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Variable Rate Application of Irrigation Water with Center Pivots

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This publication provides information about the electronic controls and communication equipment that have been developed to allow center pivots to deliver irrigation water based on spatial production levels, soil texture, fertility, or field topography. Though the focus of this publication is center pivot irrigation systems, some of the information also could apply to sprinkler irrigation systems that move in a straight line across the field.

Tailoring Water Applications

Traditionally, the objective of a center pivot sprinkler irrigation system has been to apply water as close to 100 percent uniformity as possible. Sprinkler package design includes sprinkler spacing and position on the center pivot pipeline to apply the same depth of water along the entire length of the center pivot. However, 100 percent uniformity is being questioned in light of the variation in grain and forage yields displayed in yield maps produced by harvesting equipment currently being used. In essence, yield maps suggest that uniform distribution of production inputs has not been translated into uniform yield.

Consequently, one way to make more efficient use of the water applied may be to tailor water applications to field productivity levels. Intuitively, when a field presents considerable spatial variability, the goal of 100 percent production uniformity may not be economically viable.

Sector, zonal, precision application, variable rate irrigation (VRI), and site-specific irrigation are terms developed to describe water application systems designed to control irrigation water application depths or rates. Water application can be varied spatially and temporally with the goal of maximizing the economic and/or environmental return of the irrigation water applied via the center pivot irrigation system. Agricultural field productivity may vary due to differences in topography, soil texture and quality, fertility levels, depth to groundwater, nonuniform emergence and crop development, and localized pest distributions.

Only a few of the items that contribute to yield variation are controlled by the operator. Extreme field-to-field and season-to-season variation can further exacerbate the ability to match water applications to field productivity levels.

Even though center pivots are capable of applying water in a variable manner, the underlying causes of

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year-to-year variation in crop performance due to various field characteristics are not fully understood. Thus, the use of center pivot control panels to alter water application depth must be combined with a clear understanding of how variable water application will help fully realize the potential for yield enhancement that should result if all areas of the field receive the optimum amount of water.

Center Pivot Control Options

Center pivots employ a range of system drive technologies (e.g., water, electric, and hydraulic drive) to propel the center pivot around in a circle. Early means of center pivot control used manual adjustment of the speed of travel to alter the water application depth by using a percent timer setting. Typically, the change in system speed was justified due to the water needs of different crops that may be grown under a single center pivot.

Developments also provided a limited set of controls to turn end guns on and off and to stop the center pivot operation based on field position or completion of an irrigation cycle. These controls were accomplished with switches positioned on the metal structure at the pivot point and had to be positioned using trial and error to ensure the desired outcome occurred at the correct position of the center pivot's rotation.

Development of programmable control panels by manufacturers initially allowed the center pivot travel speed to be adjusted multiple times (usually <10 times) during an irrigation event. In addition, changes in system operation could be implemented at a more precise location in the system's rotation.

However, these control panels lacked the flexibility necessary to supply water at rates required to meet the management objectives of relatively small and/or irregularly-shaped field areas. Manufacturers now market control panels with the option to change

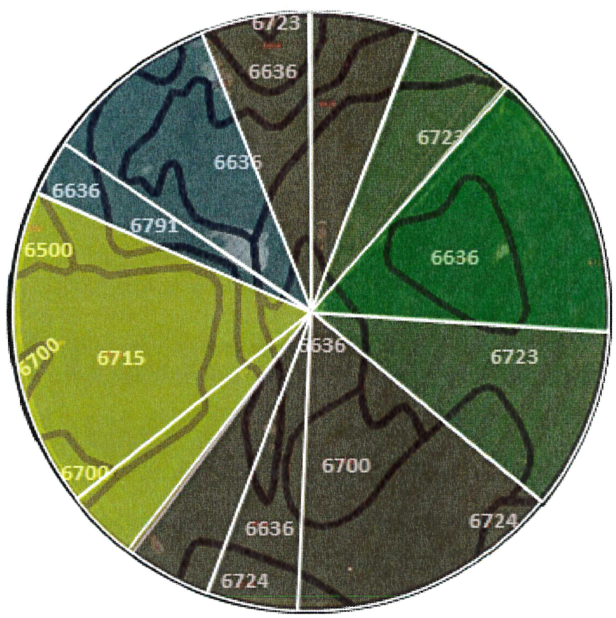

Figure 1. Quarter section of land showing soil mapping units and unequally-spaced center pivot speed control zones. Pie-slice-shaped areas with the same color have equal pivot travel speeds.

the system travel speed and auxiliary equipment operation at minimum increments ranging from <1° to 10° of the pivot rotation.

