) followed with its own ground water controls, which have received less attention and are less active.

At the heart of the URNRD's allocation scheme is the mandatory installation of flow meters on all large capacity wells. Measured in acre inches, the URNRD's rules limit the volume of water pumped during five-year time periods. If the five-year limit is not exceeded, agricultural users are free to pump as much as their crops need each year. Water users are entitled to carry forward accumulated allocation credits, if their measured ground water use was less than the limit established for a particular five-year interval. The URNRD board's initial five-year irrigation allocation was intended to take into account the URNRD's semiarid climate and the predominance of relatively low moisture holding, sandy soils. The initial allocation was 508 millimeters (mm) for 1979. Subsequent experience prompted reductions. The current five-year irrigation allocation is 1842 mm or 368 mm per year (J. M. Jess, 1999, personal communication).

As an additional means of slowing the general water level decline in the URNRD's portion of the High Plains aquifer, its board imposed restrictive spacing requirements applicable to the construction of new large capacity wells. Spacing restrictions were more severe in so-called "critical townships" where observations indicated water level declines continued at an unacceptable pace. The URNRD board's current set of management rules replaced the minimum spacing provisions and substituted a district wide moratorium which prohibits construction of new wells intended to pump more than 0.189 cubic meters per second (50 gallons per minute) (J. M. Jess, 1999, personal communication).

As an aside, the UBBNRD consists of all or part of several counties in southeastern Nebraska. A survey of the residents in Seward and York counties was conducted in 1998 to determine the residents' top three natural resources issues (Hoegh, 1999, unpublished M.S. thesis, University of Nebraska-Lincoln). Seward County residents did not rank water conservation in the UBBNRD control area as one of these three issues. However, the York County residents ranked water conservation as the second highest issue in the county. Seward County is only partly in the UBBNRD, while York County is entirely within the UBBNRD. Apparently, a ground water control area

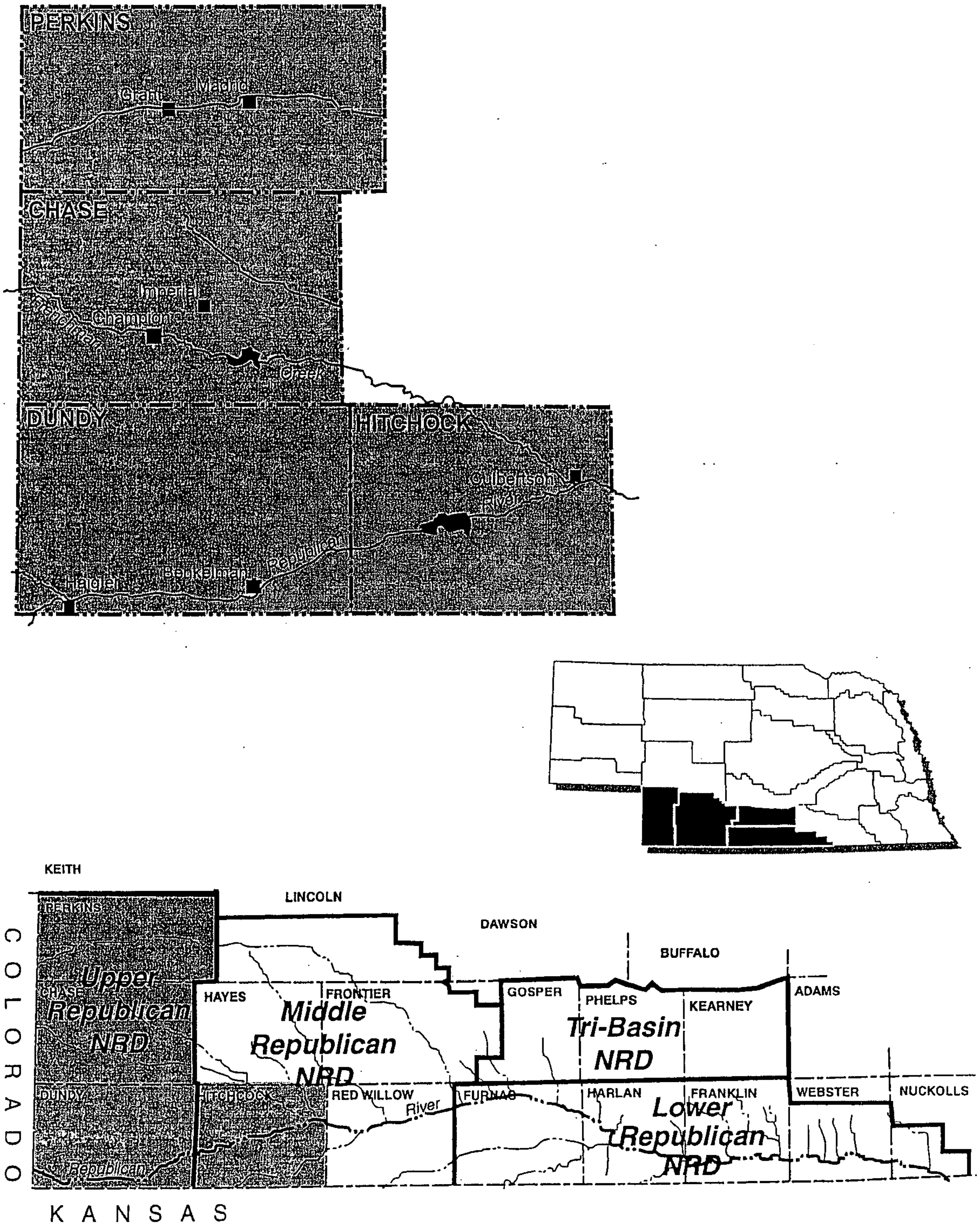

Figure 1. Location in Nebraska of the Upper Republican Natural Resources District(URNRD) and the Republican River.

encompassing an entire county is more likely to make residents cognizant of the need for water conservation, while the residents of a county only partly within the bounds of the UBBNRD control area are less likely to be concerned about water conservation (Hoegh, 1999, unpublished M.S. thesis, University of Nebraska-Lincoln).

DATA SOURCES AND COMPUTATIONAL METHODOLOGY

This section covers a procedure to compute irrigation efficiency and concludes with a discussion of the effectiveness of the URNRD ground water control area using the allocation limits reviewed in this and the previous section. Irrigation efficiency in this study means that producers are applying water at a rate equal to or less than crop requirements, after accounting for effective precipitation. Effective precipitation (P) is that moisture that infiltrates into the soil profile and is available for crop consumption after adjusting for runoff, deep percolation, and initial abstraction. Deep percolation is defined as the amount of moisture that will reach an aquifer.

