NebGuide

University of Nebraska–Lincoln Extension, Institute of Agriculture and Natural Resources

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Minimum Center Pivot Design Capacities in Nebraska

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

Irrigators investing in a center pivot irrigation system need to consider this important question: *How much irrigation water is required to supplement rainfall?*

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 can occur during some portion of the growing season. If the capacity is too high, surface runoff may result, and capital investment for the pumping plant and center pivot will be greater than necessary.

Design capacities for center pivots may be determined by considering the crop type, 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

For any 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_c) 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 which varies 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 0.36 inches per day in the west to 0.32 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 fully be used when rain occurs or when crop water use is less than the peak rate.

If the operator plans to accept some risk by using stored soil water, and not replace peak crop water use, the operator can reduce the system capacity.

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 root zone to replace crop water use. The amount of water supplied can be less than the peak water use rate.

Water Application Efficiency (WAE) is the fraction of the water pumped that reaches the crop root zone. Water application efficiency for a center pivot is assumed to be 0.85 (85 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 using the equation below:

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

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

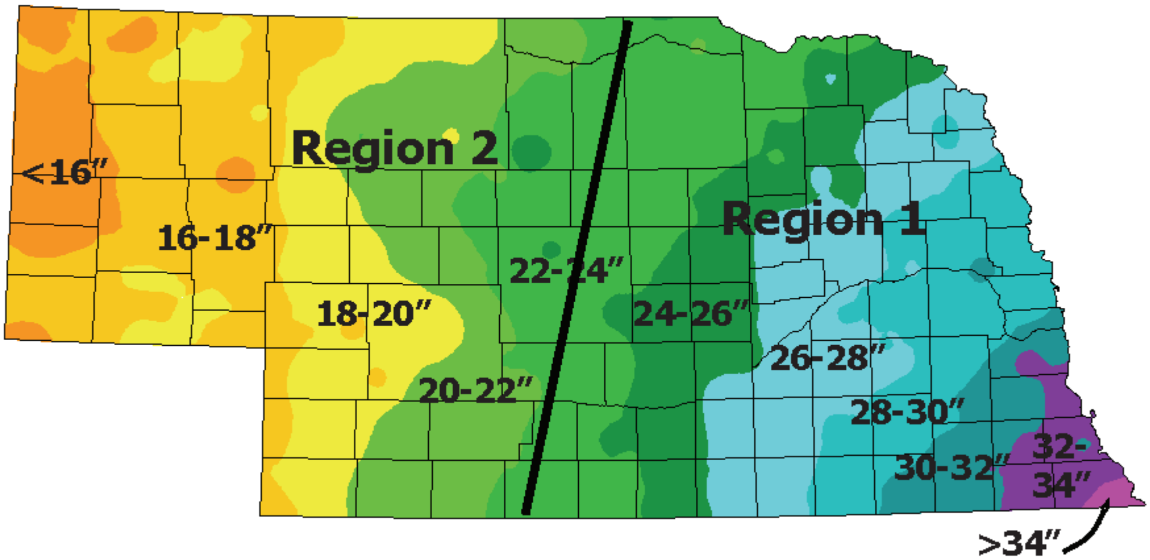

Figure 1. Long term average annual rainfall amounts and the climatic regions for irrigation system capacity determination.

For example, if the peak crop water use rate were 0.32 inches per day and the pump operates 22 hours per day, the gross system capacity would be (0.32 × 453)/(22 × 0.85) or 7.75 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 requires a pump flow rate or gross system capacity of 1,008 gallons per minute.

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

Soil Texture	*Plant Available Water Capacity (inch/ft)*	*Net Capacity* 9 of 10 years* Region 1 (gpm/ac)*	*Net Capacity* 9 of 10 years* Region 2 (gpm/ac)*
PEAK ET**		**5.65**	**6.60**
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

*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 Water Holding Capacity

Net system capacities to replace 100 percent of crop water use are presented in the top line of *Table I*. However, net system capacity can be reduced by assuming some crop water requirements are provided by stored soil water or rainfall during peak crop water use periods. Accounting for stored soil water 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 from occurring.

Operators can assume some risk of crop stress to minimize the capital investment for the irrigation system (well, pump, motor, pivot). One reasonable scenario 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.

The plant available water capacity of a soil is an important aspect of irrigation system design. Plant 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 available level.

