CENTER PIVOT IRRIGATION SYSTEM
INCREASING EFFICIENCY THROUGH OPTIMUM UNIFORMITY OF APPLICATION

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SUMMARY

Mechanized irrigation systems are crucial in enhancing agricultural operations' efficiency and water management worldwide. This paper highlights the potential for improving water use efficiency in center pivot irrigation systems. Specifically, it focuses on the methods to achieve higher application uniformity with the Reinke Electrogator® 3 (E3) precision series of center pivots. The insights provided are intended to benefit professionals in universities, public institutions, government, regulatory agencies, and the private sector.

INTRODUCTION

Mechanized irrigation systems are essential tools for agricultural producers and operators worldwide. They enable efficient management of water resources and the application of chemicals, fertilizer, and, in some cases, other liquids. These systems are designed to apply the optimal amount of water at critical times during a crop's life cycle, thereby enhancing crop health and maximizing yield potential. A mechanized irrigation system typically comprises a mechanical structure, drivetrain, and control system.

One prevalent type of mechanized irrigation system is the center pivot arrangement. This system features a central pivot point around which the structure rotates, swivels, or revolves. A "span" in this context refers to a structural assembly that includes a section of the irrigation pipeline, struts and braces, a truss rod connection system, and outlets for sprinkler attachment and water conveyance. A span is supported by a "tower" containing the drivetrain and control system to move the span through the field. Center pivot systems can consist of multiple spans of varying sizes, lengths, and end boom configurations.

Each span contains several outlets designed for sprinkler devices, arranged based on a standard distance known as the nominal outlet spacing. For example, in a span measuring 160 feet, the outlets might be nominally spaced 57 inches apart along its length. This spacing aims to maximize the coverage and efficiency of the sprinkler system.

The span travels in a fixed circular path relative to the central pivot point, with its radial position determining the area it can irrigate. The irrigated area is calculated using standard mathematical methods, as discussed in numerous papers and journals on center pivots (Martin et al., 2017). These calculations allow for predictable water demands and the associated discharge rates or capacity determinations for each sprinkler location.

In scenarios where sprinklers are spaced equally, the required discharge for each sprinkler is a function of its distance from the center pivot point L_s. In other scenarios where the outlet spacing varies L_e, an adjusted formula using the average distance between adjacent sprinklers provides the best possible discharge rate for the system's overall effectiveness.

The following formula is used when the sprinklers are spaced at equal distances.

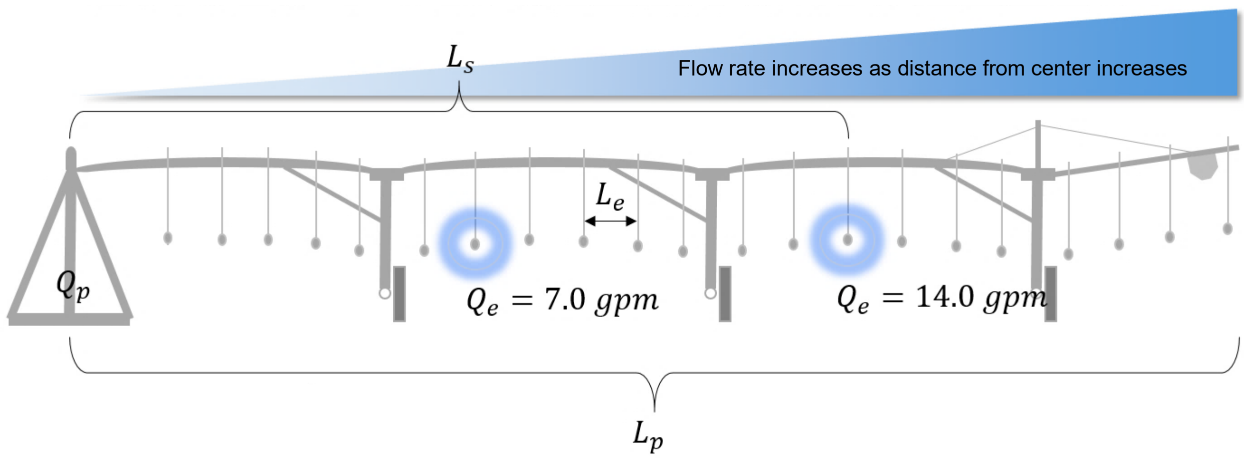


Figure 1: Depicts standard variables for calculating sprinkler rates based on location

$$Q_e = \frac{2 \times L_s \times Q_p \times L_e}{(L_p + R_g)^2}$$

Q_e = sprinkler flowrate (gpm)
L_s = distance to sprinkler (ft.)
Q_p = pivot flowrate (gpm)
L_e = sprinkler spacing (ft.)
L_p = length of pivot (ft.)
R_g = end gun radius (ft.)