Adjusting the system speed of travel effectively changes the application depth in radial sectors (or pie-slice-shaped areas) of the field *(Figure 1)*. Generally, no additional hardware is needed. This technique is commonly referred to as speed or sector control. The complication is that field variation seldom occurs in pie-slice-shaped parcels. Thus, since the sprinkler packages apply the same depth along the entire lateral length, adjusting the speed of travel will not miss surface drains or provide setbacks unless these obstacles are in line with the center pivot pipeline.

A number of different methods have been under development to address varying application depths along the center pivot lateral. In 2004, information about a variable flow sprinkler that used a mechanically-activated pin was published by the USDA Agricultural Research Service. This variable flow sprinkler could adjust a sprinkler's flow rate over a range of 35 percent to 100 percent of its design flow rate.

Each sprinkler on the center pivot required a device that would also require special control panel capabilities. The pin was controlled using either electric or hydraulic actuators. The main disadvantage was that the water application pattern and water droplet size distribution of the sprinkler changed with engagement of the pin, resulting in nonuniform water applications, crop growth, nutrient uptake, and yield.

Controlling irrigation water application depth also may be accomplished through the use of multiple manifolds attached to the underside of the center pivot pipeline. In this arrangement, each manifold is equipped with a different sprinkler package. These systems include either two or three manifolds activated by solenoid valves to control the operation of individual manifolds.

Each manifold irrigated a half span or full span of the center pivot. This allowed adjustment of the water application rate and depth per irrigation event between 30 percent and 100 percent of the full application. Different water application depths would conform to trapezoidal-shaped areas of the field similar to those shown in *Figure 2b.* These systems were

