MINIMUM CENTER PIVOT DESIGN CAPACITIES

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Irrigators investing in a center pivot irrigation system need to consider an important question "How much supplemental water is required by the crop?" Irrigation system capacity required to meet crop requirements is defined in units of gallons per minute (GPM) or gallons per minute per acre (GPM/AC). If the system capacity is too low, crop stress will occur during some portion of the growing season. If the capacity is too high, surface runoff may result or capital investment for the pumping plant and center pivot may be greater than necessary.

Design capacities for center pivots can be determined by considering the peak crop water use rate, soil type, local climatic conditions, potential for electrical load control, and estimated system down time for repair or maintenance. This NebGuide discusses how these factors can be used to determine the appropriate system capacity.

PEAK CROP WATER USE

Crop water use expressed in inches per day depends on prevailing climatic conditions and the stage of crop development. Early and late in the growing season, daily crop water use or evapotranspiration (ET) is low (less than 0.15 inches per day). Near the beginning of the reproductive stage of crop development (flowering, tassle emergence, boot), the crop water use rate reaches its peak. The crop water use rate during this period is referred to as the peak crop water use rate. Peak crop water use rates vary from east to west across Nebraska. In Nebraska, the average peak crop water use rate over a period of 3-5 days varies from 0.37 inches per day in the west to 0.33 inches per day in the east.

Rainfall and crop water use rates vary daily and from year to year. When a system is designed to replace the peak crop water use, there is certainty that the system will prevent the crop from experiencing stress. However, a system that is designed to replace the peak water use will not be fully utilized when rain occurs or when crop water use is less than the peak rate.

A growing crop will use water dictated by atmospheric conditions and the stage of crop development. The amount of water required to replace peak crop water use 100% of the time is largely independent of soil type or annual rainfall amounts. If the operator is willing to accept the risk of not replacing peak crop water use, the rate at which water is supplied to the system can be reduced.

SYSTEM CAPACITY

On average, an irrigation system distributes less water to the crop or soil than is pumped from the water supply. The following definitions will be used in the discussion that follows:

Net System Capacity: The amount of water which must be supplied to the crop or soil to replace crop water use. The amount of water supplied can be less than the peak water use rate.

Water Application Efficiency: The fraction of the water pumped which reaches the crop or soil. The water application efficiency for a center pivot is assumed to be 0.80 (80%) in lieu of more accurate field estimates.

Gross System Capacity: The amount of water which must be pumped to insure crop water use requirements are met. Gross system capacity is determined by the net system capacity required and the water application efficiency of the system:

$$\text{GROSS CAPACITY} = \frac{\text{PET X 453}}{\text{HRS X WAE}}$$

where:

GROSS CAPACITY = pumping rate required, gpm/acre
PET = peak water use rate, inches/day
HRS = hours of pumping per day, hours
WAE = water application efficiency, decimal
453 = conversion factor between gallons per minute and acre-inches per hour

For example, if the peak crop water use rate were 0.30 inches per day and the pump operates 22 hours per day, the gross system capacity would be (0.30 x 453)/(22 x 0.80) or 7.72 gallons per minute per acre irrigated. Total pumping rate is determined by multiplying the system capacity by the number of acres irrigated. For this example a 130 acre center pivot would require a pump flow rate or gross system capacity of 1003 gallons per minute. Net system capacities to replace 100% of crop water use are presented at the bottom of Table 1. Depending on how efficiently water is applied, the gross system capacity can be determined using the number listed below the appropriate region of the state.

SOIL TYPE

The available water capacity of a soil is an important aspect of irrigation system design. The available water capacity is the maximum amount of water held in the soil that the crop can use. To insure that plant stress is minimized, the available water capacity should be maintained above the 50% level. A silty clay loam soil holds approximately 8 inches of water in a 4-foot profile, while a fine sand holds only 4 inches. The extra water stored in the silty clay loam soil increases the amount of water available to the plant during peak water use periods allowing the net system capacity to be decreased.

The primary soil textures found in Nebraska and associated available water capacities are listed in Table 1. Soils having similar water holding capacities can be found in Kansas and Colorado.

Net system capacity can be reduced by assuming that some crop water requirements will be provided by stored soil moisture or rainfall during peak crop water use periods. Accounting for stored soil moisture and rainfall assumes that the irrigation system may fall short of supplying crop water needs during years when timely rainfall does not occur. If the net system capacity is reduced, it is uncertain whether the system can prevent crop stress for occurring.

