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Agricultural Irrigation Initiative: Overview of Center Pivot Irrigation Systems

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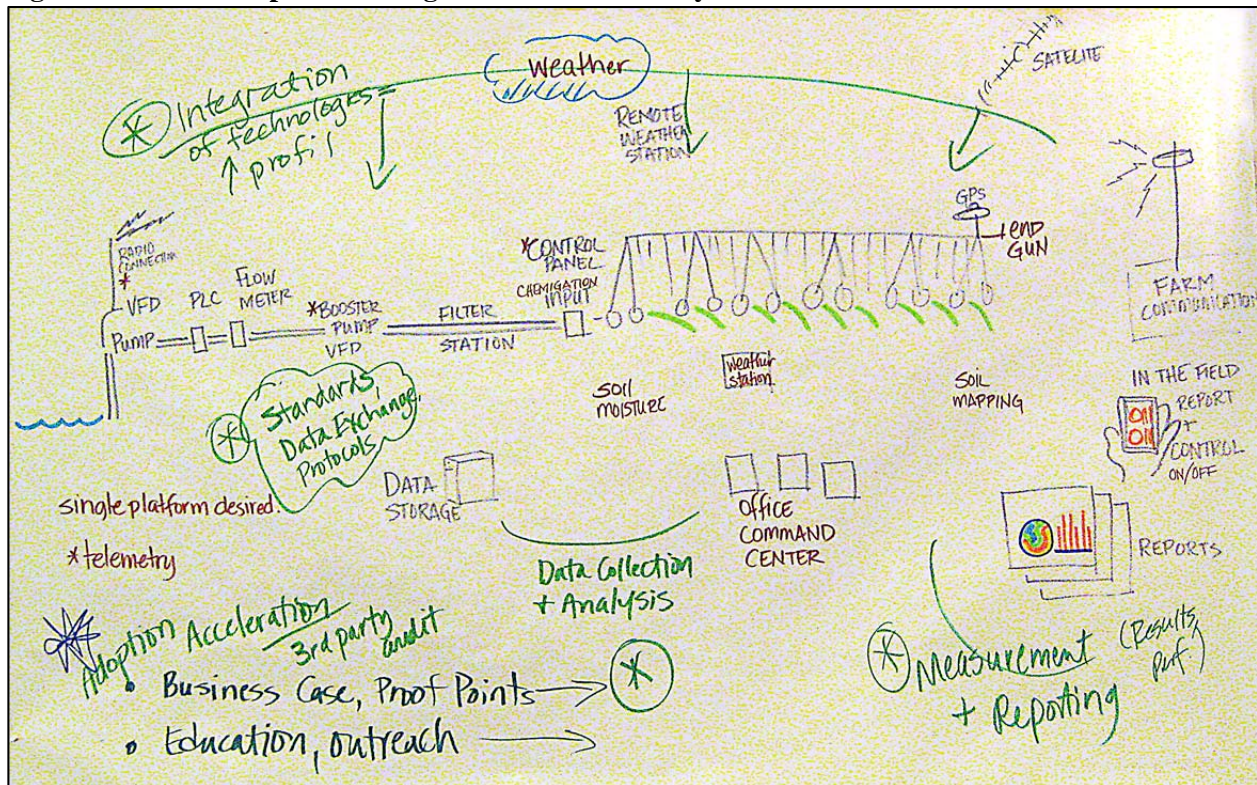
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Executive Summary

This report provides a basic introduction to and overview of center pivot systems, including key components of the system and basic interconnections among components.

Center pivot technology is a primary method for irrigating farmland. Center pivots cover the largest proportion of acreage of pressurized irrigation in the Pacific Northwest. However, the pivot itself is part of a larger system. When the Northwest Energy Efficiency Alliance (NEEA) Agricultural Irrigation Initiative began in Walla Walla, Washington in November 2011, the attendees (including growers, irrigation vendors, consultants, utility representatives, and NEEA staff) drew their version of a complete system, shown in Figure 1 below. This image illustrates that the center pivot connects to pumping systems, weather systems, data systems (local and remote), telemetry systems, and control systems. The center pivot, while at the heart of the irrigation system, relies upon an entire set of intersecting systems, controls, and data connections.