For this study, a ratio (Rwc) between the amount of water pumped (WP) by producers and computed crop irrigation requirements (CIR) was developed for each growing season between 1986 and 1999. Before calculating Rwc, seasonal CIRs were adjusted to account for effective precipitation. When Rwc is less than one, producers applied less water than was required by crops, even after adjusting for the effective precipitation. Conversely, if Rwc is greater than one, more water was applied than was required.

$$Rwc = WP / CIR \qquad (1)$$

The amount of water pumped for irrigation in Chase, Dundy, and Perkins Counties for the study period was acquired from URNRD. These data were partitioned according to the quantity of water applied to corn and wheat acreage during each production season. The data were queried by crop and irrigation type in terms of depth of water applied in inches for each control area well for each year for the period 1986 to 1999. Since URNRD mandated water metering on all registered wells within the management area, this information should provide an accurate assessment of the quantity of water that was used by producers in each growing season from 1986 to 1999.

CIR daily values were determined by using a modified Penman-Monteith potential ET formulation (Jensen, 1980). Daily potential ET was determined for a well watered alfalfa crop at full canopy. These values were then adjusted by using a crop specific coefficient (Kcrop) directly related to the particular stage of development for the crop of interest.

$$CIR = Kcrop\ ET - P \qquad (2)$$

In order to calculate daily potential ET, effective precipitation (P), and subsequent CIRs, weather data from the High Plains Climate Center Automated Weather Data Network (AWDN) and National Weather Service daily rainfall stations were used. Two AWDN stations are located within the URNRD management area – Champion (Chase County) and Grant (Perkins County). No AWDN station is located within Dundy County, so the Champion station was used as a proxy. These stations were used for determining ET. National Weather Service stations in Imperial, Culbertson, and Grant were used to determine P in Chase, Dundy, and Perkins Counties, respectively. Culbertson is not in Dundy County as shown in Figure 1. Data gaps in the Benkelman and Haigler National Weather Service stations precluded using either of these stations for rainfall data for their county. Data input for the calculation of daily potential ET include relative humidity, wind speed, solar radiation, and air temperature. The most important variables to consider when calculating CIRs are the crop type, emergence date, and hybrid class.

Effective precipitation in Equation (2) was computed based on precipitation data from weather stations and experience developing soil moisture models by University of Nebraska-Lincoln, Institute of Agriculture and Natural Resources scientists (A. L. Dutcher, 2000, personal communication). For the soils of the URNRD, all rainfall was assumed to infiltrate the surface unless an event exceeded 2.54 cm (A. L. Dutcher, 2000, personal communication). If an event exceeded this amount, the remaining rainfall was assumed to become surface runoff. Both the infiltrated rainfall and runoff were summed for each growing season for each precipitation station. Infiltration becomes deep percolation or is taken up by the crop. Seventy percent of the infiltration was assumed to become crop uptake (A. L. Dutcher, 2000, personal communication), which is effective precipitation, or the variable P in Equation (2).

The curve number method (CNM) developed by the Natural Resources Conservation Service (Chow *et al.*, 1988) was used to compute runoff for the Champion AWDN station for the period 1986 to 1999 to help verify the validity of the above runoff calculation. Assuming the Chase County soils represented by this station had a soil moisture content typical of irrigated conditions, or CNM antecedent moisture condition III (Chow *et al.*, 1988), the growing season runoff total computed by CNM and the above approach by

Dutcher (2000, personal communication) gave virtually the same results.

Beside determining the above irrigation efficiency ratios, there is another means of determining the effectiveness of the URNRD control area. Since the ground water irrigation pumpage data were analyzed for the period 1986 to 1999, there were ten five-year pumpage moving averages that could be computed. Five-year ground water irrigation allocations in the URNRD have consisted of (1) 2,032 mm for sprinkler irrigation and 2,540 mm for gravity irrigation for the period 1983 to 1987; (2) 1,905 mm for both types of systems for the period 1988 to 1992; and (3) 1,842 mm for both types of systems for the periods 1993 to 1997 and 1998 to 2002. Two of the allocation periods fall entirely within the period 1986 to 1999 allowing comparison of ground water allocations for these two periods to the corresponding five year moving averages and helping determine the effectiveness of the control area.

RESULTS AND DISCUSSION

Analysis of Irrigation Efficiency in URNRD Control Area

This analysis reveals how efficiently irrigators are using ground water in the URNRD management area. Irrigation requirements from 1986 to 1999 for Chase, Dundy, and Perkins counties are presented in Figure 2a (corn) and Figure 2b (wheat). Corn required considerably less irrigation during 1996, wheat required considerably less irrigation during 1991, and both required little irrigation during 1993 and 1995. Corn did not require much irrigation in 1996, because of considerable rainfall late in the summer, when corn is irrigated the most. Wheat did not require much irrigation in 1991, because of considerable rainfall early in the summer, when winter wheat is irrigated the most. The timing of significant rainfall can have a large impact on the CIR throughout the URNRD. Above normal rainfall was observed in 1991, 1993, and 1995. Precipitation during 1987 and 1992 was below normal during the growing season, but timely rain events reduced irrigation demands for corn. Except for the 1992 growing season, wheat exhibited a similar trend. Although rainfall was above normal during the summer, it was below normal during the critical May pollination period.

Figure 3 shows ratios of pumpage to crop irrigation requirement computed with Equation (1) and illustrating the efficiency of the URNRD irrigators. Figure 3a represents the ratio of ground water pumped by gravity irrigation to the CIR for corn in Chase, Dundy, and Perkins Counties. Figure 3b is identical to Figure 3a, except it represents center pivot irrigation of corn. Figure 3c is identical to Figures 3a and 3b except it exhibits the ratio of ground water pumped to the CIR for center pivot irrigated wheat. No continuous gravity irrigation pumpage data were available for wheat in Chase, Dundy, and Perkins Counties. Figure 3 indicates that the ratio of ground water pumped to required irrigation water was frequently less than one. Figure 3 also implies that when the entire URNRD area is analyzed, producers applied less water than the crops required. Although some yield reductions may have occurred, most producers managed to remain within the water allocations set forth by the URNRD.

Some of the lower ratios presented in Figure 3 can be attributed to favorable precipitation during the growing season and nongrowing season soil water storage. Cool temperatures and timely precipitation during 1992 significantly reduced irrigation demands, evidenced by the dramatic drop in the ratio of water pumped to the CIR for corn in Figures 3a and 3b. Irrigators are able to bank unused water during years with favorable growing season precipitation and use it during drier growing seasons as long as they do not exceed the URNRD five-year allocation limits.

In addition to banking unused water, producers have become more creative in managing their water allocations (Klocke and Schneekloth, 1997). One example is irrigating lower water use crops. Another is applying water to only a portion of a previously irrigated tract of land while planting the remainder with a dry land crop, thereby allowing an increase in the irrigation application to the irrigated portion. Water application techniques now employed by producers include incorporating surge irrigation into gravity fed systems, reducing the distance from center pivot application hoses to the crop canopy, and delaying applications until the critical pollination and grain fill periods. Surge irrigation is an application technique in which irrigation water is discharged from only a portion of the length of gated pipe laid out for watering. This substantially increases the depth of water applied to that part of the field, resulting in the irrigation front always reaching the end of the field and a more uniform infiltration depth throughout the length of the field. Most irrigators track ET demands on a daily basis, measure available soil water on a regular basis, and continually scout fields in an effort to determine if the crop is undergoing stress. Tracking ET demand refers to the irrigator monitoring or calculating the loss of moisture from the transpiring crops and evaporation of moisture from the cropland soil surface.