A silty clay loam soil holds approximately 8 inches of plant available water in a 4-foot profile, while 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 their associated plant available water capacities are listed in *Table I*.

Environmental Factors

The location of the center pivot within the state also is important. Rainfall varies by as much as 18 inches from east to west across 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.

Other environmental factors that impact irrigation requirements are relative humidity and average wind speed. The ability to evaporate water is usually less when air is humid than when air is dry, and the ability to evaporate water usually increases with increasing wind speeds.

Eastern Nebraska is more humid and less windy, meaning less water will be evaporated from the soil and plant surfaces than in western Nebraska. Thus, net system capacities can be reduced in high humidity areas (e.g., growing season average humidity >50 percent). Nebraska can be divided into two regions of differing environmental conditions, mainly rainfall, as shown in *Figure 1*.

Because precipitation and other weather variables change gradually as one moves across the state from east to west, it would be impossible to provide enough columns in *Table I* for each location. Thus, center pivot owners located near the division line should interpolate between the two regions to get a more accurate estimate of the minimum net system capacity. For example, a center pivot with a silt loam soil located in western Rock County should use a value of about 4.24 gpm/acre for the net system capacity [*(3.85+4.62)/2) = 4.24 gpm/acre*].

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 also decreases total operating time per week.

Even the best-maintained center pivot or pumping plant eventually breaks down and requires repair of some part of the system. These shutdowns further decrease the total pumping time per week.

Electrical Load Control

Electrical load control occurs when the electrical power supplier regulates the peak power use rate for the distribution system by controlling power use by individuals 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 frequency that the electric power supply can be interrupted.

The control period is generally from about 9:30 a.m. to 10 p.m., which allows power use between 10 p.m. and 9 a.m. regardless of the type of control the user selects. Four types of control are utilized by Nebraska Public 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.

Hours per day control allows the power district to interrupt power for a specified number of hours per day. In this scenario, the power user agrees to let the power supply be interrupted for four, six, eight, 10 or 12 hours per day on Monday through Saturday.

Load control programs are aimed at reducing peak power use rates, but the impact to the irrigation system is to reduce water application 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. The multiplication factor for any number of downtime hours can be determined using the equation:

$$\textbf{Multiplier} = (168) \div (168 - DT)$$

Where: DT = hours of downtime

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 (168/(168-24)). The actual system capacity is determined by multiplying the system capacity with no downtime by the multiplication factor (in our example: 7.75 gpm/acre x 1.17 = 9.07 gpm/acre).

Finding the Minimum Center Pivot System Capacity Needed

The following example shows how to determine the gross system capacity needed for a center pivot irrigation system using *Table I* 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 that replacing peak crop water use rates nine years out of 10 is acceptable. The operator will enroll the system in the two-day electric load control program, and will need three hours per week for 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. Assume the load control per week is 24 hours.
5. Assume that repair and maintenance down time is three hours per week.
6. Add the load control and repair and maintenance times together to obtain the total estimated down time per week.

   24 hours + 3 hours = **27** hours of downtime

7. Calculate the multiplication factor for 27 hours (168) ÷ (168 - 27) = 1.19
8. Determine the total net system capacity by multiplying steps 3 and 7 together.

   step 3 *step 7*

   4.24 net gpm/acre × **1.19** = **5.05** net gpm/acre

9. Determine the number of acres to be irrigated.

   Area = 130 acres

10. 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 8 × *step 9* = total system capacity

    5.05 net gpm/acre ×**130** acres = **656** gallon per minute

11. Divide the total net water supply rate (step 10) by the application efficiency (use 0.85 percent for high pressure impacts; 90 percent for low pressure impacts; 92 percent for low pressure spray heads on top of the pipeline; and up to 95 percent for spray heads on drop tubes at truss rod height).

    step 10 ÷ *Efficiency*

    656 gpm ÷ 0.85 = **772 gpm**

This example shows the minimum water supply rate for a center pivot equipped with high pressure impact sprinklers should be approximately 772 gallons per minute (656/0.85). The minimum system flow rate for a center pivot with low pressure spray nozzles at truss rod height would be 690 gpm (656/0.95).

Summary

Determining the appropriate 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 water stored in the soil and rainfall that occurs and making adjustments for system down time due to repair and maintenance or load management modify the flow rate that must be supplied to the center pivot. Taking these factors into consideration assures the irrigation system has adequate capacity to carry out the operator's management scheme while minimizing system ownership costs.

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