Determine the flowrate required by a sprinkler located 750 ft. from the pivot, if the sprinkler spacing is 17 ft. Pivot flowrate is 700 gpm.

$$Q_e = \frac{2 \times 750 \times 700 \times 17}{(1{,}000 + 130)^2}$$

$$Q_e = \frac{17{,}850{,}000}{1{,}276{,}900}$$

$\mathbf{Q_e = 14.0}$ **gpm**

(Nelson Irrigation Corporation)

Figure 2: Standard mathematical calculations for determining the sprinkler flow rate

As previously mentioned, the formula for determining sprinkler discharge is highly effective when the spacing between sprinklers remains constant. However, in center pivot systems where spacing often varies, an adjustment to the formula uses the average distance between adjacent sprinklers on either side of the sprinkler in question. For example, L_{e23}, L_{e24} and L_{e25} distances may vary. To find the discharge rate for L_{e24}, an average distance is arrived at by averaging its distance from L_{e23} and L_{e25}. With this, the formula now accounts for the variability in spacing, resulting in a discharge rate that reflects the average spacing rather than the absolute spacing. This adjustment enhances the water distribution to a point despite irregular spacing. As a result, the variability in outlet spacing impacts the overall system's water uniformity.

HURDLES TO WATER APPLICATION UNIFORMITY

The inherent mechanical design burdens achieving optimal water application uniformity for irrigation systems, specifically when outlet spacing collisions result in either too wide or too narrow a gap. Furthermore, the connecting members of the span located over a tower can also increase or narrow the outlet spacing, which is more common among center pivot irrigation systems. Although discrepancies typically occur over the tower, they can also happen near the middle or end of adjoining pipe segments within the span. Regardless of where the discrepancies occur, the impact on the sprinkler discharge rate is the same.

For instance, take a span 160 feet long with 57 inch outlet spacing. The span length of 160 feet is not equally divisible by 57 inch outlet spacing, resulting in a distance discrepancy between one or many outlets. Depending on the manufacturer, the location of the discrepancy will vary. Most commonly, they occur over the span's tower structure, which will further be argued as the worst place for the discrepancy. This will be illustrated further in Figure 3 below.

Within the chart, series "A" illustrates sprinkler spacing that widens over the tower, resulting in a sprinkler discharge rate above the average rate at that location on the system. This can be observed at every tower location along the length of the system as marked. Series "B" on the chart illustrates sprinkler spacing that narrows by adjacent pipe segments, resulting in a sprinkler discharge below the average rate at that location on the system as marked.