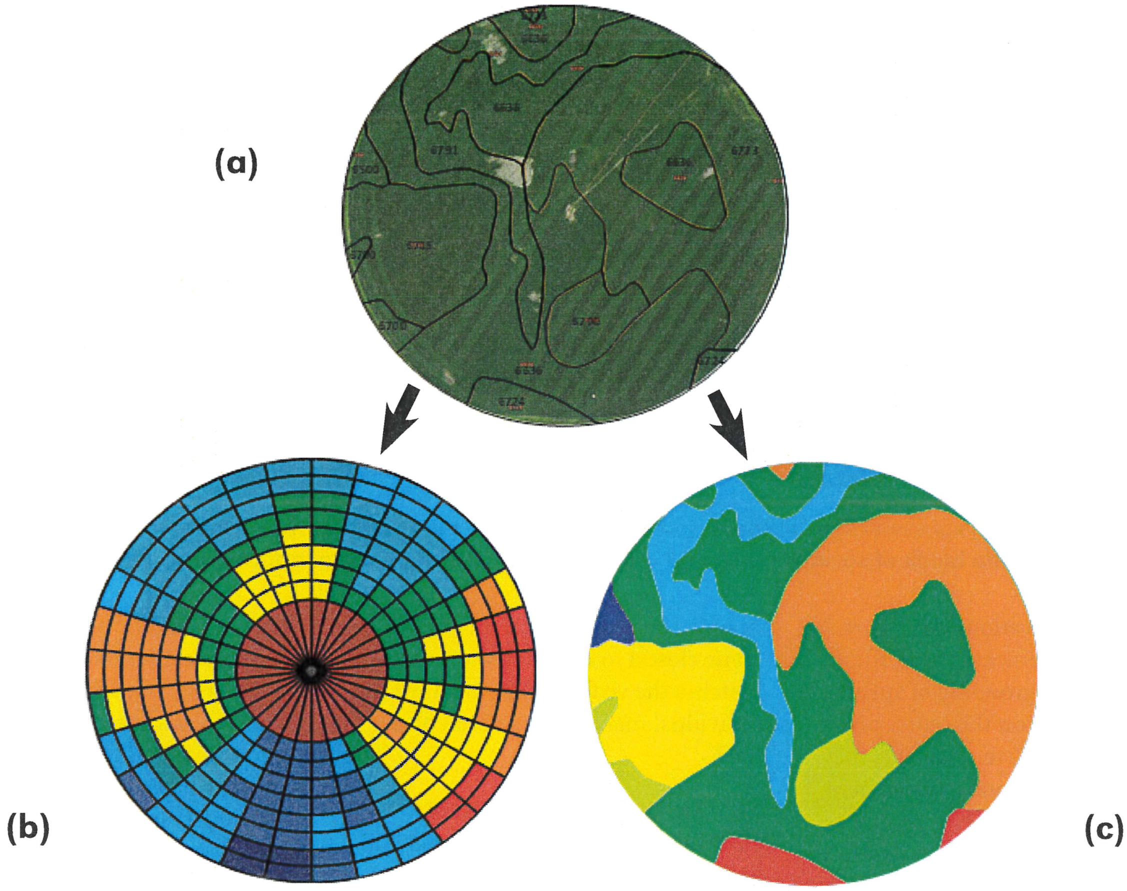

Figure 2. Quarter section of land showing soil mapping units (a), 270 potential center pivot control zones (b), and the potential map for a system equipped with individual sprinkler controls and seven management zones (c).

developed as a means of applying different depths for research conducted to evaluate crop response to water and have never been viable for use by center pivot operators.

Though speed control techniques are the most common systems used today, zone control systems have a greater potential for conserving water and energy. Zone control involves the spatial definition of irregularly-shaped field areas or management zones based on crop yield maps, soil textures, fertility levels, topographic variations, or no irrigation areas. Most zone control systems vary water application depths using the on-off cycling of individual sprinklers or groups of sprinklers using a single system speed. However, zone control systems also could be combined with speed or sector control to help balance the water flow rates required by the irrigation system.

The most common use of zonal rate irrigation is the nonuniform irrigation of areas such as surface water impoundments or streams, roads, drainage ways, or rocky outcrops. However, variable water application also has application when using a center pivot to apply liquid animal waste to field areas where there are legally required setbacks.

Similarly, setbacks may be required to meet water quality protection goals when applying pesticides. In these situations, normal cost recovery based on crop yield may become secondary to the potential for savings in product application cost or to meet legal requirements.

Banks of Sprinklers

One commercially available approach to varying water application depth along the center pivot is to control groups or banks of sprinklers. The field soils map presented in *Figure 2a* is based upon the soil mapping units for a quarter section of land in Nebraska presented in *Figure 1.* The map in *Figure 2b* showing 270 VRI management zones is not an actual map developed for this field site. Rather the VRI map is provided as an example of how the system is set up. One of the advantages to this arrangement is that the number of solenoid control valves is limited to nine, thus reducing the number of potential valve failures and the associated operation and maintenance costs.

If the water management zones were defined based only on the soil mapping units, grouping three to five sprinklers together in blocks along the lateral (different-colored rectangular shapes on the pivot) might fit

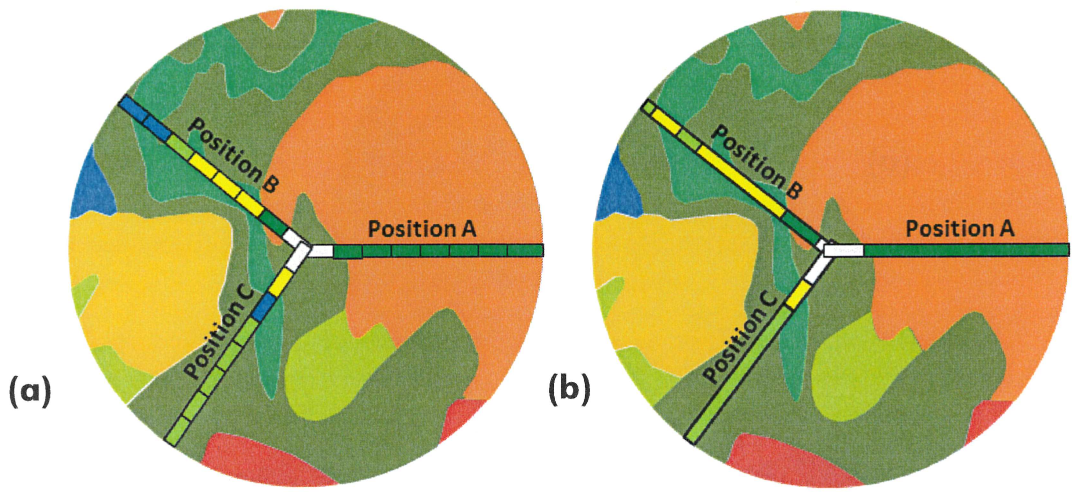

Figure 3. Schematic representation of the potential ability of the water application system to match field conditions when using the block of sprinklers (a) and individual sprinkler (b) control approach to VRI.

the contour at Position A of *Figure 3a* quite precisely. However, at Positions B and C, since the grouping of sprinklers is hard-plumbed on the center pivot, the same three to five sprinklers may irrigate more than one management zone. Thus, the attempt to precisely match the water application depths to irregularly-shaped management zones using blocks of sprinklers may limit the number of management zones that can be implemented within a field.