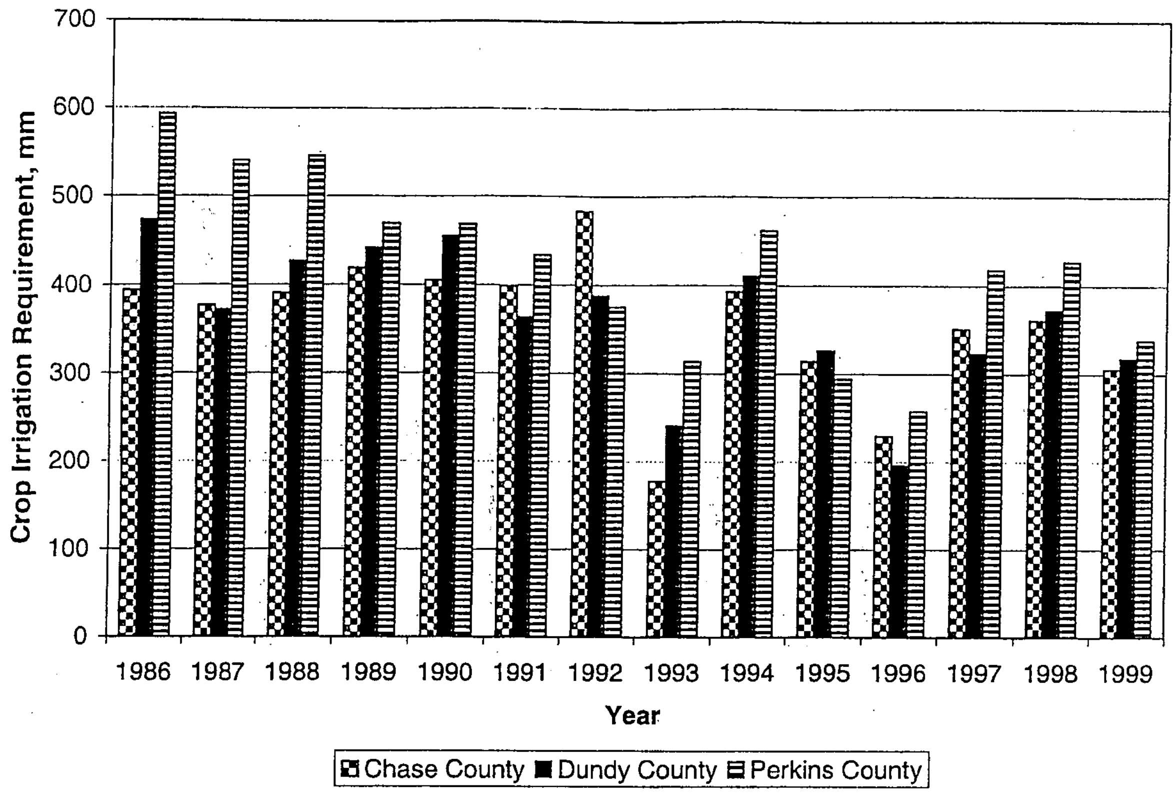

Figure 2a. Crop Irrigation Requirement for Corn.

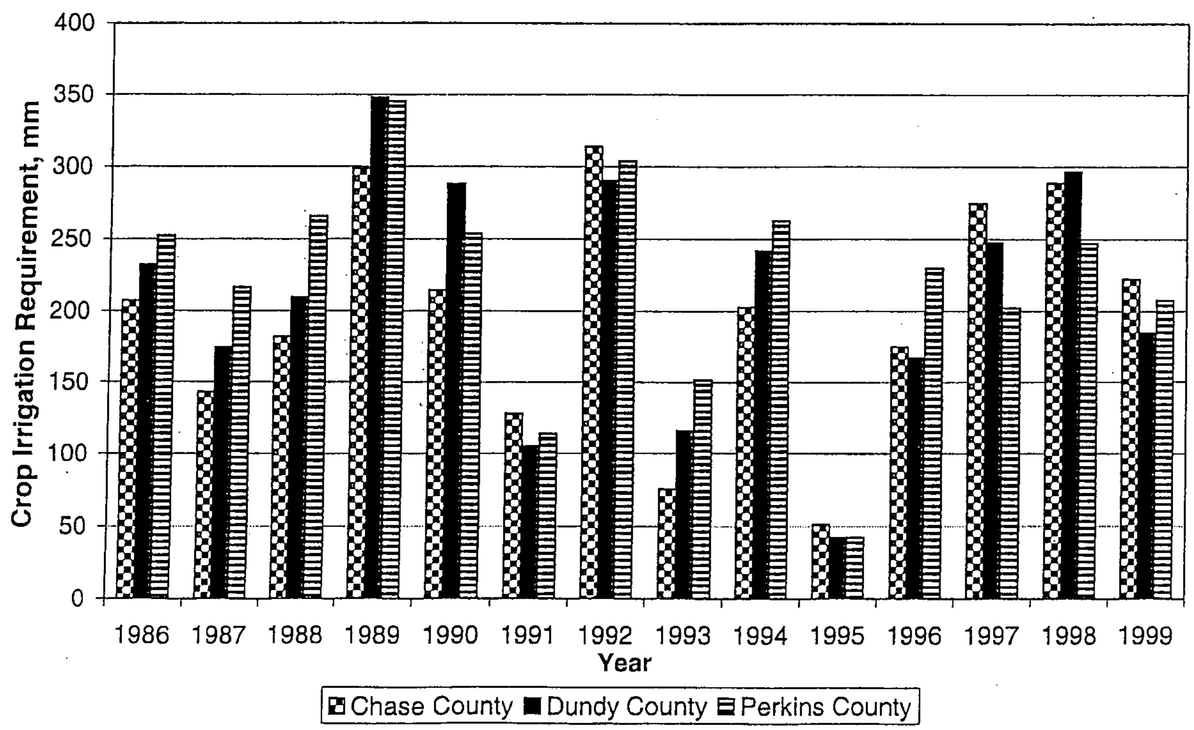

Figure 2b. Crop Irrigation Requirement for Wheat.