Figure 1. First Concept of an Integrated Center Pivot System with NEEA Partners



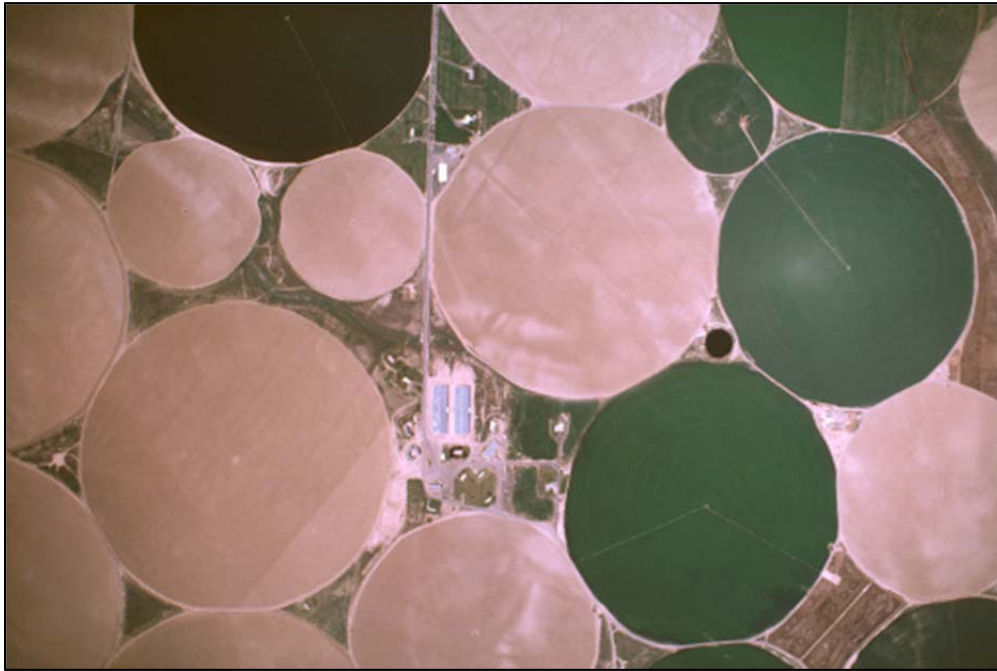
This report is one in a series of twelve reports addressing particular areas of NEEA's Agricultural Irrigation Initiative. All twelve reports are available at <http://neea.org/reports>.

1. Introduction

This report is designed as a companion to the other eleven reports¹ in the series based on the activities in the Northwest Energy Efficiency Alliance's (NEEA's) Agricultural Irrigation Initiative. NEEA is an alliance funded by more than 140 utilities and energy efficiency organizations in Idaho, Oregon, Montana, and Washington working to accelerate the innovation and adoption of energy-efficient products, services, and practices in the Northwest.

Center pivot irrigation is a method of **crop irrigation** in which equipment rotates around a pivot. The pivot naturally irrigates a **circular area**, often creating a circular pattern in crops when viewed from above, as shown in Figure 2. Individuals looking out the windows on flights over the Midwest portion of the United States on a clear day can see large circles on the farmland below. Growers created those circles using center pivots.

Figure 2. Aerial View of Center Pivot Circles



Based on type of crops, available water, and soil conditions, irrigators may choose to plant a crop circle uniformly, in halves, quarters, or subsection wedges.

Constant linear move systems for irrigating square or rectangular fields use technologies similar to those of center pivot systems. This report does not address linear move systems, but many of the same observations would apply.

¹ All twelve reports, each of which addresses a specific area of NEEA's Agricultural Irrigation Initiative, are available at <http://neea.org/reports>.

Given the industry-specific and scientific natures of some terms used in this report, please refer to the [AgGateway AgGlossary \(http://agglossary.org/wiki/index.php/main_page\)](http://agglossary.org/wiki/index.php/main_page) for definitions.

1.1. Advantages and Disadvantages of Center Pivot Systems²

Center pivot systems offer many advantages over other irrigation application methods:

- Potential for automated operation, reducing labor costs
- Simplified and predictable water delivery
- Ability to apply to more shallow depths
- Uniform distribution of water
- Increased ability to plan and schedule irrigation applications
- Easier to apply agri-chemicals (chemigation)
- Little annual setup required
- Reliability

Disadvantages of center pivot systems include:

- Relatively high initial cost
- Relatively high pipe-friction losses
- Circular pattern leaves dry corners and potentially lower yield
- Topographic changes cause potential operating pressure variations
- Can have operational challenges requiring human interventions
- Potential risk for injury if the operator is not familiar with operation

1.2. Center Pivot System Layout

Center pivot irrigation is a form of overhead ([sprinkler](#)) irrigation consisting of several segments of pipe (usually [galvanized steel](#) or [aluminum](#)) joined together and supported by [trusses](#), mounted on wheeled towers with sprinklers positioned along its length. The major components include:

- Pivot
- Pivot tower
- Control Panel (see Figure 10)
- Spans of pipe between towers
- Trusses to support the spans
- Tower drive wheels

² Many of these advantages and disadvantages would likewise apply to linear move systems

Figure 3 and Figure 4 show two different brands of center pivots and their main components.