Individual Sprinkler Control

Another approach is to independently control each individual sprinkler along the pivot lateral. *Figure 2c* presents the same soils maps as those in *Figure 1* using the individual sprinkler control system. The difference is that as the pivot makes a revolution, individual sprinklers can be combined in groups based on the field management zones and not based on the center pivot's plumbing.

At Position A, the same sprinklers included in blocks shown in *Figure 3a* may be controlled in blocks of individual sprinklers shown in *Figure 3b*. At Positions B and C, completely different sets of sprinklers can be combined to match the zone contour at that location as precisely as was obtained at Position A. Thus, the use of individual sprinkler controls will come closest to applying water that matches the water requirements of the individual management zones of the field.

Due to the large number of electronically controlled solenoid and hydraulic valves installed to control every sprinkler, it is anticipated that individual sprinkler controls could potentially increase sprinkler control failure and center pivot maintenance requirements in the long run. For example, a 1,320-foot-long center pivot with a sprinkler spacing of 5, 7.5, or 9.33 feet would have a total of 264, 176, or 141 sprinklers on the center pivot, respectively. Thus, the potential for maintenance increases by three to five times when compared to the system that is equipped with controls for banks of three to five sprinklers.

Management Considerations

Successful implementation of the true value of variable rate water application for center pivots will depend on the integration of data collection systems, management strategies, and hardware controls. Implementation of sector, block, or individual sprinkler control systems requires the development of a management scheme to determine where, when, why, and by how much the water application rate should change. The management scheme is generally referred to as a variable rate irrigation map or prescription map. The first step in the process is to collect field-based information on a spatial scale.

Figure 4 depicts the process of combining soil mapping unit information and a grain yield map to develop a sector control map. The images are not from a specific field nor is the final sector map meant to display the preferred outcome. Rather, the bottom two pieces of information in *Figure 4* are combined using Geographic Information Systems (GIS) models to mathematically define individual management zones within the irrigated field. The center pivot control panel must then be programmed to change the speed of travel based on the variability attributes shown in the map.

The use of sector, block, or individual sprinkler type controls leads to areas of transition parallel and perpendicular to the center pivot lateral travel direction. The land area impacted by the transition from one management zone to another is directly related to the wetted radius of the sprinklers installed on the center pivot and the distance of the transition from the pivot point.