The operator can assume some risk of crop stress in order to minimize the capital investment for the irrigation system (well, pump, motor, pivot). The maximum risk that should be assumed is when the net system capacity is adequate to insure stress will not occur 9 years out of 10. The net system capacities required to ensure that crop water needs are satisfied 9 out of 10 years are presented in Table 1 for different soil textures by region. These capacities were developed from 20 years of rainfall and crop water use records.

The split between regions shown in Figure 1 follows the 22 inch annual rainfall contour quite closely. Data used to develop these net system capacities were obtained from southwest and south central Nebraska for Region 2 and Region 1, respectively. Thus, for much of the northern part of Kansas and eastern Colorado, these same estimates can be used. However, where extreme crop water use rates exist in Kansas and Colorado, net system capacities may need to be increased slightly (for example: 0.2 to 0.5 gallons per minute per acre).

Table 1. Minimum net system capacities for the major soil texture classifications and regions of Nebraska

Soil Texture (inch/ft.)	Available Water Capacity (gpm/ac)	Net Capacity* 9 of 10 years	
		Region 1 (gpm/ac)	Region 2
Loam, silt loam very fine sandy loam, w/silt loam subsoil	2.5	3.85	4.62
Sandy clay loam Loam, silt loam very fine sandy loam, w/silty clay subsoil	2.0	4.13	4.89
Silty clay loam Clay loam Fine sandy loam	2.0	4.24	5.07
Silty clay	1.6	4.36	5.13
Clay Sandy loam	1.4	4.48	5.19
Loamy sand	1.1	4.83	5.42
Fine sands	1.0	4.95	5.89
PEAK ET**		5.65	6.60

* Data taken from von Bernuth, R.D, D.L. Martin, J.R. Gilley and D.G. Watts. 1984. Irrigation System Capacities for Corn Production in Nebraska. Transactions of ASAE 27(2): 419-424, 428.
**Net system capacity required to replace average peak water use rate.

ENVIRONMENTAL FACTORS

The location of the center pivot within the state is also important. Rainfall varies by as much as 18 inches in Nebraska (Figure 1). Similar variation occurs across Kansas. An irrigation system in western Nebraska or eastern Colorado must be capable of supplying more water during the growing season to account for receiving lower rainfall amounts.

Other environmental factors that impact irrigation requirements are relative humidity and the average wind speed. The ability to evaporate water is less when air is humid than when the air is dry and evaporation increases with increasing wind speeds. Eastern Nebraska is more humid and less windy, meaning less moisture will be evaporated from the soil and plant surfaces than in western Nebraska. Net system capacities can be altered to account for humidity. Research has shown that Nebraska can be divided into two regions of differing environmental conditions as shown in Figure 1. Using average annual rainfall as the major indicator, the division line could be extended straight south into Kansas (Figure 2).

ELECTRICAL LOAD CONTROL

Electrical load control occurs when the electric power supplier regulates the peak power use rate by controlling power use during high use periods. Irrigators can agree to have their power interrupted in return for a reduction in power cost. The cost savings is determined by the amount of time the system power supply can be interrupted.

Three types of control are common to most Nebraska power districts. One day control is when the power cooperative is authorized to interrupt an irrigation system power supply for one 12 hour period per week, on a predetermined day of the week. Two day control is similar only with two 12-hour periods of potential power interruption weekly. Anytime control authorizes power districts to interrupt power up to six 12-hour periods during a week or about 40% of the time. Even though the power district may be authorized to interrupt power 67 hours per week, field data show that center pivots are rarely shut down more than 42 hours per week. The control period is generally from 10:00 a.m. to 10:00 p.m. which allows power use between 10:30 p.m. and 10:00 a.m. regardless of the type of control the user selects.

Load control programs reduce operating time. If a system can only be operated during part of the day, the water supply rate must be increased to meet crop water needs. Table 2 contains multiplication factors used to adjust water supply rates for the number of hours the power might be interrupted. For example, if the system was on 2 day control, the power could be interrupted for 24 hours so the multiplication factor would be 1.17. The net flow rate required is determined by multiplying a net system capacity from Table 1 by the multiplication factor for power interruption.

REPAIR AND MAINTENANCE

For irrigation systems to operate at a high efficiency, maintenance must be performed. These jobs can only be performed when the system is shutdown which decreases the total operating time per week.

Even the best maintained center pivot or pumping plant will break down and require repair of some part of the system. These shutdowns further decrease the total operating time per week. The same multiplication factors used for electric load control are used in adjusting the net flow rate for downtime due to repair and maintenance each week. These factors are used just like the load control factors.