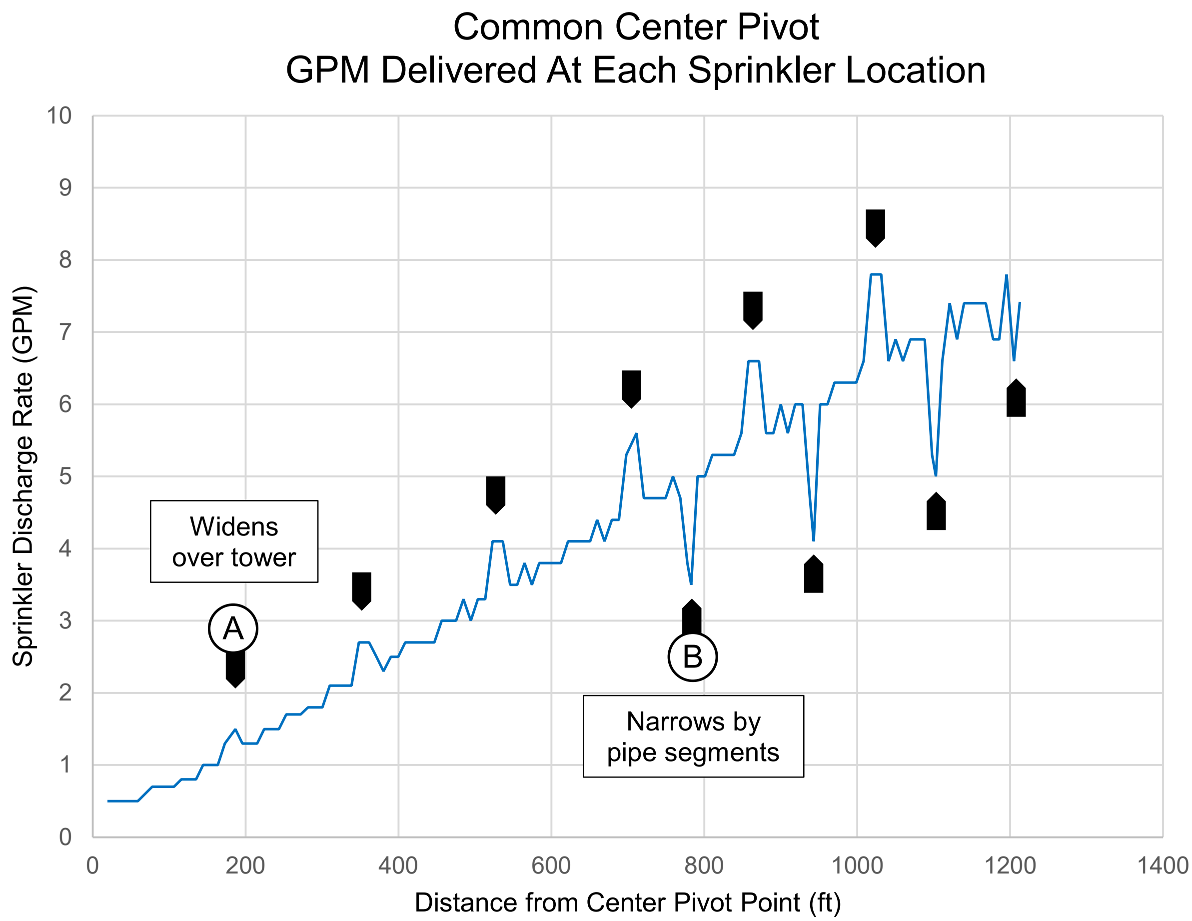


Figure 3: Chart of a common center pivot discharge rate at each sprinkler location

Furthering this example, an outlet spacing may widen crossing the span's tower structure could be illustrated as follows:

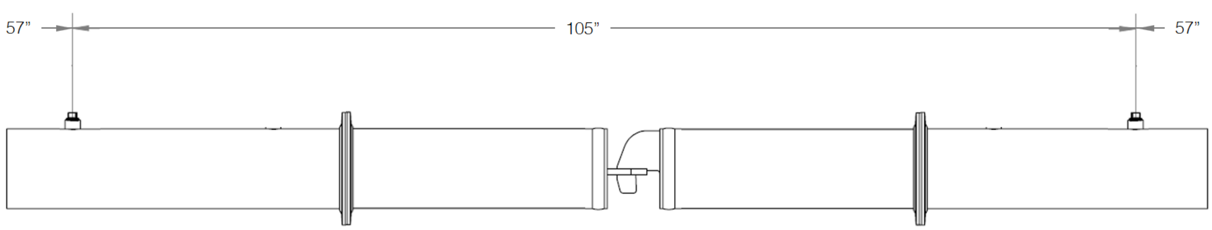


Figure 4: Illustration of the spacing discrepancy which can occur over the center pivot tower

In another example, an outlet spacing may narrow at a pipe segment transition as follows:

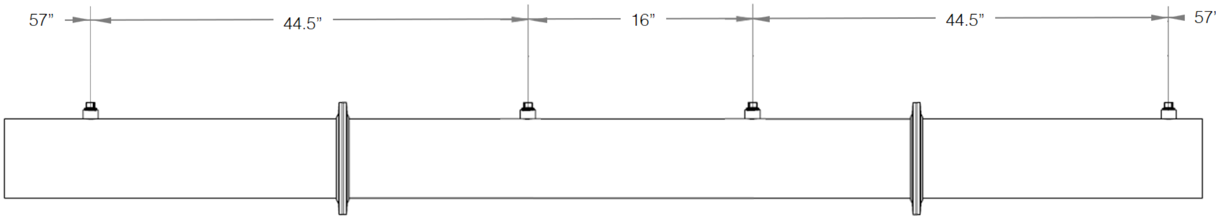


Figure 5: Illustration of the spacing discrepancy which can occur within the center pivot span

