MATCHING SPRINKLER PACKAGES WITH FIELD CONDITIONS

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INTRODUCTION

Sprinkler irrigation systems and specifically center pivots have been adapted to operate on many different soils, to traverse extremely variable terrain, and to provide water to meet a number of different management objectives. As a buyer, you will be furnished with an array of different sprinkler types, many that are capable of performing adequately. However, you should make a selection based upon accurate field based information, and careful consideration of the interaction among several factors. Only then will the system installed meet your expectations. Let's begin with some basic calculations.

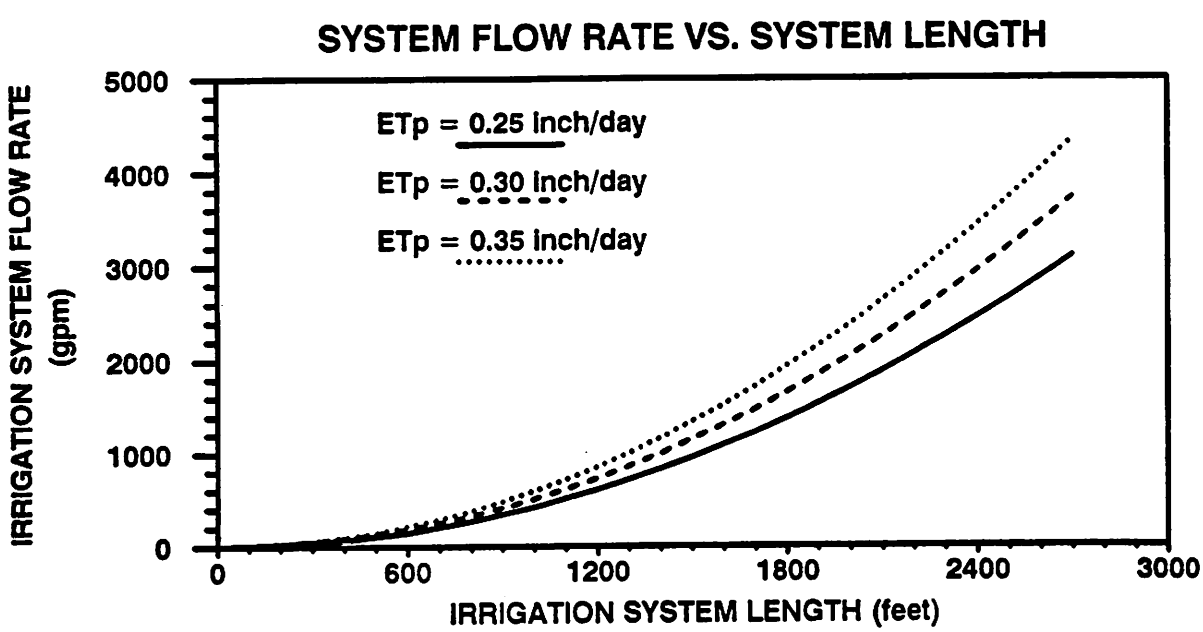


Figure 1. Impact of potential ET estimate on system flow rate for different irrigation system lengths.

Determine flow rate required

When the desire is to replace the peak water use, the flow rate required in Nebraska is virtually the same for all crops. The reason is that although the duration and timing of a specific crop's peak water use rate varies, peak water use rates are similar. Figure 1 shows the impact of peak water use on the required system flow rate. The system flow rate determines how other factors impact system operation. For example, if the flow rate is greater than necessary, the peak water application rate may cause runoff toward the outer end of the pivot lateral. The system flow rate also determines the size of sprinkler head required at each position of the system.

When estimating the needed system flow rate (Equation 1), there are three important considerations: a) environmental factors; b) estimated system downtime; and d) the soil water holding capacity. The most important environmental considerations are the likelihood of rainfall and the peak ET rate of the crop. NebGuide G89-932 presents a procedure for determination of the net water capacity of center pivots in Nebraska. Estimated crop water use, and rainfall data from different locations in the Nebraska were evaluated. The analysis identified areas where the system flow rate should be increased to account for lower annual precipitation and greater peak ET rates. Our best estimate is that systems located west of the 20 inch per year annual precipitation line should have greater flow rates.