Table 2. Power Interruption and Repair and Maintenance Multiplication Factors for Different System

	Shutdown Time (Hours) Per Week					
	0	12	24	36	48	60
Multiplier	1.00	1.08	1.17	1.27	1.40	1.56

FINDING THE MINIMUM CENTER PIVOT SYSTEM CAPACITY NEEDED

Net system capacities in Table 1 are in gallons per minute per acre for continuous operation and must be adjusted using estimates of system down time for electric load control, system maintenance or repair requirements. The total system inflow rate is determined by the water application efficiency, hours of operation, and the number of acres to be irrigated.

The following example shows how to determine the gross system capacity needed for a center pivot irrigation system using Tables 1 and 2 and Figure 1.

Example

Determine the gross system capacity needed for a 130 acre center pivot irrigation system located in Chase County in southwest Nebraska. The soils are primarily silt loam or loam textured. The operator has decided that replacing peak crop water use rates 9 years out of 10 would be acceptable. The operator will operate the system on one day electric load control and will need 12 hours per week to conduct repair and maintenance.

CENTER PIVOT SYSTEM CAPACITY WORKSHEET

1. Select soil texture.
   (Table 1) Soil texture silt loam/loam.

2. Select the region of the state. (Chase County).
   (Figure 1) Region number ____2____ (southwest)

3. Select the net system capacity opposite the soil texture in Table 1.

   (Table 1) Net system capacity ____4.62____ GPM/AC

4. Select the load control multiplication factor.

   (Table 2) Load control factor ____1.08____ (12 hours)

5. Select the repair and maintenance multiplication factor.

   (Table 2) Repair and maintenance factor ____1.08____ (12 hours)

6. Determine the total net system capacity by multiplying steps 3, 4, and 5 together.

step 3 step 4 step 5

4.62 net gpm/acre X 1.08 X 1.08 = 5.39 net gpm/acre

7. Determine the number of acres to be irrigated.

130 acres

8. Multiply the net system capacity (step 6) by the number acres (step 7) to determine the total net water supply rate needed for the system.

step 6 step 7

5.39 net gpm/acre X 130 acres = 700 gallon per minute

9. Divide the total net water supply rate (step 8) by the application efficiency (0.80 for center pivots).

step 8

700 gpm/0.80 = 875 gpm

This example shows that the minimum water supply rate for this center pivot should be approximately 875 gallons per minute.

SUMMARY

Determining the appropriate net system capacity for a center pivot is an important decision. Choosing a system capacity which is too low could result in crop stress. Choosing a system capacity which is too high will result in an unnecessary investment in a pump, motor and other distribution system components. Utilizing the moisture stored in the soil and rainfall that occurs, reduces the flow rate which must be supplied to the center pivot. Adjustments should be made for system interruption due to repair and maintenance or load management. Taking these factors into consideration will assure that the irrigation system has adequate capacity to carry out the management scheme of the operator.