Figure 3. Valley Center Pivot System

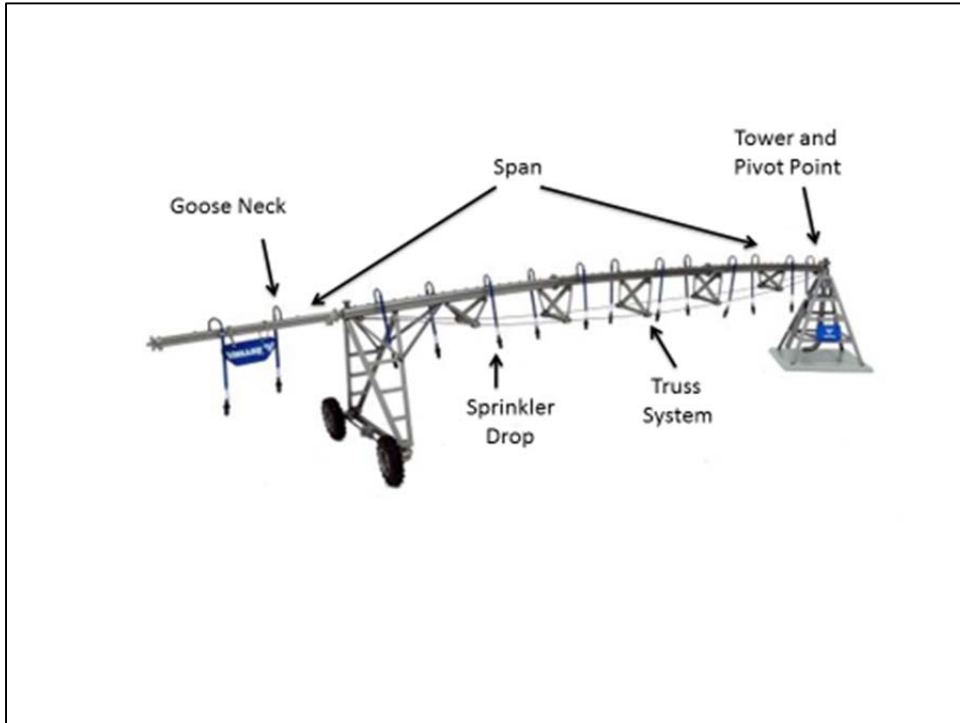
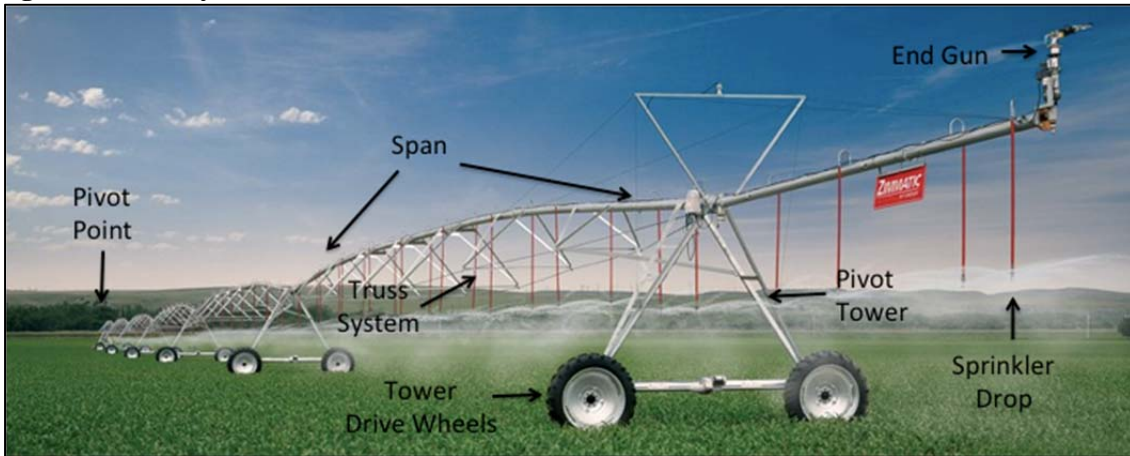
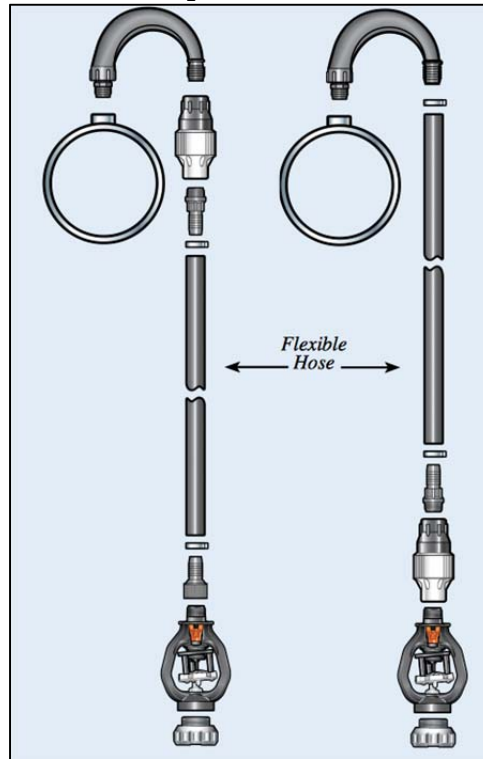


Figure 4. Lindsay Center Pivot with End Gun



Most center pivot systems now have drops³ hanging from a U-shaped pipe called a gooseneck (see example in Figure 5) attached at the top of the pipe with sprinkler heads positioned a few feet (at most) above the crop, thus limiting *evaporative* losses and wind drift.