$$Q_p = (K \times ET_p \times A \times t_i) / (E_i \times t_f) \qquad 1)$$

where:

Q_p = irrigation system flow rate, gpm
K = constant, 18.9
ET_p = peak water use rate, in/day
A = irrigated area, acres
t_i = irrigation interval, days
E_i = irrigation efficiency, decimal
t_f = irrigation time per event, days

Determine peak water application rate

One of the most important criteria for selecting a sprinkler package involves the peak water application rate for the system. Three factors affect the peak application rate--system length, system flow rate, and sprinkler wetted radius (Equation 2). Quite often an elliptical shaped water distribution pattern is used to depict sprinkler application patterns. With that assumption, Figure 2 shows the impact of the sprinkler wetted radius on the water application pattern of the sprinkler. Note that the application time is decreased with every decrease in wetted radius. Thus, the consequence of reducing the

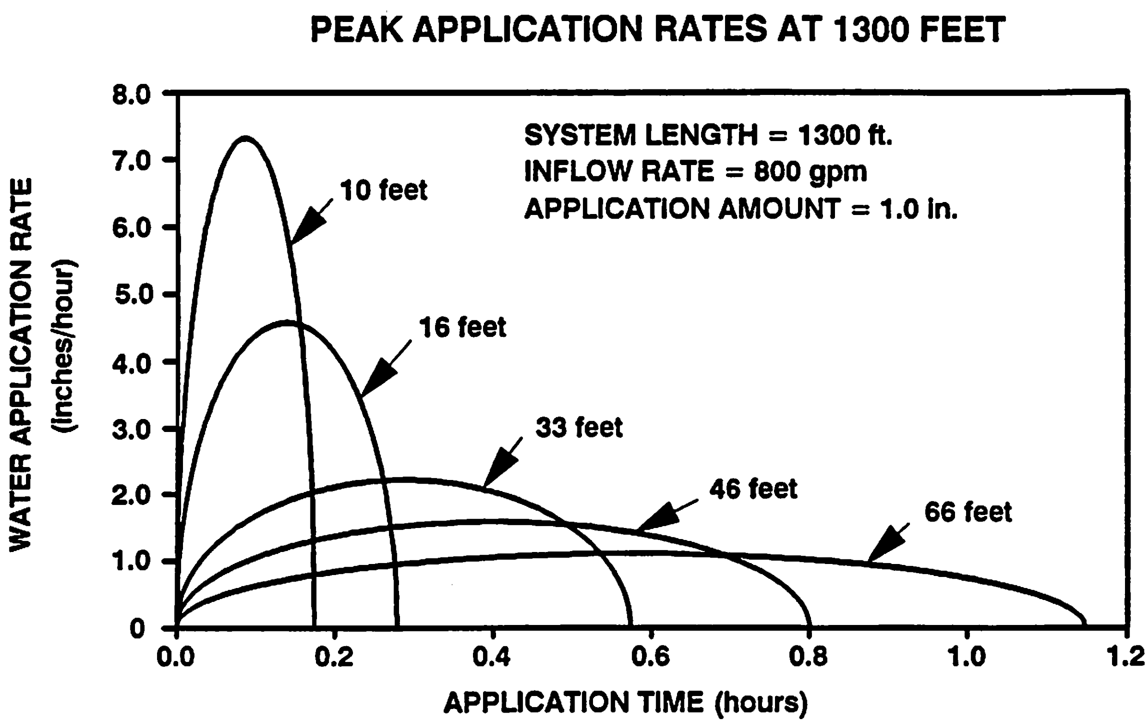


Figure 2. Water application patterns for sprinklers with wetted radii of 10', 20', 40', and 60' for an application of 1" of water.