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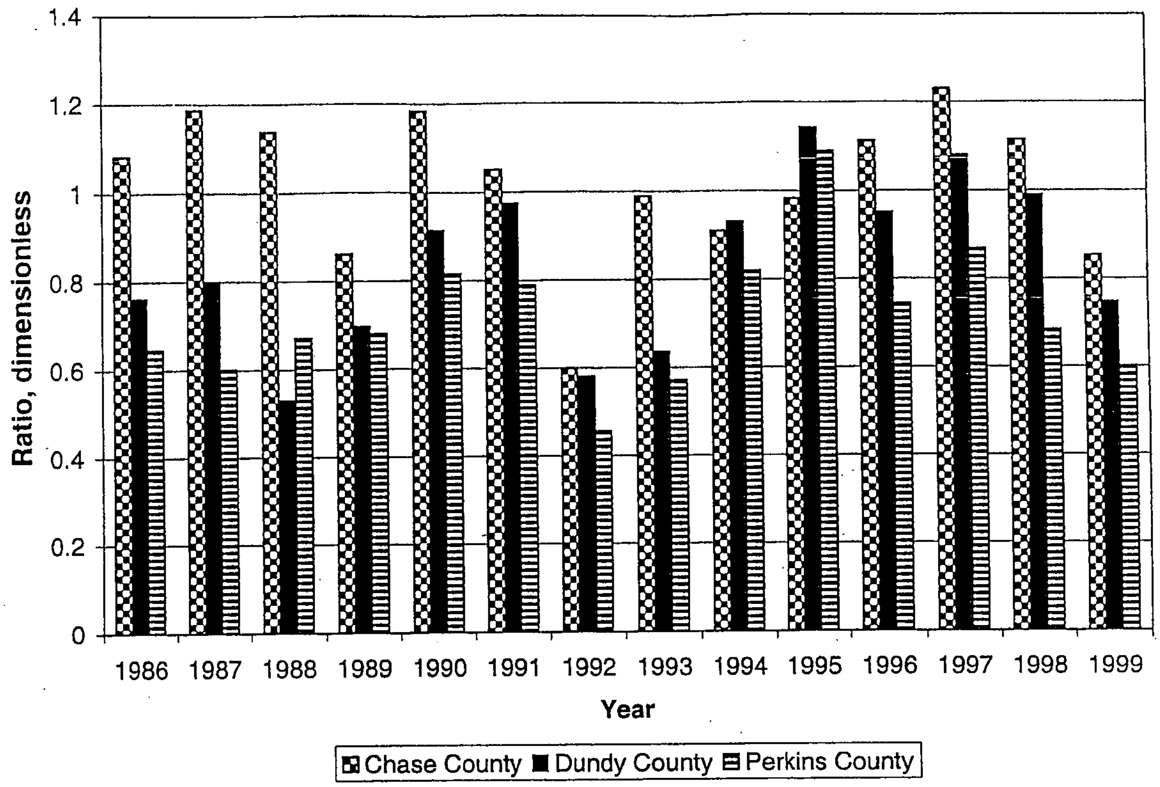

Figure 3a. Ratios of Pumpage to Crop Irrigation Requirement for Gravity Irrigated Corn.

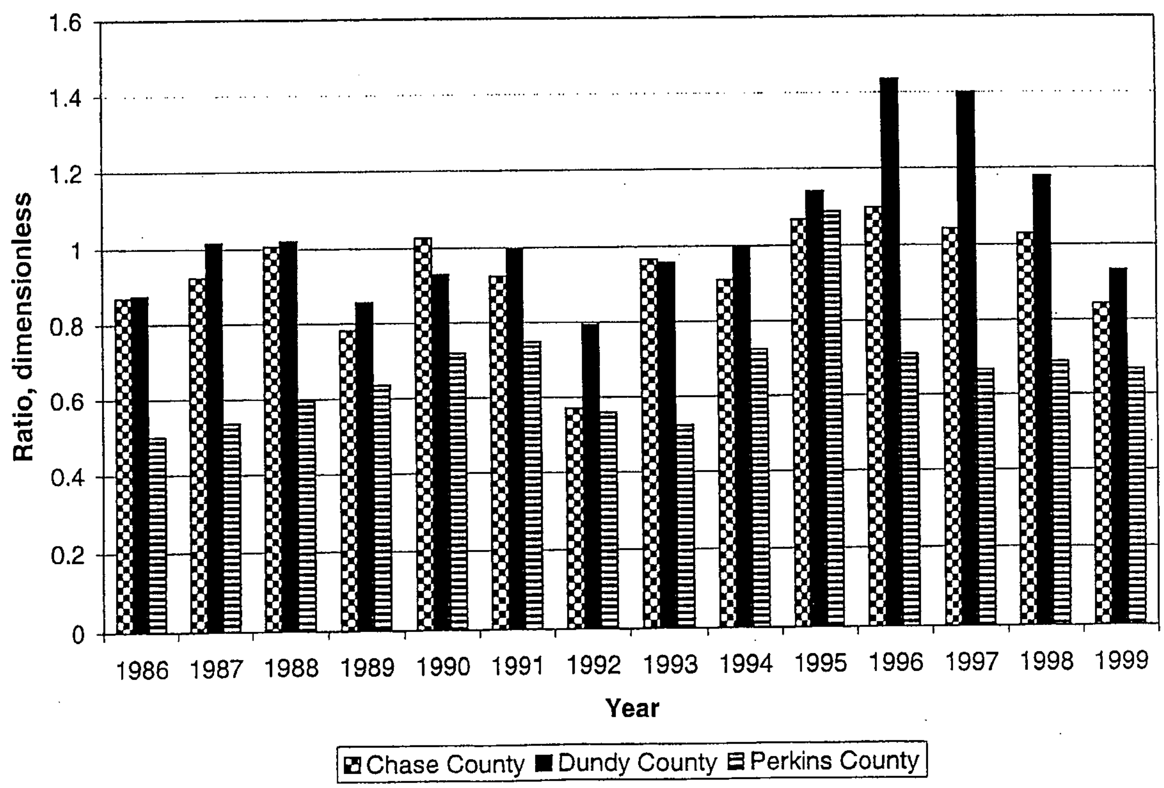

Figure 3b. Ratios of Pumpage to Crop Irrigation Requirement for Center Pivot Irrigated Corn.