Sprinkler design packages for center pivots have attempted to compensate for these mechanical discrepancies by adjusting the water application rate intensity in the areas with irregular spacing. The following chart best illustrates this compensation for both a widened and narrowed example. Refer to Figure 6 below. Wherever there is a change in sprinkler spacing, as shown in column "C", the sprinkler discharge rate changes, as shown in column "G". These adjustments can significantly impact the discharge rate, either exceeding or falling short of the average rate for that location.

		C				G					
173	834.1						PLUG				
174	838.9	9.5	LB15	21.8	9.3	9.1	R3000	White	61	#37	Prpl w/blck
175	843.6						PLUG				
176	848.4	9.5	LB15	21.7	9.4	9.6	R3000	White	62	#38	Black
177	853.1						PLUG				
178	857.9	9.5	LB15	21.7	11.2	11.3	R3000	White	63	#41	DrkTrq w/ms
	864.3	TOWER NO. 5			INLINE PRESSURE: 21.6 PSI						
179	866.6						PLUG				
180	871.4	13.5	LB15	21.6	11.4	11.3	R3000	White	64	#41	DrkTrq w/ms
181	876.1						PLUG				
182	880.9	9.5	LB15	21.5	9.8	9.6	R3000	White	65	#38	Black
183	885.6						PLUG				
184	890.4	9.5	LB15	21.4	9.9	10.2	R3000	White	66	#39	Black w/trq
185	895.1						PLUG				
186	899.9	9.5	LB15	21.4	9.6	9.6	R3000	White	67	#38	Black
187	904.6						PLUG				
188	909.4	9.5	LB15	21.3	10.0	10.2	R3000	White	68	#39	Black w/trq
189	914.1						PLUG				
190	918.9	9.5	LB15	21.2	9.9	9.6	R3000	White	69	#38	Black
191	923.6						PLUG				
192	928.4	9.5	LB15	21.2	10.4	10.2	R3000	White	70	#39	Black w/trq
193	933.1						PLUG				
194	937.9	9.5	LB15	21.1	8.1	8.2	R3000	White	71	#35	Green w/prp
195	941.6						PLUG				
196	942.9	5.0	LB15	21.1	7.2	7.3	R3000	White	72	#33	Ornge w/grn
197	946.6						PLUG				
198	951.4	8.5	LB15	21.0	9.8	9.6	R3000	White	73	#38	Black
199	956.1						PLUG				
200	960.9	9.5	LB15	21.0	10.6	10.7	R3000	White	74	#40	DrkTurquse
201	965.6						PLUG				

Figure 6: Section of a sprinkler chart highlighting areas impacted by the discrepancies in outlet spacing

In summary, areas on the center pivot with wider spacing discrepancies between sprinklers calculate higher discharge rates because the water has to cover a larger area, resulting in a higher instantaneous application rate. This can adversely impact the machine environment, given that it commonly occurs over the system's tower and wheel track areas.

Irrigation applications can push the limits of water absorption beyond the allowable infiltration rates for certain soil types and topography conditions, thereby contributing to the runoff of water, chemicals, and fertilizer, and contributing to potential pollution while also causing erosive activity. The non-uniformity of the application only accentuates this problem.

Conversely, areas with closer spacing and narrow spacing discrepancies between sprinklers calculate lower discharge rates, resulting in lower water application intensity and less-than-optimal water uniformity and application efficiency.

PRECISION OUTLET SPACING METHOD

A new precision series of center pivot spans and end booms, the Electrogator® 3 (E3™), has been created to address these issues. This enhances water application uniformity over previous systems and removes discrepancies in outlet spacing. Designed as a precision series of center pivots, E3 provides several span options that can be used in any combination without resulting in outlet spacing discrepancies from the beginning to the end of the system.

Compared to Figure 3 above, the E3 removes any previously observed wider or narrow outlet spacing discrepancies. This remains true regardless of the system design's span or end boom combination. Refer to Figure 7 below for a chart representing the E3 sprinkler discharge at each location when uniform sprinkler spacing is present. The wide and narrow discrepancies have been eliminated.