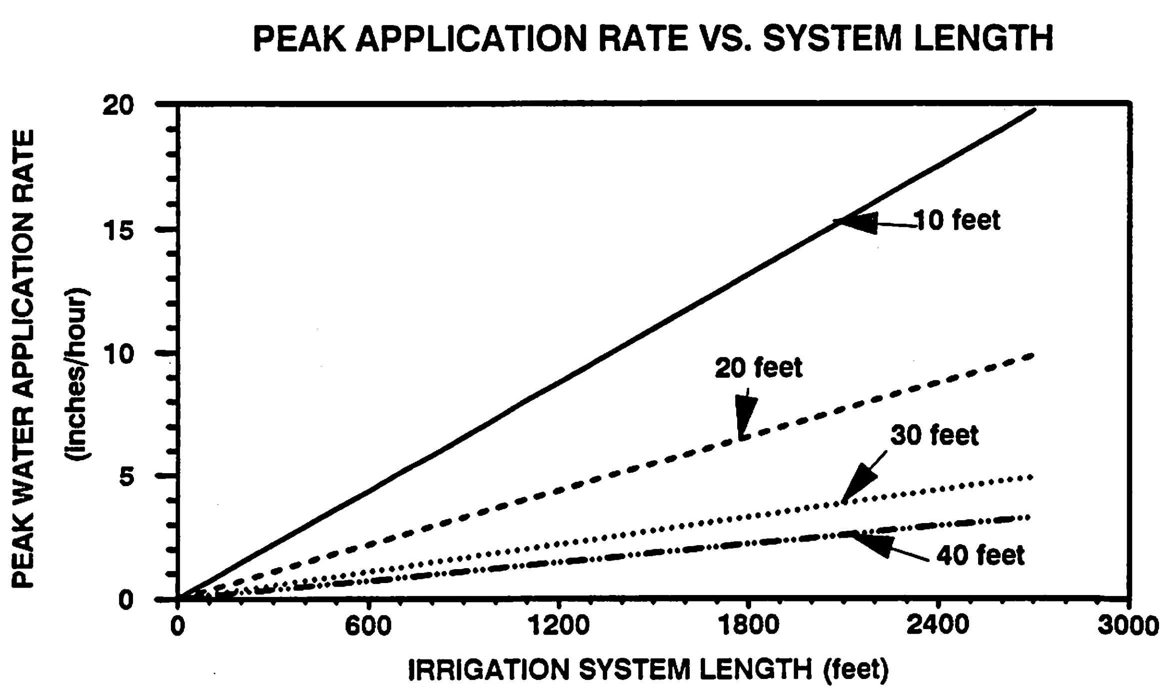


Figure 3. Impact of sprinkler wetted radius on peak water application rate when designed for 0.35"/day ETp.

wetted radius (and thus the operating pressure) of the sprinkler is that the same amount of water will be applied to the soil during a shorter period of time. Selecting a sprinkler package with a peak water application rate that is too great could cause runoff to develop. The key is to select a sprinkler package such that the peak water application rate does not exceed the soil infiltration rate.

$$I_p = (K_2 \times Q_p) / (R_s \times R_{sp}) \qquad 2)$$

where:

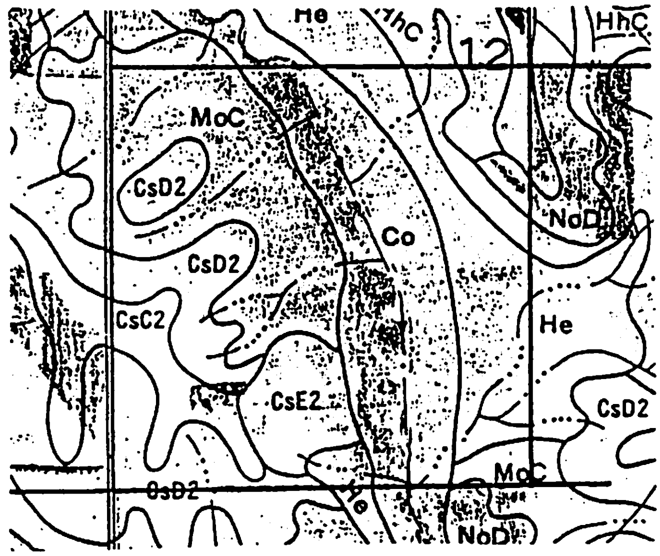
K_2 = constant, 122.5
Q_p = irrigation system flow rate, gpm
R_s = irrigation system wetted radius,ft.
R_{sp} = wetted radius of sprinklers, ft.
I_p = peak water application rate,in/hr.

Equation 2 indicates that as system length increases, the peak application rate increases. Figure 3 provides a visual representation of how wetted radius impacts the peak application rate as system length increases. The relationships are linear with the difference being the slope of the line. Thus, since the line for the 10 ft. wetted radius has a greater slope, the gap between it and larger radii continues to increase with length.