Figure 5. Senninger Sprinklers with Gooseneck Pipes



Irrigators typically install pressure regulators upstream of each nozzle to ensure each is operating at the correct design pressure. They can also use drops with drag hoses that deposit the water directly on the ground between crops or with spray-type sprinklers less than two feet (0.6 meters) off the ground. These types of systems are respectively known as *Low Energy Precision Application (LEPA)* or *Low Elevation Spray Application (LESA)*.

Most center pivots originally operated with high water pressure, a practice later replaced by *hydraulic* systems and electric motor-driven systems. Most systems today are driven by an *electric motor* mounted at each tower.

³ A drop is a hose between the gooseneck and the sprinkler assembly or emitter. It is often made of a plastic such as polypropylene or polyethylene.

2. How Center Pivots Work

Center pivots are well-engineered structures that effectively deliver water to large circular fields. Each has a main water delivery pipe suspended over the field out of the way of the crops. Sprinklers or spray nozzles can be spaced along that pipe to apply water wherever the pipe is traveling. At each tower, pipe sections are connected with flexible joints that allow the pipe to move through a limited range without twisting or breaking. This flexibility also allows vertical bending that enables pivots to climb moderate hilly slopes.

2.1. General Center Pivot Movement

The machine moves in a circular pattern, and is fed with water from the pivot point at the center of the circle. The water is usually pumped from a source such as a well or a river. The pump is connected to the pivot at the pivot point (see Section 3.1 for details). The outside set of wheels covers the greatest distance and thus sets the master pace for the rotation. The inner sets of wheels are mounted at hubs between two segments and use angle sensors to detect when the bend at the joint exceeds a certain threshold (the wheels should be rotated to keep the segments aligned). Most center pivots irrigate a circular area a quarter-mile (0.4 kilometer) in radius, although some can cover a larger area. Center pivots are typically less than one-third of a mile (0.5 kilometer) in length. Most manufacturers offer a way to adjust the speed of the pivot, and thus the amount of water being applied over a given area, a process called Variable Speed Irrigation (VSI).

Some manufacturers offer packages that not only vary the speed, but also turn on and off valves for groups of sprinklers on the pivot system during operation. This is known as Variable Rate Irrigation (VRI). The *Irrigation Delivery Systems* report provides more information on VSI and VRI systems.

2.2. Wiper Pivots

A wiper pivot (or a “half-circle pivot”) runs in a half-circle (or more), reversing its course when a lever hits a stop placed in the field. Figure 6 shows a field irrigated with a wiper pivot. In many instances, irrigating a long, narrow field with a single center pivot designed to operate in a half-circle configuration is less expensive than irrigating that field with two smaller, full-circle pivots. Wiper pivots exhibit two important differences from center pivots:

1. Since the pivot does not automatically return to its original starting point, the grower may have to run the pivot “dry” back to that point before irrigating again, which adds wear to the system
2. If the grower does not return the pivot to its original starting point before the next irrigation cycle is started, the driest area of the field (the area irrigated first during the last cycle) will receive water last

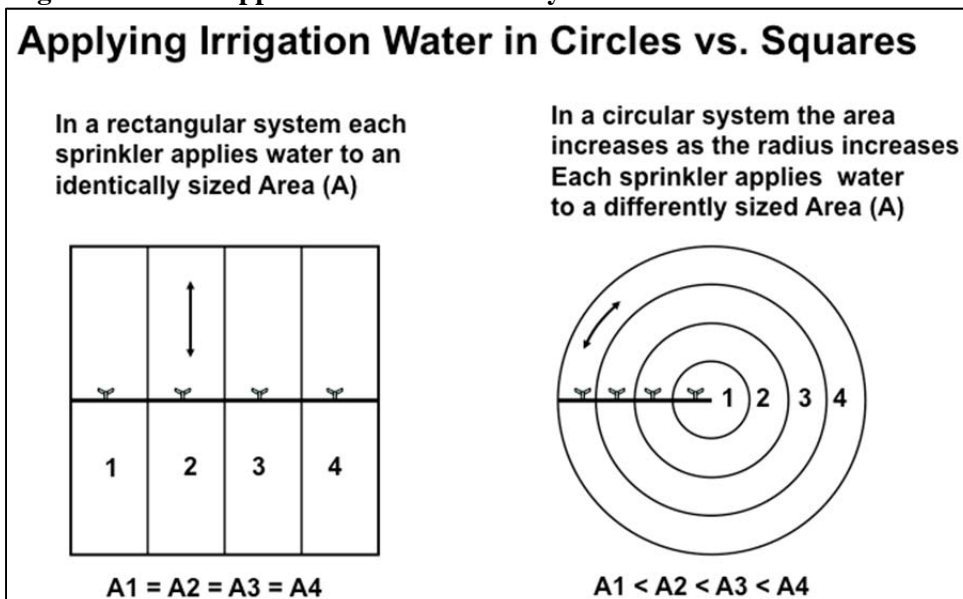
Figure 6. Field Irrigated with a Wiper Pivot