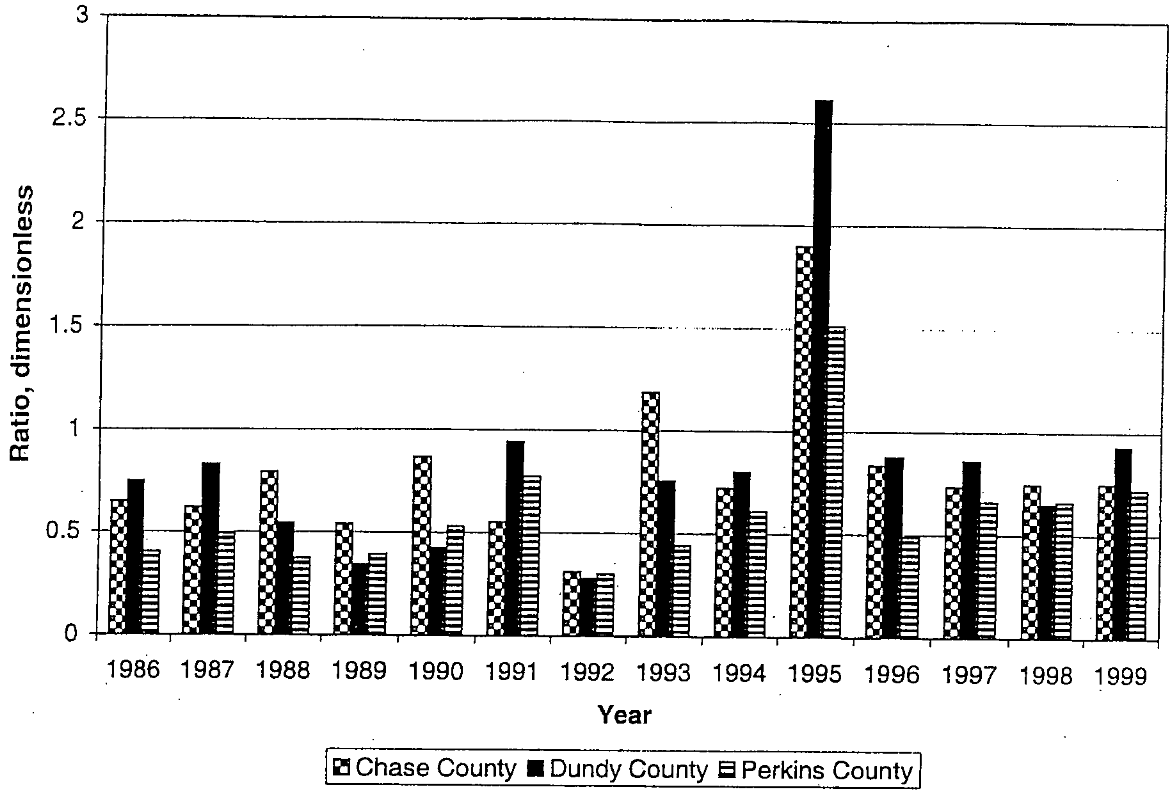

Figure 3c. Ratios of Pumpage to Crop Irrigation Requirement for Center Pivot Irrigated Wheat.

In order to make more efficient use of limited water supplies, many producers now alternate dryland and irrigated crops within the area under center pivot systems. A producer may only irrigate a portion of the area under the pivot, while planting a less water-demanding crop such as wheat and sorghum on the remaining area. Under this scenario, a farmer can increase applications on the irrigated section, since the water allocations are determined by the total registered area under each center pivot system. The farmer is not required to use the entire water allocation and can bank unused portions for future use in years where growing season climatic conditions are less favorable.

Figure 3c shows some results that need further explanation. The ratios of pumpage to CIR all exceed 1.5 for 1995. This would indicate the center pivot irrigated wheat producers were very inefficient in 1995. However, the pumpage for wheat was low relative to other years, while the CIR was significantly lower compared to other years as shown in Figure 2b. This caused the ratios in Figure 3c to appear excessive.

Analysis of Compliance with Allocation Program

Annual averages of ground water irrigation pumpage data from 1986 to 1999 for Chase, Dundy, and Perkins Counties are presented in Figure 4a (gravity irrigated corn), Figure 4b (center pivot irrigated corn), and Figure 4c (center pivot irrigated wheat). The five-year moving averages of these data are presented in Figure 5a (gravity irrigated corn), Figure 5b (center pivot irrigated corn), and Figure 5c (center pivot irrigated wheat). The pumpage limit set by the URNRD Board of Directors from 1988 to 1992 was a cumulative total of 1905 mm. The URNRD meter monitoring program revealed that the average pumpage rates for the three counties under URNRD control were 1,702 mm for gravity irrigated corn, 1,727 mm for center pivot irrigated corn, and 582 mm for center pivot irrigated wheat. The pumpage limit set for the period 1993 to 1997 was a cumulative total of 1,842 mm. Average pumpage rates for this period were 1471 mm for gravity irrigated corn, 1,504 mm for center pivot irrigated corn, and 658 mm for center pivot irrigated wheat (URNRD, 2000). Producers have been in compliance with URNRD pumpage limits.

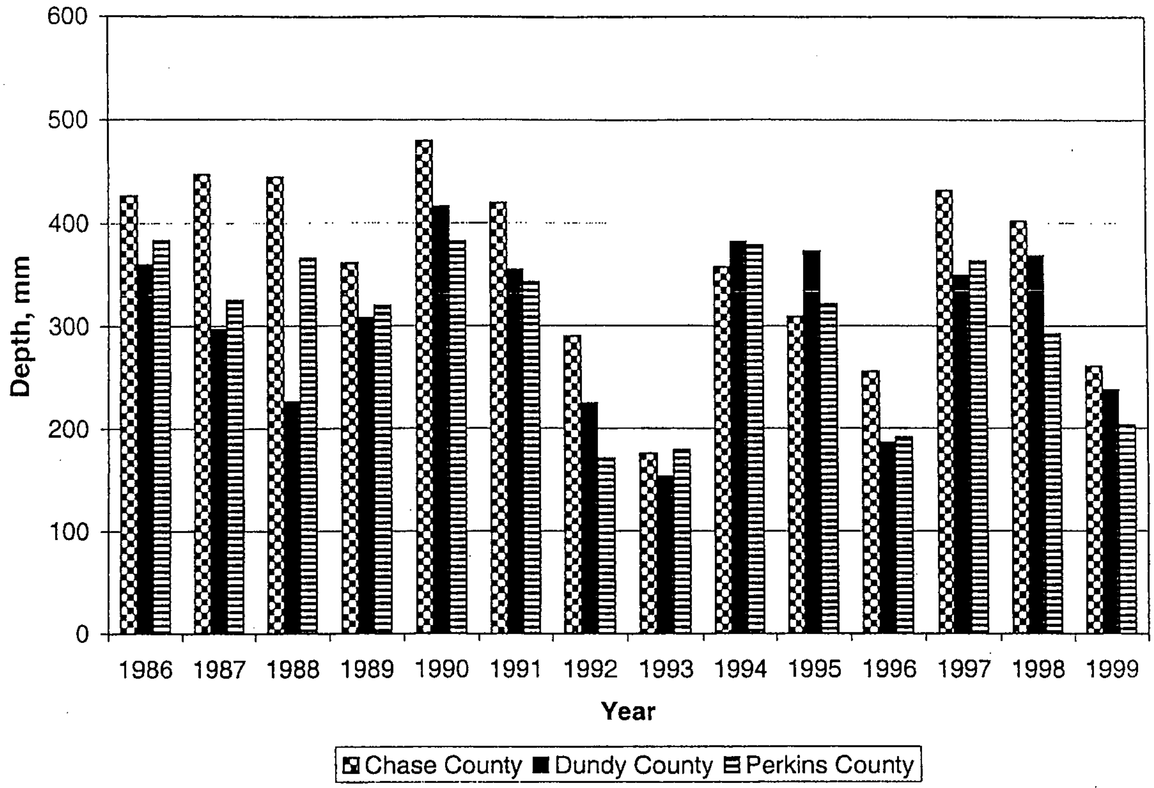

Figure 4a. Water Applied to Corn by Gravity Irrigation.