Field data collection

The Soil Survey provides an excellent source of estimates for average water infiltration rates, field slopes and soil water holding capacities. Figure 4 shows a copy of a quarter section located in Pierce county. Using a planimeter or some other means, determine the area of each mapping unit. Record the total number of acres of each unit in a table like that shown at the bottom of Figure 4. Look up the soil intake family, average field slope, infiltration rate and the soil water holding capacity information on each mapping unit and record them in the table. Be sure to include areas where soil moving has taken place.

Begin your analysis by looking at the mapping units with substantial areas. Look for areas with steep slopes (say greater than 7%) and with low infiltration rates (say less than the 0.5 Intake Family). Another factor to look for is soil water holding capacity. If sufficient area is involved, the system may need to be managed according to those areas. You most likely won't select a system to meet soils that comprise less than 10% of the irrigated area. However, field areas with 25 to 50 acres cannot be ignored. Tabulating soil information in this manner will make it easier to make decisions.



MAP SYMBOL	FIELD SLOPE (%)	INTAKE FAMILY NUMBER	WATER HOLDING CAPACITY (In/In)	FIELD AREA (ac)
Co	0-1	0.3	0.20-0.23	42.1
He	0-1	1.0	0.21-0.23	23.9
CsC2	1-7	1.0	0.20-0.23	11.0
HhC	1-7	1.0	0.21-0.23	36.8
MoC	1-7	0.5	0.19-0.22	5.3
CsD2	7-11	1.0	0.20-0.23	28.0
NoD	7-11	1.0	0.20-0.23	1.8
CsE2	11-17	1.0	0.20-0.23	11.1

Figure 4. Summary of Soil Survey information for site selection analysis prior to center pivot installation.

Surface topography

Many sprinkler packages are selected without a field site visit by the designer. However, the field visit is one of the most important aspects of selecting a sprinkler package. For example, one reason for not selecting a particular sprinkler package is field slope. Though soil mapping units give some indication of average field conditions, the data is seldom sufficiently accurate to allow a better decision. Therefore, a rough grid topography map (say 200' x 200') will determine if areas mapped as 7 to 11% slopes are closer to 7% or if there is a range in slopes.

Other information

Minimum requirements for selecting a sprinkler package also include: a) the pump output pressure and flow rate (pump curve); and b) the elevation difference between the pump and the highest elevation in the field. An accurate pump curve will indicate what impact reducing system operating pressure will have on pump output pressure and flow rate. It will also furnish a revised estimate of pumping plant performance. Without accurate estimates of these data, the sprinkler package design will be in error.

Finally, the field visit can provide valuable information related to tillage and planting practices. A field farmed on the contour can safely use a sprinkler package that would otherwise generate small amounts of runoff. Crop residues left on the soil surface absorb much of the impact energy of rainfall and irrigation, thus the soil infiltration rate would be more consistent throughout the season. Soil residues reflect incoming radiation resulting in less soil evaporation and maintain surface storage to prevent runoff. Each of these factors may cause you to make a slightly different decision. NebGuide G93-1154-A presents a summary of how crop residues impact sprinkler irrigation management.

The main goal for water application systems is to apply water uniformly in sufficient quantities to meet crop water needs without generating runoff. In addition, the system should be able to meet your management scheme. This might include the difference between 18 and 23 hour per day system operation.

Uniform water application requires that the correct sprinklers be at each position along the pivot lateral, that the pumping plant deliver water at the appropriate pressure and flow rate and that the system is not operated under adverse atmospheric conditions. Another aspect of water application uniformity is the uniformity of infiltration. Water applied to the soil with the precision of a micrometer can be overshadowed by surface runoff problems. Thus, the goal must be to consider how the sprinkler package will match up with the field conditions.

I think it is safe to say that the uniformity of water application generally increases with a decrease in sprinkler spacing. This statement assumes that the operating characteristics of the sprinkler do not change. Narrowing the spacing results in more overlap among the water application patterns of individual sprinklers. A narrow spacing also makes it more difficult for wind to alter the overall system water application pattern.