2.3. Challenges with Center Pivots

With all of its advantages, center pivot irrigation does present some challenges. Per the Natural Resources Conservation Service (NRCS) (Shae, Robinson 2009), irrigating in circular patterns is just plain “trickier” than irrigating in rectangles. In a rectangular system, each sprinkler applies water to an identically-sized area. In a circular system, the area increases as the radius increases so that sprinkler applies water to a differently-sized area (see Figure 7 below).

Figure 7. Water Application for Circular Systems Is Trickier to Calculate

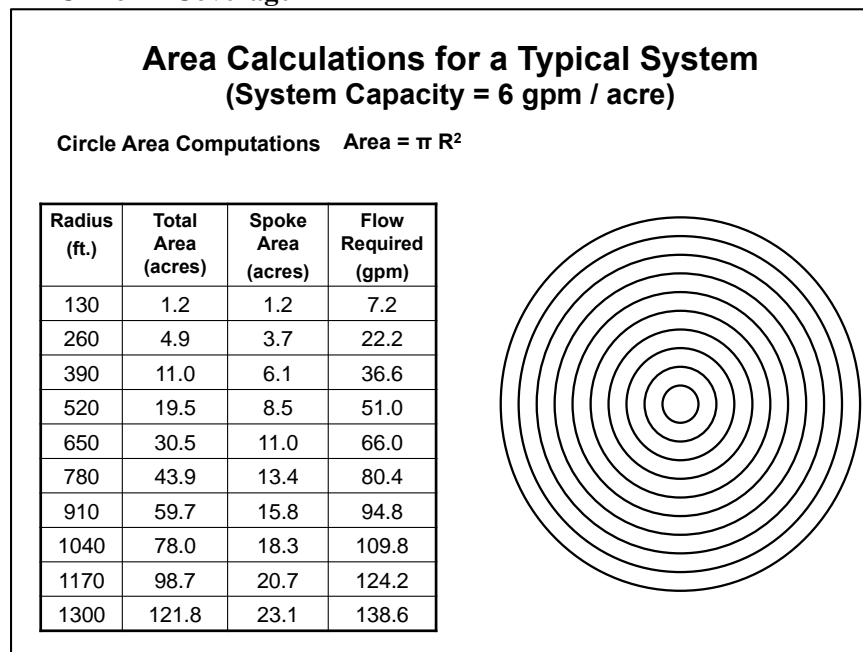


Note: Source – (Shae, Robinson 2009)

To overcome this irrigated surface area challenge, and to maintain uniform coverage, irrigators calculate and size sprinklers appropriately along the length of the pivot. This maintains uniform water application along the linear length of the center pivot. As Figure 8 shows, the greater the radius of the circle, the more the grower must adjust the gallons per minute (GPM) (or liters per minute) to overcome frictional losses and the increased delivery acreage. This is accomplished by adjusting the nozzle diameter to increase flow.

Since the outermost spans of the pivot travel farther in a given time period than do the innermost spans, nozzle sizes are smallest at the inner spans and increase with distance from the pivot point. This helps keep a uniform flow of water as the outer wheels set the pace of the rotation.