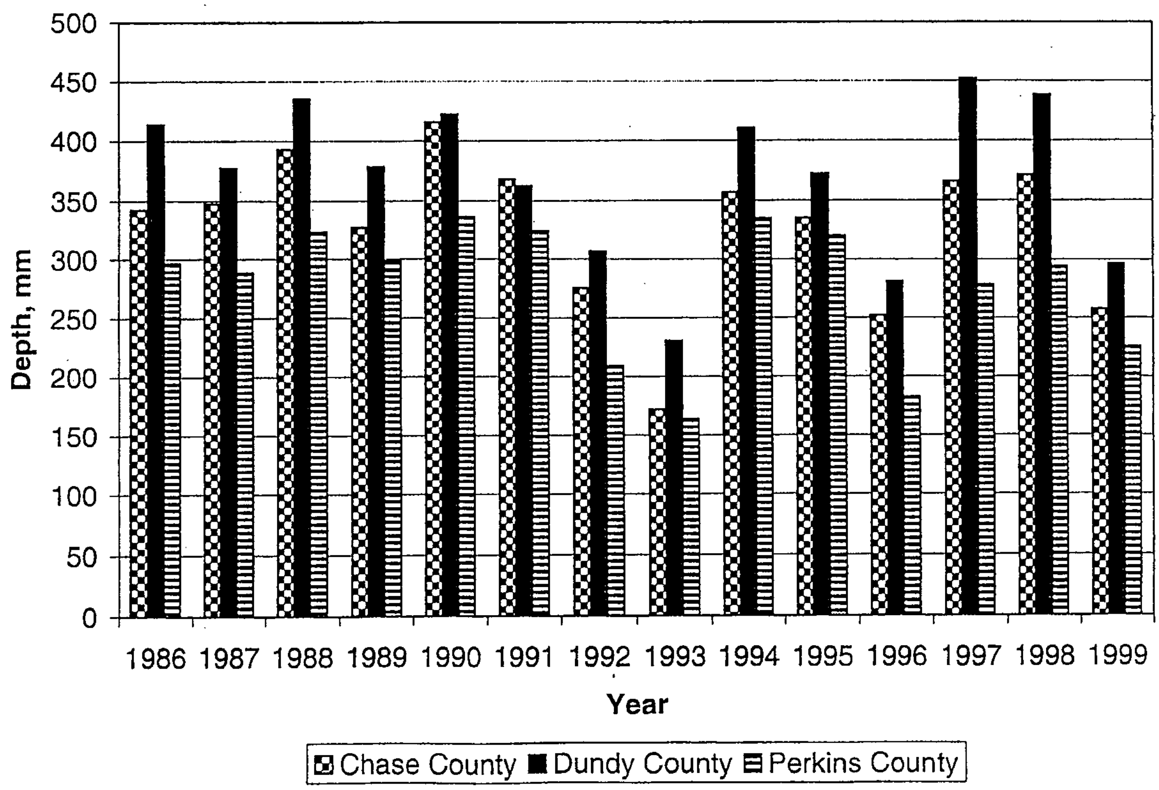

Figure 4b. Water Applied to Corn by Center Pivot Irrigation.

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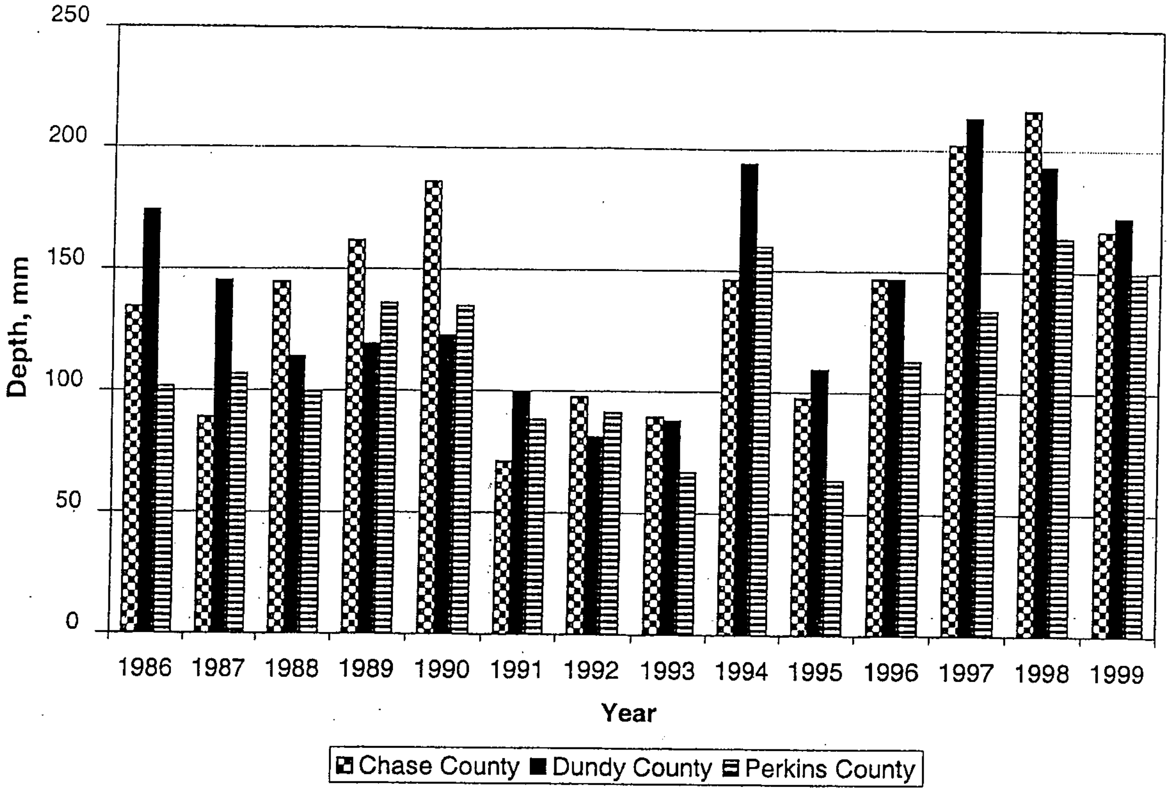

Figure 4c. Water Applied to Wheat by Center Pivot Irrigation.