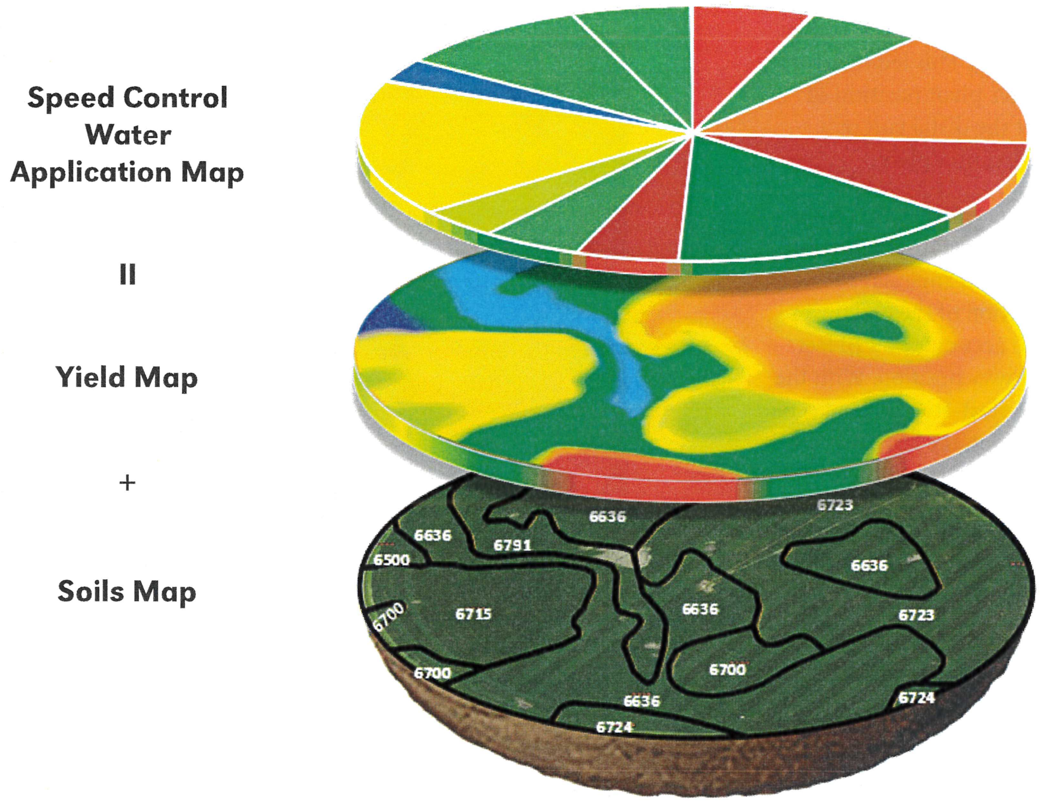

Figure 4. Image showing how GIS procedures use soil and yield maps to develop plans for adjusting center pivot water application depths using a system speed control water application approach.

The width of the transition zone also can be impacted by environmental factors such as wind speed and direction. Though several adjacent sprinklers contribute to the overall water application pattern, the transition zones may result in some application irregularities at various points of overlap along the center pivot lateral.

In most fields, the transition zones will likely conform to gradual changes in field conditions such as soil texture, topography, nonirrigated area, or some soil physical properties. Consequently, implementation of management zones and the evaluation of the impact of changes in water application must be implemented with the knowledge that the change in water application depth within zones is not instantaneous when moving from one zone to another, but rather a gradual transition from one zone to another. An example of these transition zones is depicted in *Figure 5*.

The transition zones will impact activities commonly used to manage center pivot operation. One of the major items to consider is that the location of soil water monitoring sites must be within one or more of the management zones. If soil water content is monitored in the transition zone, center pivot management could over-irrigate or underirrigate the field, which may result in unintended variability of water contained in the soil profile.

Furthermore, if the field is chemigated and the water application map includes variable rate water application, the chemical will be applied at nonuniform rates as well. The management plan may call for implementation of variable rate production practices for all crop inputs. However, the decision to use the VRI map when chemigating must consider the impact the variable chemical application rate will have on crop productivity.

Some of the potential impacts (positive or negative) of implementing zonal irrigation practices have yet to be fully researched and documented in the field. It is likely that the level of water conservation experienced with VRI will depend on the degree of variation exhibited within the management zones. However, if the desire is to precisely match variably sized and shaped management zones, the approach with the maximum amount of flexibility in sprinkler controls would be best able to capitalize on the field-based information used in developing the management zone maps.

Center Pivot Controls

One of the earliest and basic uses of sensors on a center pivot was to determine alignment and lateral position of the system. Until 2003, control systems were based largely on a digital angle resolver with an alignment accuracy of ±0.5° to 1.5° of the first tower position. This led to errors in defining center pivot position of over 100 feet at the distal end of a 1,300-foot-long center pivot.

Manufacturers now equip center pivots with Wide-Area Augmentation System-enabled GPS antennas to identify the position of the end tower to an advertised accuracy of ±10 feet of the outside tower position. With the inclusion of the start-stop cycle of center pivot movement, the last tower position can normally be determined within ±3-foot accuracy. The effect of being able to accurately determine the center pivot position is that management zone size can be reduced without increasing the potential for a misapplication of water, nutrients, or pesticides.

Recent developments have included developers of after-market control and monitoring systems. These controls can be retrofitted onto an existing center pivot manufacturer's control panel to provide remote monitoring and control of system position, speed, and direction of travel, water on-off status, programmable stop and restart by positions, and auxiliary components *(Table 1)*. The number and type of auxiliary component controls differs by the manufacturer.

The benefits of remote monitoring for the operator are that they save time and fuel by not having to drive to the field when the irrigation system is operating properly. Field visits can be reserved for times when maintenance is required or when there is an indication that some component is not functioning properly.