Figure 8. Area Calculations and Their Relationships to Flow for Uniform Coverage



3. Parts of the Center Pivot System

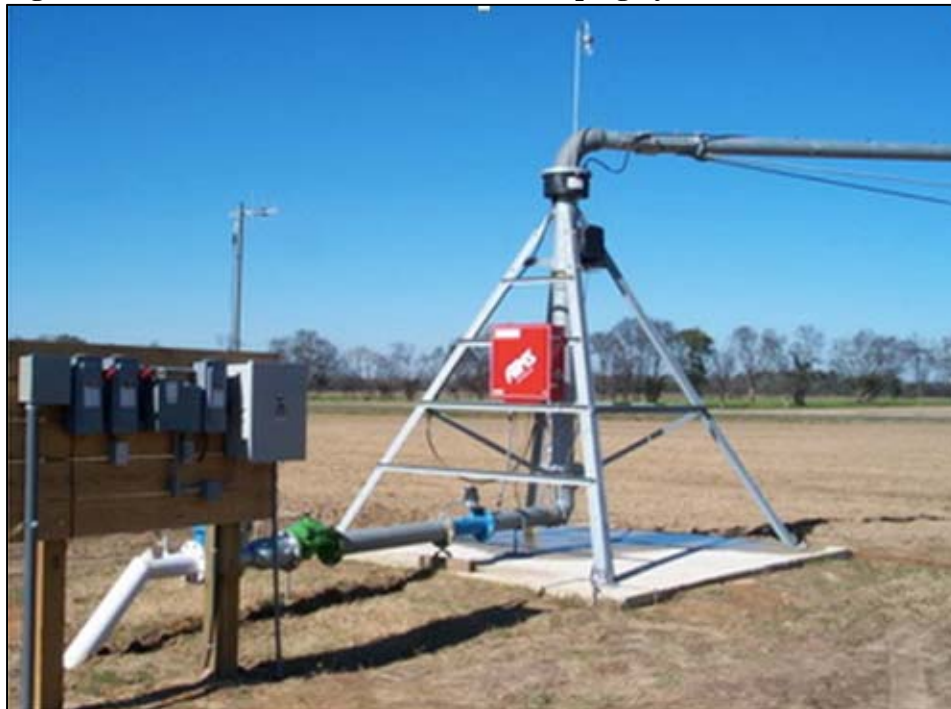
The typical center pivot system consists of a single long irrigating pipeline attached to a central tower that moves slowly over the field in a circular pattern and irrigates the plants with sprayers, or sprinklers placed on it at frequent spacings. The central tower, which houses the pivot mechanism and main control panel (electric), is anchored to a small concrete base at a fixed water supply point (hydrant) at the center of the field.

The entire irrigating pipeline is supported above ground by “A”-frame towers that move on wheels, long spans, steel trusses and/or cables. The outside end of the pipe is sometimes overhung with a sprinkler end gun. The whole system is self-propelled and rotates slowly, at a typical speed (for the outermost span) of two to three meters per minute around the fixed pivot. It applies water to the field in the form of overhead spray irrigation and covers the irrigated area in a circular pattern. The drive system features small individual electric motor drives mounted on each wheeled tower.

3.1. Central Tower and Span

At the center of the circular field, an anchored tower holds up one end of system and provides flexible joints that allow 360 degrees of movement for both water pipes and electrical wires (see Figure 9). Water and power are supplied to the system at the pivot point. Buried pipe delivers water from a nearby pond, river, or other source. Electric utilities may deliver power by means of buried wires, or power may be generated on-site by a generator attached to a diesel-, propane-, or gas-fueled engine. For irrigation systems supplied by pumped water, that engine may also drive the well pump by a drive shaft, or the generator may supply electricity to an electric well pump.

Figure 9. Anchored Tower Connected to Pumping System



Note: The pump is connected to the pivot at the pivot point

3.2. Control Panel

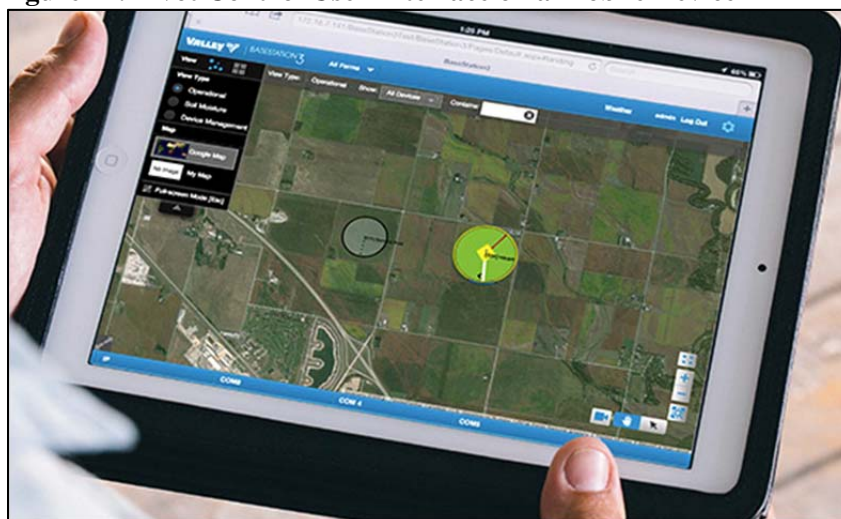
The control panel is the user interface for the center pivot irrigation system (see example below in Figure 10). Control panel technology ranges from very basic to very advanced. The primary functions of the control panel are to energize the system, select forward or reverse travel direction, and to select pivot travel speed by the percent timer setting. The entry-level basic control panels from center pivot manufacturers provide those functions and little else. Control panels at the advanced end of the spectrum incorporate more features into the package, including auto-reverse, auto-stop, digital displays, end gun controls, the ability to control pivot angles, auxiliary controls, corner catcher controls, auto-speed, programming capabilities, touch screen controls, and remote monitoring and control.

Figure 10. Example of Pivot Control Panel



In addition, most pivot manufacturers today provide user interface controls from mobile devices such as tablets and smartphones, as shown in Figure 11 below.