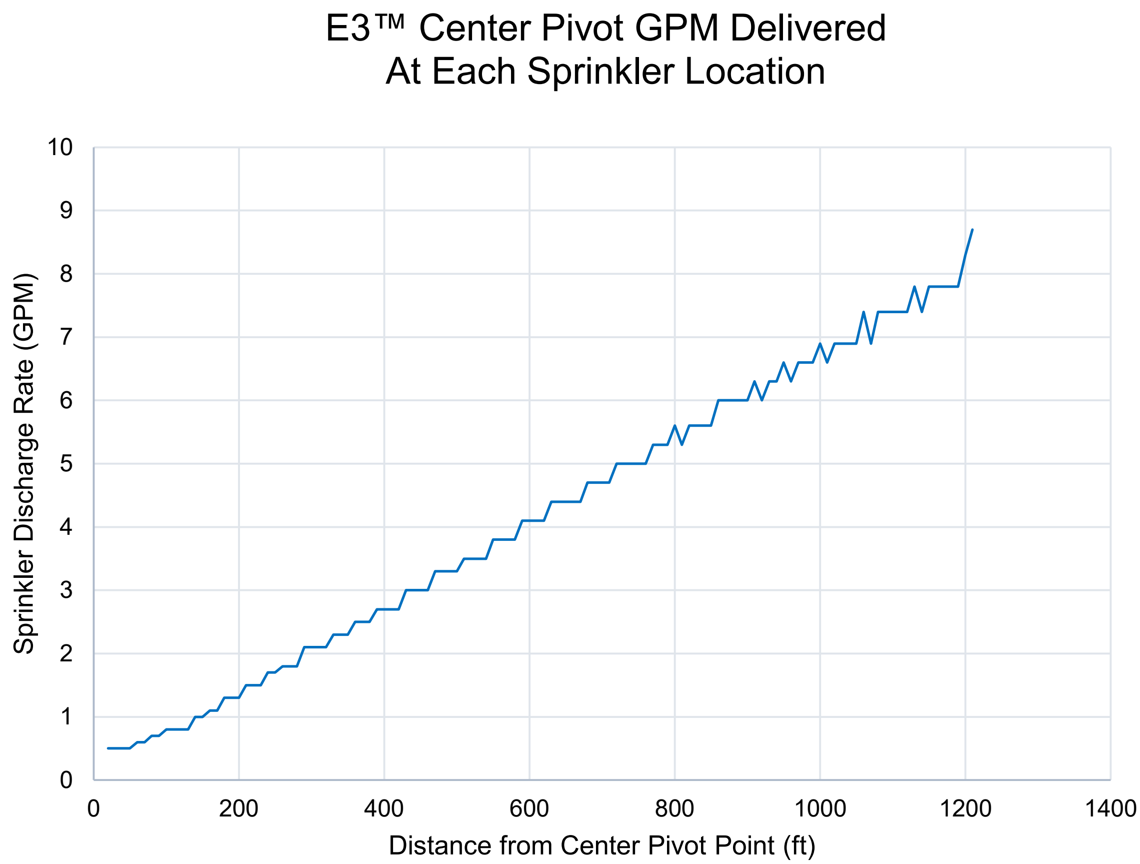


Figure 7: Chart of a E3™ center pivot discharge rate at each sprinkler location using uniform outlet spacing

The uniform outlet spacing provides an accurate platform for sprinklers to be equally spaced. Outlet spacing is available in either 30 inches or 60 inches along the length of the system (only one spacing is used throughout a single system design) in the following span and end boom lengths:

- Precision spans: 80 ft. to 220 ft. in 20 ft. increments plus a 175 ft. span option
- Precision end booms: 10 ft. to 110 ft. in 10 ft. increments

Given the length of spans and end booms are divisible by the outlet spacing offered with E3, there are no discrepancies with wider or narrow gaps between sprinkler locations over the tower or between pipe segments along the length of the system. All possible span and end boom permutations maintain uniform outlet spacing. The following illustration shows the uniform outlet spacing crossing the span's tower structure in the 30-inch and 60-inch outlet spacing options.