In the absence of some sort of flow control, the topographic features of the field can greatly alter the water distribution uniformity of a center pivot. This is particularly true for low pressure sprinkler packages. Since each sprinkler has an orifice through which water is metered, alterring the pressure supplied to that orifice changes the sprinkler output. If the field is sloped uphill from the pivot point the sprinklers located at the highest elevation will be distributing less water and those close to the pivot will be distributing more water than is indicated on the design sheet. For this reason, it is recommended that flow control devices be installed if the elevation difference results in a change of flow greater than about 10%. NebGuide G88-888 presents some considerations for different types of flow control devices.

The zero runoff goal requires that the sprinkler package selected for the system be carefully matched to the field conditions and to the operators management scheme. To often the desire to reduce pumping costs clouds over the overall system operating efficiency. An attempt should be made to select sprinkler packages that do not result in runoff. This requires that the water application pattern of the sprinkler be compared to the soil infiltration rate. If an accurate estimate of soil surface storage is available, it should be included in the analysis.

A computer program "**CPNOZZLE**", based on research conducted at Mead, NE, provides an opportunity to develop a rough estimate of how well suited the water application characteristics are to a field's soils and field slopes. The program is also useful in predicting how much the design criteria should be changed to eliminate a potential runoff problem. For example, if the normal operation of applying 1.25 inches of water per revolution produces runoff, the program can be used to determine a safer water application depth. If you are in the process of alterring the sprinkler package, the program can be used to select an appropriate system flow rate and sprinkler wetted radius.

Water droplet impact should be considered with all sprinkler package selections. Each sprinkler will deliver water to the soil with a particular range of water droplet sizes and distribution of water droplets. In general, larger water droplets are concentrated toward the outside of the wetted radius and smaller droplets fall closer to the sprinkler. It is the large water droplets that tend to be a concern. Large water droplets carry a substantial amount of energy that is transferred to the soil upon impact. The impact will tend to break down the soil clods causing the soil to consolidate. Eventually a thin crust will be formed on the surface that can reduce soil infiltration by up to 80% compared to protected conditions.

A note of CAUTION! The move toward smaller water droplets should be tempered by the knowledge that small water droplets are more likely to be transported by wind. In addition, due to the increase in droplet surface area that results from the smaller sizes, evaporation loss in the air will be slightly greater for small water droplets than large droplets.

SPRINKLER TYPES

Pressure ratings for center pivot sprinkler packages span a broad range. Within each major category the range in pressure could be 15 to 25 psi. The exact breakoff point between categories is always a point of discussion. Below is a general list of sprinkler package categories.

--High pressure impact (HPI)
---50 to 70 psi
--Medium pressure impact (MPI)
---40 to 55 psi
--Low pressure impact (LPI)
---30 to 45 psi
--Low pressure spray (LPS)
---10 to 30 psi

As you look for suitable retrofit options, remember to consider the existing distribution system. For example, a water drive system requires high pressure to operate the drive mechanism. Thus, it is impractical to install a reduced pressure sprinkler package. Likewise, older electric drive systems typically have wide spacings between sprinkler outlets. Hence, more outlets would need to be added to install low pressure spray nozzles.

Sprinkler orientation represents the largest change in sprinkler package options. The trend has been toward more narrow spacings but at largely constant spacings between sprinklers. This results in a larger number of sprinkler heads, but limits the size of individual sprinklers at the outer end of the system. For low pressure spray nozzles, 9 to 10 feet is a common spacing.

Low pressure spray nozzles can be mounted on top of the pipeline, or on drop tubes below the truss, at canopy level, or at various levels within the canopy. The most extreme case is to mount the nozzle about 12-18" above the soil surface. Each arrangement alters a number of water application factors--most notably, the peak water application rate. For example, nozzles operating 12-18 inches from the soil in the bubble mode apply water at a peak application rate of approximately 70 in/hr. **NO** soil can intake water that rapidly. Thus, some means of supplying soil surface storage is an absolute necessity (see NebGuide G91-1043). A typical spray nozzle mounted at truss level may have a peak application rate of 8-10 in/hr.

Positioning the sprinkler near or in the corn crop canopy reduces the impact of wind drift and canopy evaporation. Therefore, the potential to save water is a motivation. However, it may cause two negative outcomes. In general, the closer the nozzle is to the ground the greater the runoff potential. If the nozzle is positioned well into the canopy in a field with a very sandy soil, plant stems and leaves may deflect a portion of the water pattern, causing poor water distribution. Flexible tubing tends to ride up on corn stems alterring the water application pattern drastically. Poor uniformity may result in decreased production under some conditions.

