G89-932 Minimum Center Pivot Design Capacities in Nebraska

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Minimum Center Pivot Design Capacities in Nebraska

Factors to consider in choosing an appropriate center pivot design are covered here.

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Irrigators investing in a center pivot irrigation system need to consider this important question: *How much supplemental water is required by the crop?*

Irrigation system capacity needed 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 occurs 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 may 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, tassel 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 three to five 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 designed to replace peak water use will not be fully used when rain occurs or when crop water use is less than the peak rate.

A growing crop's water use is dictated by atmospheric conditions and the stage of crop development. The amount of water required to replace peak crop water use 100 percent of the time is largely independent of soil type or annual rainfall amounts. If the operator accepts 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 are used in the discussion that follows:

Net System Capacity is the amount of water that 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 is the fraction of the water pumped that reaches the crop or soil. Water application efficiency for a center pivot is assumed to be 0.80 (80 percent) in lieu of more accurate field estimates.

Gross System Capacity is the amount of water that must be pumped to ensure 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:

$$\textbf{Gross Capacity} = \frac{\text{PET} \times 453}{\text{HRS} \times \text{WAE}}$$

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 × 453)/(22 × 0.80) or 7.72 gallons per minute per acre irrigationd.

Total pumping rate is determined by multiplying the system capacity by the number of acres irrigationd. For this example a 130 acre center pivot requires a pump flow rate or gross system capacity of 1,003 gallons per minute.

Net system capacities to replace 100 percent of crop water use are presented at the bottom of *Table I*. 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.

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

Soil Texture	Available Water Capacity (inch/ft.)	Net Capacity* 9 of 10 years	
		Region 1 (gpm/ac)	Region 2 (gpm/ac)
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.

Soil Type

The available water capacity of a soil is an important aspect of irrigation system design. Available water capacity is the maximum amount of water held in the soil that the crop can use. To ensure that plant stress is minimized, available water capacity should be maintained above the 50 percent level.

A silty clay loam soil holds approximately eight inches of water in a four-foot profile, while a fine sand holds only four 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 their associated available water capacities are listed in *Table I*.

Net system capacity can be reduced by assuming some crop water requirements are 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 the system can prevent crop stress from occurring.

Operators can assume some risk of crop stress 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 ensure stress will not occur nine years out of 10. The net system capacities required to ensure that crop water needs are satisfied nine out of 10 years are presented in *Table I* for different soil textures by region. These capacities were developed from 20 years of rainfall and crop water use records.

Environmental Factors

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

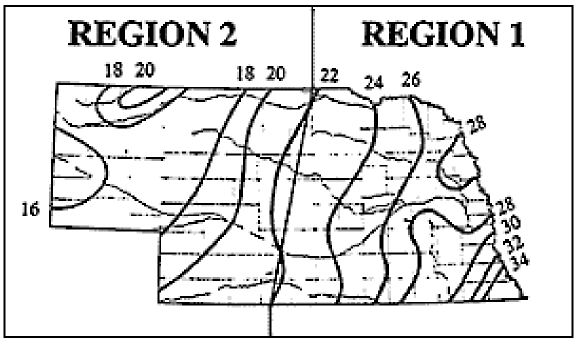

Figure 1. Long term average annual rainfall amounts and the climatic regions for irrigation system capacity determination (Taken from *An Analysis of Nebraska's Precipitation Climatology--With Emphasis on Occurrences of Dry Conditions*, Extension Miscellaneous Publication MP42).

Other environmental factors that impact irrigation requirements are relative humidity and average wind speed. The ability to evaporate water is less when air is humid than when air is dry, and the ability to evaporate water 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 reduced in high humidity areas. Research shows Nebraska can be divided into two regions of differing environmental conditions as shown in *Figure 1*.

Electrical Load Control

Electrical load control occurs when the electrical 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 percent of the time. Even though the power district may be authorized to interrupt power 72 hours per week, field data show that center pivots rarely are shut down more than 42 hours per week. The control period is generally from 10 a.m. to 10 p.m., which allows power use between 10:30 p.m. and 10 a.m. regardless of the type of control the user selects.

Load control programs reduce operating time. If a system can be operated during only part of the day, the water supply rate must be increased to meet crop water needs. *Table II* contains multiplication factors used to adjust water supply rates for the number of hours the power might be interrupted.

Table II. 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

For example, if the system was on two-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 I* by the multiplication factor for power interruption.

Repair and Maintenance

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

Even the best-maintained center pivot or pumping plant breaks down and requires 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.

Finding the Minimum Center Pivot System Capacity Needed

Net system capacities in *Table I* are in gallons per minute per acre for continuous operation, and must be adjusted using estimates of system downtime 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 number of acres to be irrigationd.

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

Example:

Determine the gross system capacity needed for a 130 acre center pivot irrigation system located in Antelope County in northeast Nebraska. The soils are primarily silty clay loams. The operator has decided replacing peak crop water use rates nine years out of 10 is acceptable. The operator will operate the system on two-day electric load control, and will need 12 hours per week to conduct any repair and maintenance.

Center Pivot System Capacity Worksheet

1. Select soil texture.
   (*Table I*) Soil texture *silty clay loam*.

2. Select the region of the state. (Antelope County).
   (*Figure 1*) Region number **1** (northeast)

3. Select the net system capacity opposite the soil texture in *Table I*.
   (*Table I*) Net System capacity **4.24** GPM/acre

4. Select the load control multiplication factor.
   (*Table II*) Load control factor **1.17** (24 hours)

5. Select the repair and maintenance multiplication factor.
   (*Table II*) 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*		
4.24	net gpm/acre ×	**1.17** ×	**1.08** =	**5.36**	net gpm/acre

7. Determine the number of acres to be irrigationd.
   130 acre

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*	
5.36	net gpm/acre ×	**130** acres =	**696** gallon per minute

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

   step 8
   696 gpm/0.80 = **870 gpm**

This example shows the minimum water supply rate for this center pivot should be approximately 870 gallons per minute.

Summary

Determining the appropriate net system capacity for a center pivot is an important decision.

Choosing a system capacity that is too low can result in crop stress. Choosing a system capacity that is too high results in an investment in a pump, motor and other distribution system components that is greater than necessary.

Using the moisture stored in the soil and rainfall that occurs reduces the flow rate that must be supplied to the center pivot. Make adjustments for system interruption due to repair and maintenance or load management. Taking these factors into consideration assures the irrigation system has adequate capacity to carry out the operator's management scheme.

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