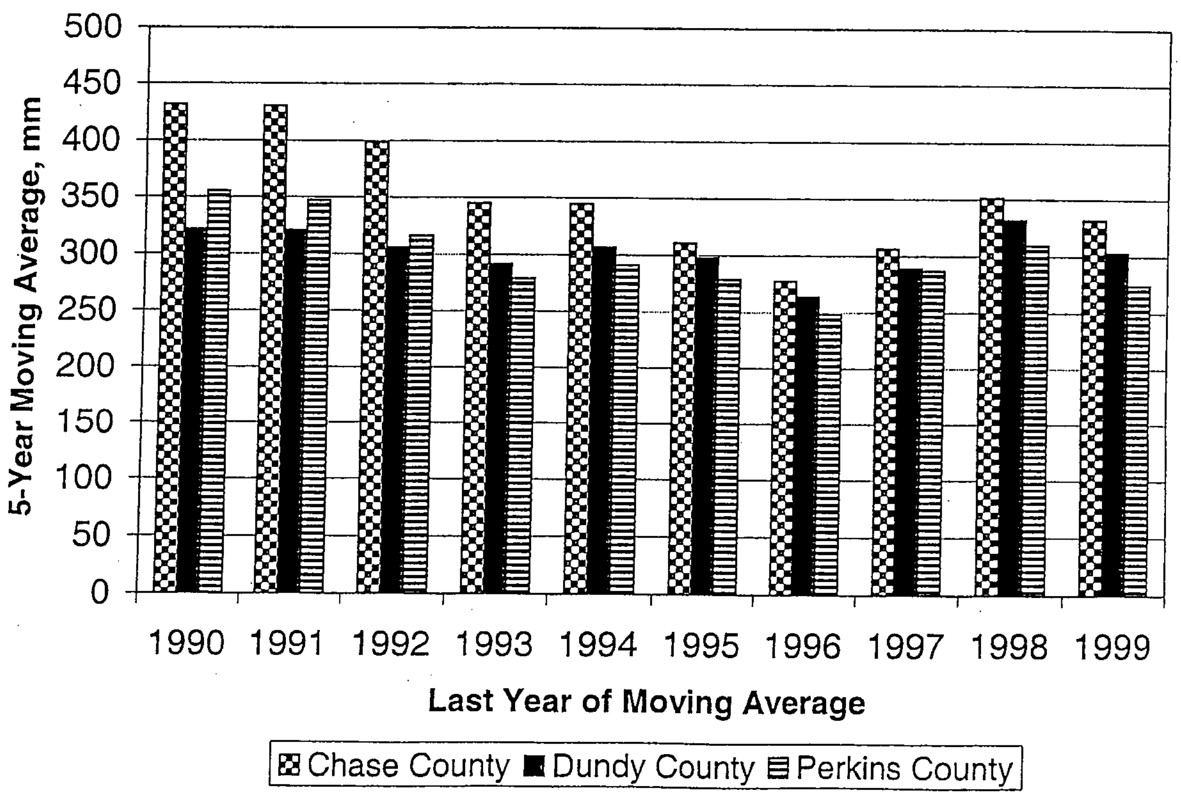

Figure 5a. Five-Year Moving Average of Pumpage for Gravity Irrigated Corn.

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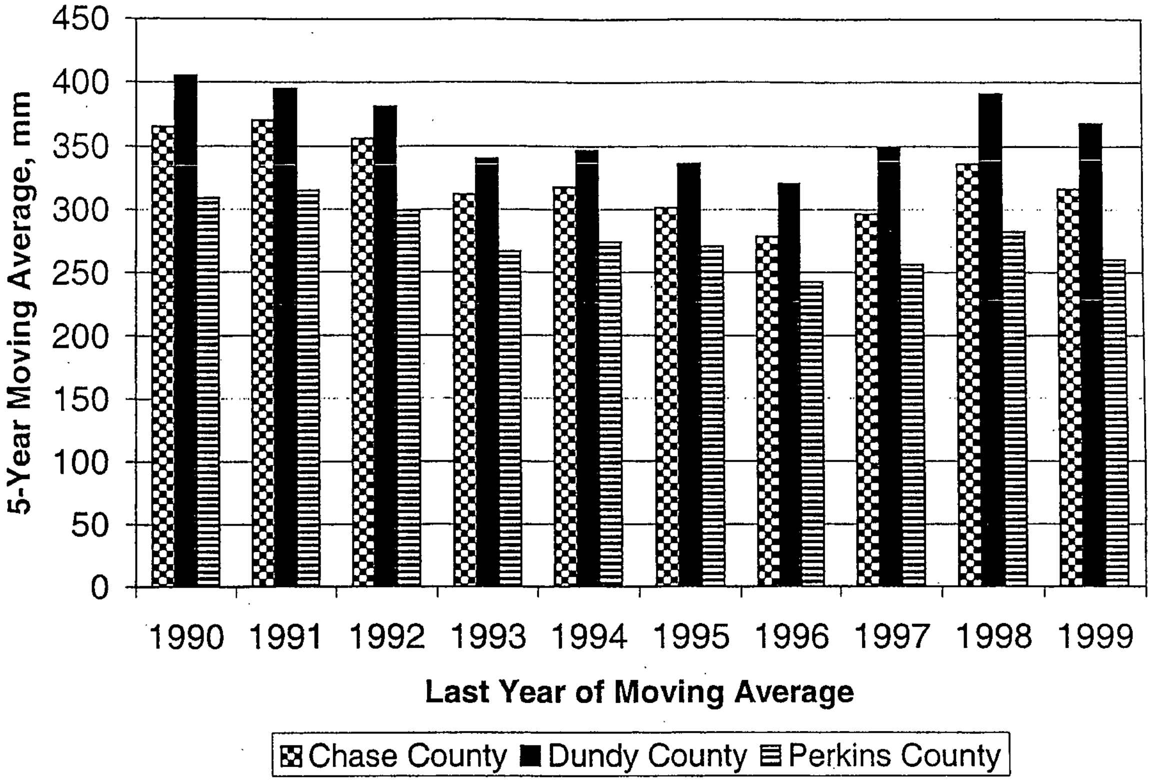

Figure 5b. Five-Year Moving Average of Pumpage for Center Pivot Irrigated Corn.