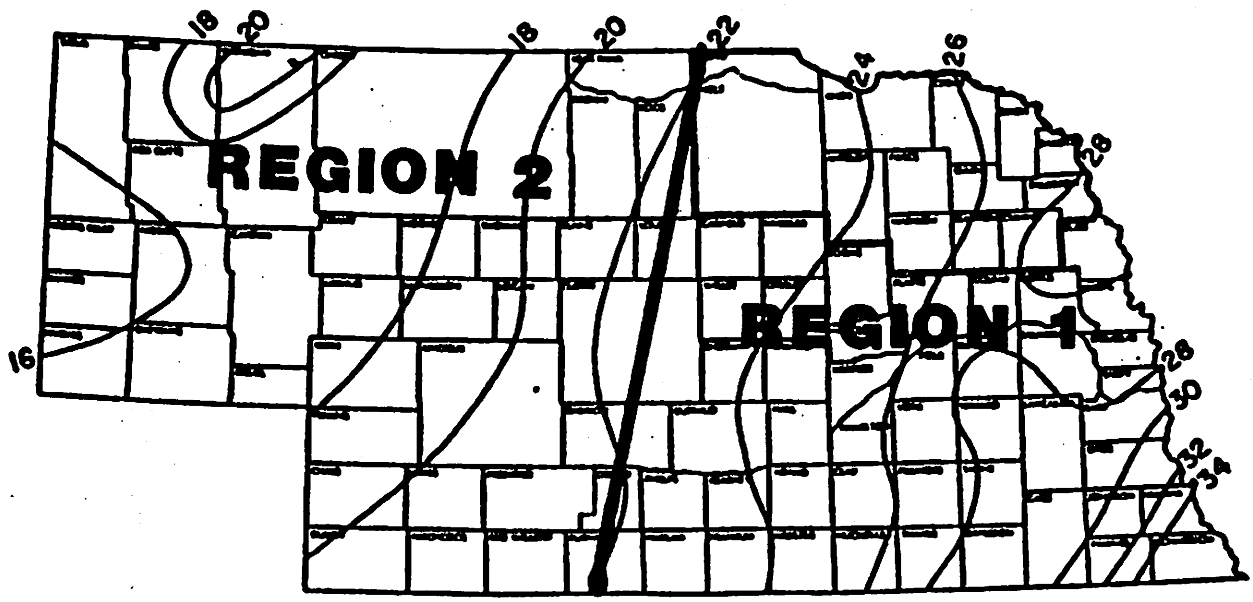

Figure 1. Long term average annual rainfall amounts and the climatic regions for irrigation system capacity determination. (Taken from An Analysis of Nebraska's Precipitation Climatology-With Emphasis on Occurrences of Dry Conditions. Extension Miscellaneous Publication MP 42).

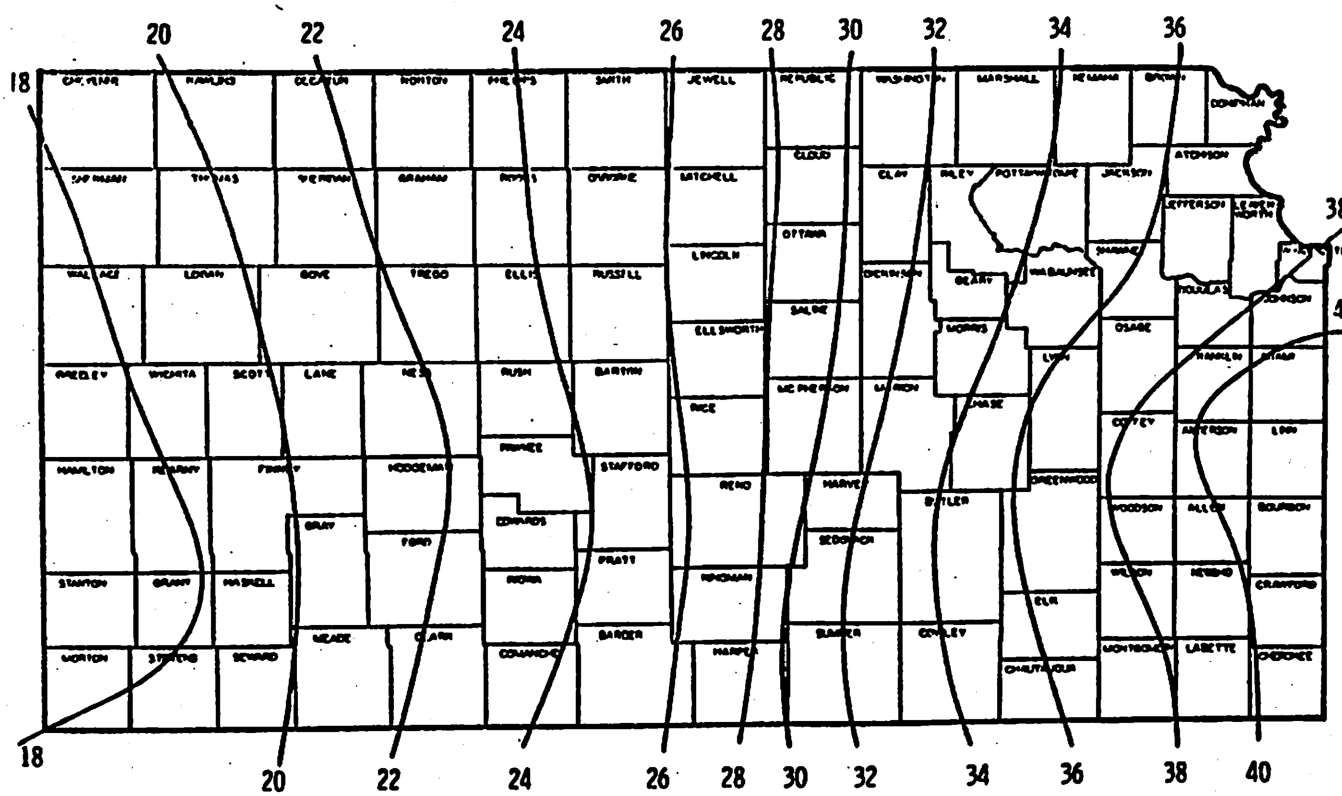

Figure 2. Normal Annual Precipitation - For Kansas, 1941-1970 (prepared by L.D. Bark)