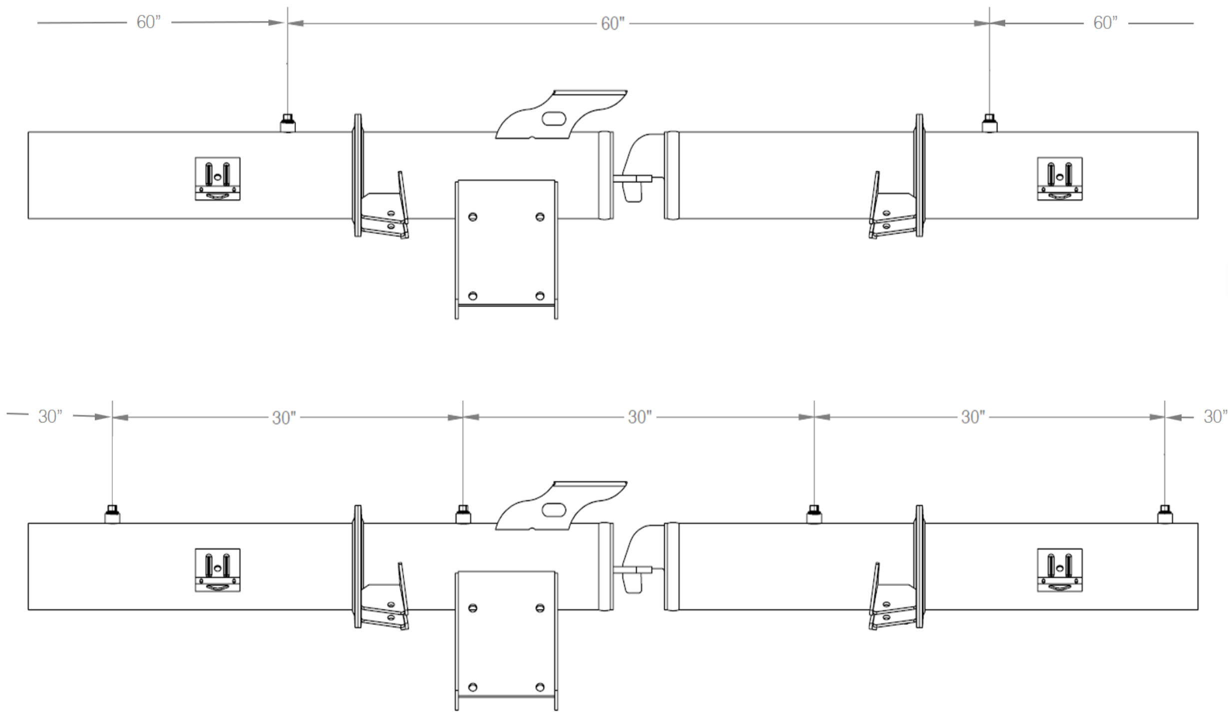


Figure 8: Illustration of the E3 uniform outlet spacing in 30 and 60 inch crossings over the span's tower structure.

COMPARISON STUDIES

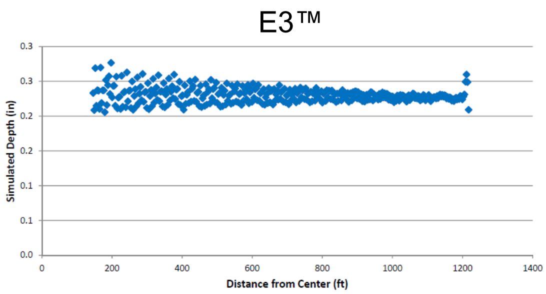
To evaluate the impact of this new precision series of center pivots, comparison testing was conducted using the United States Department of Agriculture (USDA) Center Pivot Evaluation and Design (CPED) simulator. These comparison tests will now be covered.

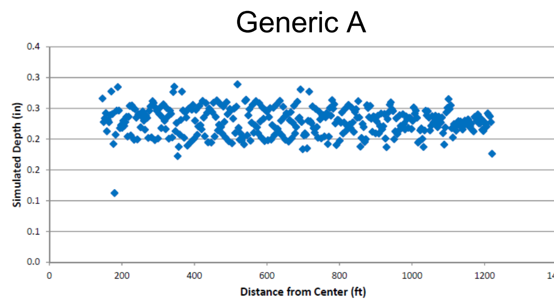
Comparison Test 1: Sprinklers on Drops Uniformity Results