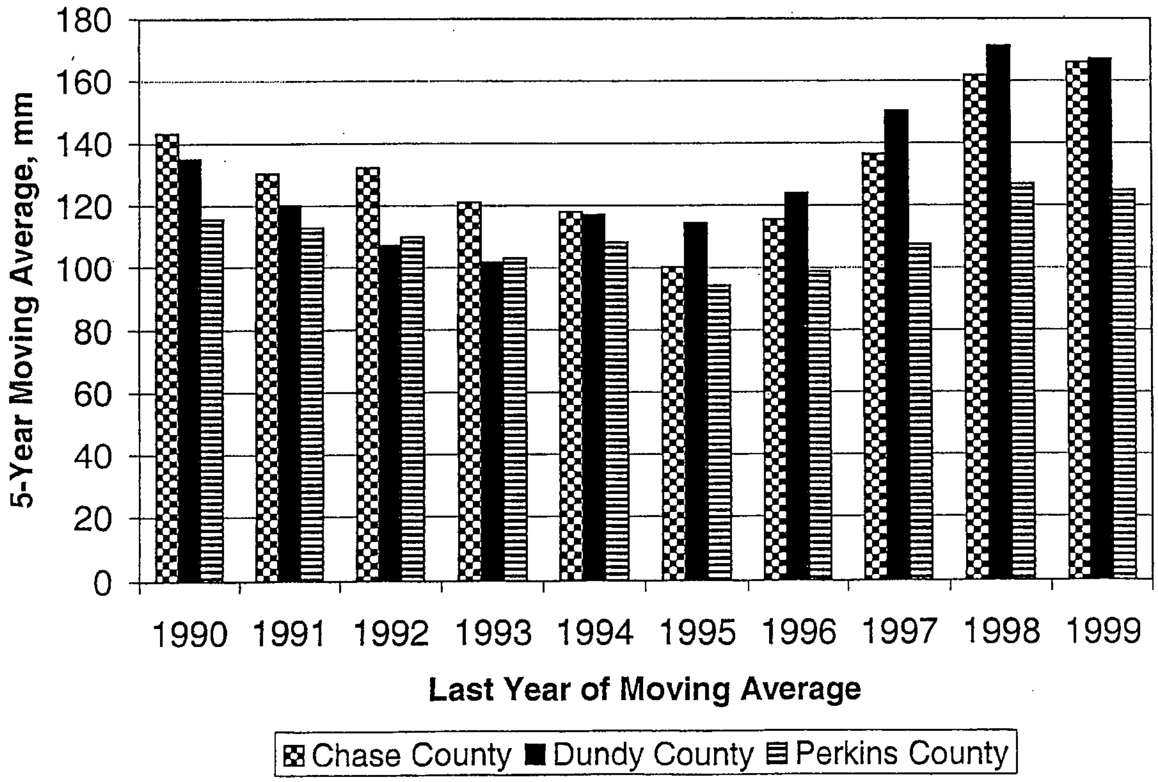

Figure 5c. Five-Year Moving Average of Pumpage for Center Pivot Irrigated Wheat.

CONCLUSIONS

Since water controls were mandated by the URNRD in the mid-1970s, producers can no longer apply unlimited water to irrigated crops. This analysis indicates that irrigators have been able to remain within URNRD allocation limits on an area weighted basis. The dimensionless ratio of ground water pumped to CIR for corn and wheat from 1986 to 1999 has frequently remained less than one on center pivot and gravity fed irrigated cropland. This suggests that farmers are applying less water than theoretically could be used by the crops, if water was not limited.

To reduce irrigation applications, producers have incorporated different management techniques into their farming practices. These include alternating dryland and irrigated crops, developing new irrigation technologies, tracking daily crop water requirements, and minimizing water applications until the critical reproduction phase of the crop. During the 1986 to 1999 period, half of the ratios of water pumped to crop CIRs remained at or below 0.80 (Figure 6). If further water restrictions were required, these ratios suggest that producers could survive with 1,473 mm of water (1,842 * 0.80) during any five-year allocation period given favorable climatic conditions. The five-year average pumpage for center pivot and gravity irrigated corn for the allocation period 1988 to 1992 was considerably greater than 1,473 mm. However, the average pumpage for center pivot and gravity irrigated corn for the more recent period 1993 to 1997 was much closer to this value and indicates that this goal is already being achieved.

One of the broader implications of the control area program is the improved reliability of the public water supplies in the control area (C. L. Summers, 1980, personal communication). All URNRD public water supplies have only wells as their source. Without the control area, the underlying aquifer probably would have been mined, so that many farm/domestic and public water supply wells would have gone dry and large, expensive regional water systems would have to be constructed. With the control area, sufficient ground water may be available well into the future, protecting the farm/domestic and public water supply wells and negating the need for regional water systems. The control area also may have been an asset to irrigation, as it will extend the lifetime of irrigation in the control area.

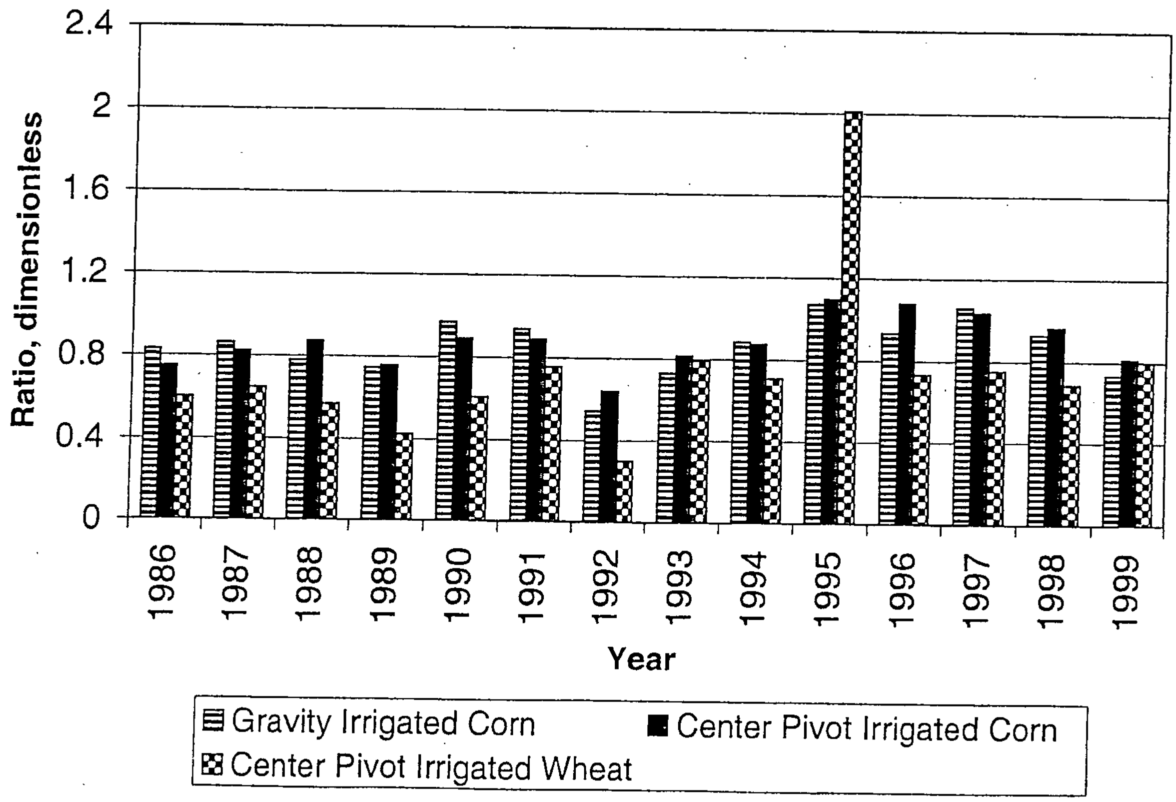

Figure 6. Means of Pumpage to Crop Irrigation Requirement Ratios for Three Counties.

DISCLAIMER

The views expressed in this paper are those of the author and not those of the State of Nebraska, the Nebraska Department of Natural Resources, Nebraska Attorney General, or the University of Nebraska.

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