Figure 11. Pivot Control User Interface on a Mobile Device



3.3. Remote Control of Pivot Systems

Manufacturers and consultants offer center-pivot irrigation monitoring systems, which may be included either in the base station or through a small unit mounted on the end tower of the pivot system. Those units, which include a GPS and a cell phone modem, monitor and control several functions of the pivot. Growers purchase the unit and pay an annual fee for a service through which they can check the status of their system(s) via their own home pages associated with the service’s website. They can also control several pivot functions, depending on which unit they have, including remote starting/stopping, accurate end gun control, water pressure, and pivot speed changes. The pivot controller (see examples in Figure 12) can also record the amounts and locations of applied water.

Figure 12. Examples of Pivot Controllers Mounted onto a Pivot



3.4. Sprinklers

Sprinklers are the devices that actually deliver the water to the plant and/or soil. The purpose of a sprinkler is to distribute the water uniformly over an area in droplet form. In order to cover a large area, a sprinkler must propel water a considerable distance. A properly-designed sprinkler “package” will take many factors into account, including water supply, soil, crop, topography, and atmospheric conditions. Center pivot systems use both high-pressure, impact-type sprinklers and low-pressure, spray-type sprinklers. Regardless of the type of sprinkler used, each system’s design should meet the crop water requirements for the crop and area irrigated.

Spray-type sprinklers (referred to as spray nozzles) require considerably less pressure, and thus less energy, than do impact sprinklers. Spray nozzles are often installed at the end of drop tubes/hoses to release water closer to the crop canopy to reduce wind and evaporative losses. However, the smaller wetted diameter of spray nozzles causes very high application rates at the outer end of the pivot. In “heavier” soils (soils with lots of clay),⁴ this often leads to application rates that exceed the soil infiltration rate, causing runoff. The larger nozzles of impact sprinklers produce large wetted diameters, which result in lower application rates.

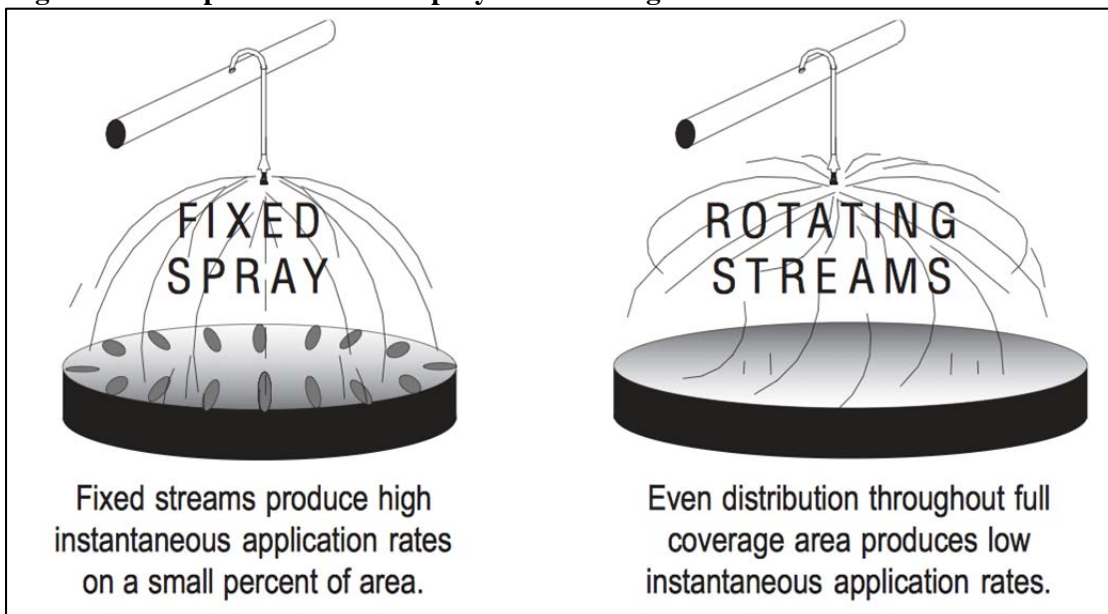
⁴ The *Soil Science and the Basics of Irrigation Management* report provides more information on soil textures.

Sprinkler manufacturers today offer an extensive array of spray-type sprinklers along with a few models of impact-type sprinklers. Spray-type sprinklers are currently available with water impact plates that rotate, spin, wobble, or remain fixed to provide various water application patterns to meet most conditions. Figure 13 shows an example of a rotating sprinkler and Figure 14 illustrates the differences between fixed and rotator sprays. Impact sprinklers come primarily in two formats – low-angle water trajectory and high-angle water trajectory.