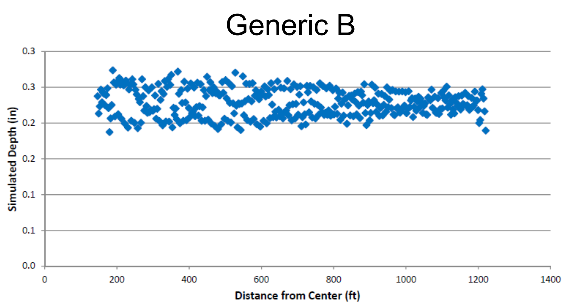
Test system configurations

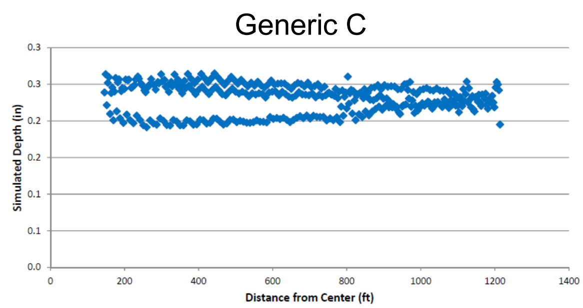
System Name	E3™	Generic A	Generic B	Generic C
Nominal Outlet Spacing	60 in.	57 in.	108 in.	108 in.
System Flow	500 GPM	500 GPM	500 GPM	500 GPM
End Pressure	15 PSI	15 PSI	15 PSI	15 PSI
Nominal Sprinkler Spacing	5 ft.	9.5 ft.	9 ft.	9 ft.
Sprinkler Device	Nelson® D3000	Nelson® D3000	Nelson® D3000	Nelson® D3000
Sprinkler Plate	Nelson® Blue	Nelson® Blue	Nelson® Blue	Nelson® Blue
Pressure Regulator	Nelson® 10 PSI	Nelson® 10 PSI	Nelson® 10 PSI	Nelson® 10 PSI
Drop Type	Hose	Hose	Hose	Hose
Ground Clearance	30 in.	30 in.	30 in.	30 in.
Actual System Length	1,220 ft.	1,225 ft.	1,222 ft.	1,221 ft.
Span Configuration				
Span 1	175 ft.	175 ft.	179 ft.	180 ft.
Span 2	175 ft.	175 ft.	179 ft.	180 ft.
Span 3	175 ft.	175 ft.	179 ft.	180 ft.
Span 4	175 ft.	175 ft.	179 ft.	180 ft.
Span 5	160 ft.	160 ft.	179 ft.	160 ft.
Span 6	160 ft.	160 ft.	157 ft.	160 ft.
Span 7	160 ft.	160 ft.	157 ft.	160 ft.
End Boom	40 ft.	42 ft.	14 ft.	18 ft.

Comparison Test 1: CPED simulation charted results









Comparison Test 1: CPED key indicator uniformity results

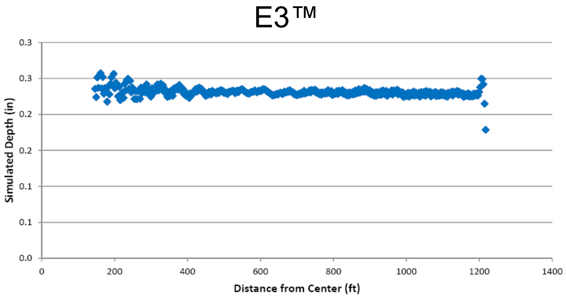
Metric	E3™	Generic A	Generic B	Generic C
Uniformity Coefficient (CU)	97.2%	93.0%	93.9%	93.9%
Low Quarter Uniformity (DUlq)	95.8%	88.6%	90.7%	89.9%

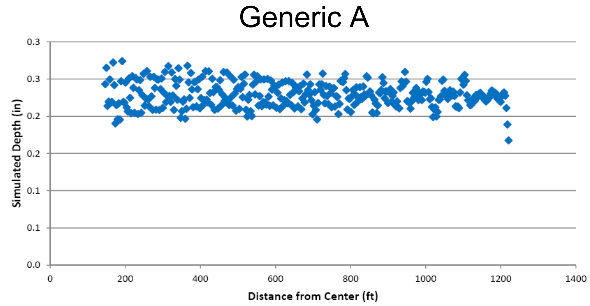
Comparison Test 2: Sprinklers On Top of Pipe Uniformity Results