Communication with the center pivot control panel via cell phone also allows the operator to monitor multiple center pivots from any location with cell phone coverage. Web-based posting provides the advantage of data recording and overview that may help in making long-term decisions.

Figure 5. Quarter section of land showing transition zones that result from using individual sprinkler controls to vary water application depth.

Potential for Energy Conservation

Intuitively, if less water is pumped, it follows that somewhat less energy should be needed to pump irrigation water through a center pivot equipped with VRI technology. However, whenever a group of sprinklers is cycled on and off to adjust the water application depth, the pump adjusts to the new operating requirements.

The impact of the on-off cycling on pump operation depends on how many sprinklers are being controlled at one time and where the sprinklers are located on the center pivot. For example, if a group of 10 sprinklers is being controlled near the distal end of the center pivot, this could mean a 100 gpm fluctuation in system flow rate. This change would cause the pump to operate at a less efficient point on the pump impeller curve as shown in *Figure 6*.

To minimize the impact of the fluctuation in flow rate on the pump and distribution system, VRI systems use a combination of hardware and software to cycle smaller groups of sprinklers on and off to minimize the hydraulic impact on the water delivery system. Using the aforementioned example of controlling 10 sprinklers, each individual sprinkler or group of sprinklers would be activated for a different portion of a one-minute time frame. Thus, if the treatment would apply 0.60 inch of water to a zone instead of a 1-inch water application, the center pivot hardware would cycle each sprinkler or group of sprinklers off for 24 seconds of every minute *(24 seconds ÷ 60 seconds = 40 percent offtime)*.

An example of how the software operates is to send signals to each control valve that turns each sprinkler or group of sprinklers off for three 24-second segments spread across each 60-second time period. So, sprinklers 3, 6, and 10 might be turned off for one 24-second segment; 2, 7, and 9 for a second segment; 1, 5, 8, and 4 at another segment. At no time would all 10 of the sprinklers be turned on or off. In so doing, the water flow rate needed for the center pivot fluctuates over a much narrower range than if only the hardware was used to control sprinkler operation.

Another system component that will help ensure energy conservation is

Table 1. Listing of center pivot monitor and control capabilities available from five center pivot manufacturing companies with sales in Nebraska.

	Center Pivot Manufacturer				
	Pierce	Reinke	T-L	Valmont	Zimmatic
Monitors					
Position in field and travel direction	Y	Y	Y	Y	Y
Speed of travel	Y	Y	Y	Y	Y
Wet or dry operation	Y	Y	Y	Y	Y
Pipeline pressure	Y	Y	Y	Y	Y
Pump status	Y	Y	Y	Y	Y
Auxiliary components[β]	Y(4)	Y(5)	Y(2)	Y(6)	Y(7)
Stop-in-slot and auto restart	Y	Y	Y	Y	Y
Wind speed	Y	Y	N	Y	Y
Controls					
Start and stop	Y	Y	Y	Y	Y
Speed of travel	Y	Y	Y	Y	Y
Auto restart and auto reverse	Y	Y	Y	Y	Y
End gun operation	Y	Y	Y	Y	Y
High and low pressure shutdown	Y	Y	Y	Y	Y
High and low voltage shutdown[£]	N/Y	N/Y	N/Y	Y/Y	Y/Y
System stall shutdown	Y	Y	Y	Y	Y
Auxiliary components[β]	Y(4)	Y(7)	Y(2)	Y(6)	Y(7)
System guidance[$]	Y	Y	Y	Y	Y
Maximum control points per circle[¶]	180	3600	120	180	180
Sprinkler application zones[¥]	8	84	3	30	NL
Remote Communications					
Cell phone	Y	Y	Y	Y	Y
Radio	Y	Y	Y	Y	Y
Computer base station	Y	Y	Y	Y	Y
Subscription required	Y	Y	Y	Y	Y
Data Collection and Reports					
Soil water content	Y	Y	Y	Y	N
Precipitation per season	Y	Y	Y	Y	Y
Application date and depth	Y	Y	Y	Y	Y
Irrigation events per season	Y	Y	Y	Y	N
Chemical application rate	N	N	N	N	Y
Chemical application per season	N	N	N	N	Y
System position by date	Y	Y	Y	Y	Y