Figure 13. Nelson A3000 Rotating Sprinkler for Center Pivots



Figure 14. Comparison of Fixed Spray and Rotating Streams



Note: Source – Nelson Irrigation’s “Handy Pocket Guide” for sprinkler technology

3.4.1. Water Pressure and Nozzle Size

Water pressure and nozzle size control the water droplet size distribution from a sprinkler; in turn, droplet size impacts the application rate pattern. Higher pressure creates smaller droplets while bigger nozzles produce larger droplets. Nozzle size also influences the trajectory of a given sprinkler droplet. When the initial velocities at which droplets exit the nozzle are equal, large droplets will travel farther from the sprinkler than will small droplets. Consequently, high pressure or small nozzle sizes, which tend to produce smaller droplets, increase application rates near the sprinkler; conversely, low pressure or large nozzle sizes, which tend to produce larger droplets, increase application rates farther from the sprinkler.

3.4.2. Low Energy Precision Application (LEPA) and Low Elevation Spray Application (LESA)

Low Energy Precision Application (LEPA) and Low Elevation Spray Application (LESA) irrigation systems deliver irrigation water in a precise application at reduced pressure, which reduces water losses due to wind drift and evaporation near the soil surface. The decreased evaporative losses that LEPA and LESA facilitate are especially important at field locations with high temperatures and low humidity. LEPA applies water twelve to eighteen inches (thirty to forty-five centimeters) above the ground surface for row crops; LESA uses spray nozzles instead of the drag hoses, placing them less than two feet (0.6 meter) off the soil surface. Both applications can drive energy savings due to reduced water pressure and increased application efficiency. Growers have used LEPA irrigation since at least 1981, although it is not common in the Northwest.

LEPA and LESA, as well as Mid Elevation Spray Application (MESA), can each be applied to center-pivot irrigation systems. MESA, as the full name implies, puts nozzles higher above the soil surface than either LEPA or LESA, up to five feet (1.5 meters) above ground. LEPA and LESA equipment is cost-effective, improves uniformity, allows for dry canopy, creates less wheel line tracking, and shows promise on limited soil and terrain. These technologies could prove beneficial for many crop types in the Northwest.

LEPA and LESA require attention to water management since the large volume of water each applies in a short period of time presents possible infiltration and runoff issues. LESA poses less runoff potential than LEPA, so growers can use it more frequently on rolling terrains or where the soil is more compact. Growers can prevent runoff through the addition of more drops to the pivot, changes in tillage practices, and the employment of dams or dikes in furrows. LEPA and LESA also require considerations related to their ability to provide chemigation; however, some sprinklers have multiple configurations, and if mounted on flexible drop tubes, they can be raised during the chemigation process.

3.4.3. Pivot End Guns

End guns are large impact sprinklers that are, as the name applies, located at the far end of the center pivot. They may throw water as far as 130 feet (40 meters) beyond the pivot hardware, although the effective watering radius would be approximately 100 feet (30 meters) of that. The addition of that much distance to the existing radius of the pivot-irrigated circle substantially increases the field area that the pivot can water.

End guns are not without their challenges and problems. Irrigators must carefully set the angle of operation to deliver water uniformly. Many end guns require a booster pump to raise water pressure to the desired nozzle pressure. If the water pressure at the end of the pipe is sufficient, this booster can be omitted; however, operating a pivot at higher pressure increases pumping costs and may necessitate pressure regulation on some or all of the other sprinklers on the pivot. Crop uniformity and yield drop off dramatically with the use of end guns at the far reaches of the pivot. Best practices suggest not using end guns for water and energy conservation.

Figure 15. Center Pivot End Gun



3.4.4. A Note about Irrigation Water Quality

Water quality is an important consideration in irrigation practices because of its effects on crops and soil. Irrigation water that contains sand, algae, and other suspended solids can damage sprinklers, causing them to wear out faster than normal. The *Pivot Evaluation Best Practices* report addresses this issue in greater detail.

3.5. Pumping Systems

Pumping systems supply water to center pivot systems. These pumps may be powered by gas or diesel engines, electric motors, or by using power from a tractor or truck engine via a power takeoff system (comprised of an output shaft mounted onto a tractor or truck and a corresponding input shaft on the pump). Pumps may supply a single center pivot or may supply multiple center pivot systems. The efficiency of the overall pumping plant and pump discharge pressure has a significantly affects the energy consumption of a center pivot irrigation system.

Water for center pivot systems is not always routed through filtration systems. Flow rates to center pivot systems range from as low as 200 gallons per minute (GPM) (757 liters per minute) to well over 1,000 GPM (3,785 liters per minute). Given that water for irrigation is needed most when water supplies are at their lowest levels, water sources should be adequate to supply water during extended dry periods.

Electricity from utility companies or farmers' generators can power pumps, pivots, and controls. Indeed, much of the possible energy savings in center pivot irrigation occurs at the pumping system. Alternatively, diesel engines can also drive well pumps directly and can produce electricity needed for pivot motors and controls. Figure 16 shows an image of electrical pumps used in irrigation.

Figure 16. Pumps Feeding Water to a Center Pivot



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