SPRINKLER LOSSES

The potential water losses fit into five categories--soil evaporation, runoff, deep percolation, in-air, and canopy evaporation loss. These five areas combine together to reduce the amount of water available for plant use.

Air losses refer to the water that evaporates between the sprinkler head and the soil or plant surface. In-air evaporation is typically in the 3-5% range. Evaporation is in direct relation to the surface area of the water droplet. As previously stated, small water droplets represent greater surface area and hence greater air evaporation loss. To reduce air losses the water should spend little time in the air (short transport time) or irrigation should occur predominantly during at night. This can be accomplished by directing the water stream toward the soil rather than up into the air. Water application rates and thus the potential for runoff will increase.

Canopy losses are direct evaporation of water that is intercepted by the plant foliage on its way to the soil surface. Canopy evaporation losses could range from 0 to 10% depending on the atmospheric conditions. Canopy evaporation cools the plant, reducing transpiration. However, current theory is that transpiration is reduced less than the level of canopy evaporation. Thus, the net difference is toward the evaporation loss side.

Canopy evaporation occurs for the length of time water is on the leaf surface. High pressure impact sprinkler packages have the most canopy loss because the irrigation time is the greatest (Figure 2). This factor is the main reason lower pressure sprinklers achieve higher water application efficiencies. In-canopy sprinkler packages irrigate for extremely short time periods and do not wet the entire canopy. Consequently, canopy evaporation is minimized.

Runoff loss is the water that reaches the soil but does not infiltrate. Runoff losses could range from 0 to 60% of the water applied. Runoff water is redistributed to other portions of the field (usually low lying areas) or could, in severe cases, leave the field boundaries. The amount of runoff loss depends on the matchup of the sprinkler package with the soil and slope conditions. Sprinkler packages with high application rates, matched with soils with steep slopes and low infiltration rates produce the maximum potential for runoff if soil surface storage is not provided. Conversely, low water application rates, flat slopes and high infiltration rates may produce no runoff.

Soil evaporation loss is water that evaporates directly from the soil surface. Soil evaporation is not a characteristic of sprinkler packages, but is an important component of overall irrigation efficiency. Work conducted at North Platte indicates that soil evaporation accounts for about 30% of total crop water use but is generally in the 5 to 10% range for an individual irrigation event. High pressure impact sprinklers wet 100% of the soil surface, so soil evaporation is much greater. Crop residues left on the soil surface reduce soil evaporation by reflecting incoming radiation and creating a barrier that decreases the movement of water toward the soil surface between irrigation events.

Deep percolation loss is water applied in excess of the soil water holding capacity. It is water that passes directly through the soil profile and does not contribute to plant growth. Deep percolation losses are easy to control with sprinkler irrigation systems. Water application should not occur unless the soil is able to hold it. Most deep percolation does not result from the irrigation event but from a rainfall event that occurs immediately after or during the irrigation event. One way to minimize deep percolation loss is to reserve a portion of the soil's water holding capacity for rainfall. Beyond tassle emergence the operator could reserve up to 0.5" even in a sandy soil. Up to 1" could be reserved for a silt loam or clay soil. Another key is to watch the weather reports closely and minimize the number of times an irrigation event begins when the potential for rain is 50% or above.

SUMMARY

Center pivot buyers have a vast array of sprinkler packages to choose from. Selecting the most appropriate sprinkler package for an individual field should be based upon collection of accurate field based information for soils, slopes, elevation differences, and pumping plant performance. The final selection should not be based on energy costs alone. Rather, the goal should be to apply water uniformly without generating runoff. If possible, the system should be capable of delivering sufficient water to meet crop water needs while operating under your management scheme. The "**CPNOZZLE**" computer program presents an opportunity to perform some 'what if?' sorts of analysis prior to making a sprinkler package purchase.

Because atmospheric conditions vary constantly, the sum of all potential water losses can be in the range of 3 to 60% of the water applied. Irrigating during conditions of low air temperature, high humidity, low wind velocity, and low sunlight will maximize the amount of water reaching the soil surface. Properly matched sprinkler packages and soils will limit runoff losses and crop residue management will minimize soil evaporation losses.