[£]N/Y indicates no automatic shutdown for high voltage is provided, but the panel does provide automatic shutdown for low voltage.
[β]Y(7) indicates that up to seven auxiliary components (injection pumps, end guns, etc.) can be controlled by the panel.
[$]System guidance provided by aboveground cable, belowground cable, furrow, or GPS.
[¶]Number of positions in a revolution where set points may be changed.
[¥]Number of banks of sprinklers that can be controlled along the pivot pipeline. NL means that the number of banks is controlled by the total number of sprinklers on the center pivot.

the installation of a variable-frequency drive (VFD) controller on the pumps powered by electric motors or engine monitor and control systems (EMCSs) for pumps powered by internal combustion engines. Each of these monitoring and control systems adjusts the pump speed by monitoring the pipeline pressure at the pump outlet. Thus, if the pressure increases above the set point, the pump speed is reduced and vice versa when the pressure is below the set point.

These components work best when the software control of sprinkler operation is limited to the entire group of sprinklers being cycled simultaneously, so the cycling of sprinklers as described previously would tend to limit the usefulness of a VFD of EMCS because the monitoring systems have a time lag during which the pump speed is adjusted to match the new operating conditions. Frequent cycling of sprinklers could occur nearly as rapidly as the controller can adjust the pump speed, so even though the VFD or EMCS can make the adjustment in a matter of seconds, the controller may never really stop adjusting the pump speed.

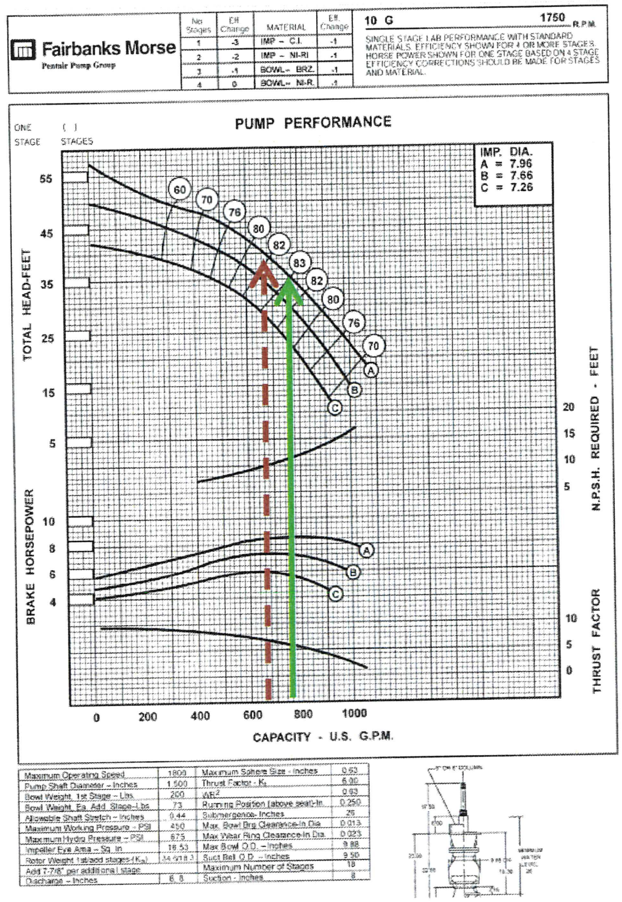

Figure 6. Deep well turbine pump impeller characteristic curve showing the impact of a flow rate change of 100 gpm on pump operating efficiency. It was assumed that the pump flow rate changed by 100 gpm. The green line is the design flow rate of 785 gpm, and the red line is a flow rate of 100 gpm less at 685 gpm. It was also assumed that the pump was operating as it was originally designed.

Summary

Electronic sensors, equipment controls, and communication protocols have been developed to meet the growing interest in VRI using center pivot sprinkler irrigation systems. Equipment necessary to adjust the water application depth to meet management criteria for relatively small management zones is commercially available from irrigation system manufacturers and after-market suppliers. The new VRI systems allow zone-specific application of water, nutrients, and pesticides. However, the availability of VRI hardware systems brings the need for criteria for locating and utilizing data acquisition systems in the field. Alteration of the water application depth based on well-defined management zones will ultimately change the soil water balance during the growing season.

Operators of VRI systems need criteria for deciding when and how the water management zone map needs to be changed to meet the water requirements of the crop. Each manufacturer also offers a range of communication systems such as cell phones, satellite radios, and Internet-based systems that allow an operator to query the main control panel or a base computer from any location at any time. While the hardware and software are available to alter water application depths, the development of the decision support system necessary to fully realize the added-value of VRI technologies needs further research.

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