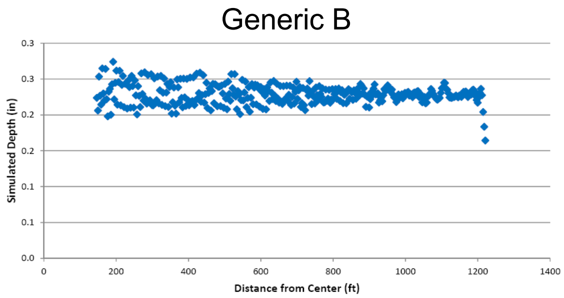
Test system configurations

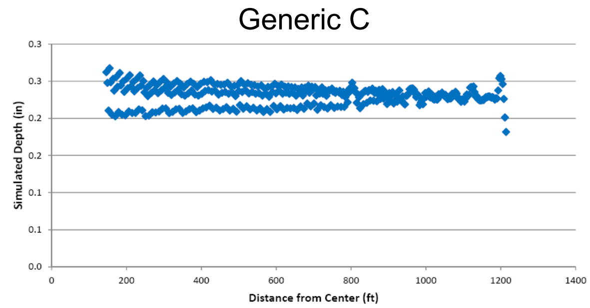
System Name	E3™	Generic A	Generic B	Generic C
Nominal Outlet Spacing	60 in.	57 in.	108 in.	108 in.
System Flow	500 GPM	500 GPM	500 GPM	500 GPM
End Pressure	15 PSI	15 PSI	15 PSI	15 PSI
Nominal Sprinkler Spacing	5 ft.	9.5 ft.	9 ft.	9 ft.
Sprinkler Device	Nelson® D3000	Nelson® D3000	Nelson® D3000	Nelson® D3000
Sprinkler Plate	Nelson® Blue	Nelson® Blue	Nelson® Blue	Nelson® Blue
Pressure Regulator	Nelson® 10 PSI	Nelson® 10 PSI	Nelson® 10 PSI	Nelson® 10 PSI
Actual System Length	1,220 ft.	1,225 ft.	1,222 ft.	1,221 ft.
Span Configuration				
Span 1	175 ft.	175 ft.	179 ft.	180 ft.
Span 2	175 ft.	175 ft.	179 ft.	180 ft.
Span 3	175 ft.	175 ft.	179 ft.	180 ft.
Span 4	175 ft.	175 ft.	179 ft.	180 ft.
Span 5	160 ft.	160 ft.	179 ft.	160 ft.
Span 6	160 ft.	160 ft.	157 ft.	160 ft.
Span 7	160 ft.	160 ft.	157 ft.	160 ft.
End Boom	40 ft.	42 ft.	14 ft.	18 ft.

Comparison Test 2: CPED simulation charted results









Comparison Test 2: CPED key indicator uniformity results

Metric	E3™	Generic A	Generic B	Generic C
Uniformity Coefficient (CU)	98.6%	94.9%	96.3%	96.3%
Low Quarter Uniformity (DUlq)	97.7%	91.9%	93.8%	93.7%

CONCLUSION

Significant improvements in water application uniformity and low quarter uniformity were observed through simulated studies. The observed results indicate that E3 exceeded national uniformity requirements on average by 13%, and 20%, respectively, with a high level of predictability.

The E3 optimizes water usage by enhancing the uniformity of water application. This enhancement potentially results in lower utility costs and a more efficient use of water resources, which is especially crucial in arid regions. Improved precision in irrigation promotes crop health, maximizes yield potential, and reduces the non-uniform application of fertilizers and chemicals, thus cutting down cost inefficiencies.

Additionally, the system's minimal maintenance can lower the overall cost of ownership, further decreasing expenses. Over time, these cost savings, combined with increased productivity and sustained crop quality, lead to a more profitable and sustainable farming operation, making the E3 a valuable investment for the future. This has implications for the USDA funding requirements for sprinkler-based irrigation projects.

Current minimum standards require at least 85% uniformity and 76% lower quarter uniformity results for irrigation funding programs such as the National Resources Conservation Service (NRCS) Environmental Quality Incentives Program (EQIP) and other similar programs (CPSSSC, 2021). The NRCS requirements should be adjusted to align with the latest technology disclosed herein.

This level of precision enables growers to better utilize and manage water resources in center pivot systems, in contrast to the diminished precision experienced previously due to the mechanical constraints of the time.

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