Center Pivot Evaluation and Design (CPED) Lite program

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INTRODUCTION

The USDA, Environmental Quality Incentive Program (EQIP) administered by the Natural Resource Conservation Service (NRCS) provides cost sharing on the installation and upgrading of irrigation systems for improving water quality or the conservation of water under irrigation. Center pivots are frequently the system of choice. There is a need to assure that installed systems will provide the desired improvement in irrigation performance. A similar need exists for any user of center pivot systems to assure that an installed or modified system will perform as designed. The NRCS has written a new Conservation Practice Standard, 442 - Irrigation System, Sprinkler. The irrigation industry, along with University and Agricultural Research Service (ARS) researchers met with the NRCS technical staff to discuss the standard and an appropriate evaluation technique for approving the design. The industry suggested that the ARS Center Pivot Evaluation and Design (CPED) program be used for the design evaluation. Discussion among the Industry representatives and the University and Government technical specialists resulted in the design of a streamlined version of CPED, CPEDlite. The use of this model would result in a mutually accredited tool to evaluate system performance for use by the NRCS field office personnel and contract EQIP Technical Service Providers (TSP's). The objective of this paper is to present the CPEDlite program that is currently being tested and made ready for evaluation of new and upgraded field center pivot systems.

EVALUATION OBJECTIVES

The selection or development of an evaluation standard and procedures should focus on the need for the evaluation. The USDA, Environmental Quality Incentive Program (EQIP) administered by the Natural Resource Conservation Service (NRCS) requires an evaluation procedure that is repeatable and can be easily accomplished by the NRCS field office personnel and TSP's. For USDA's EQIP, proposed and installed systems must provide improvement in irrigation performance and water conservation. Irrigation scheduling is of primary importance for optimizing the use of water. Efficient scheduling requires knowing the amount of water applied per irrigation. Selecting the appropriate depth for scheduling (Duke et.al. 1992) requires knowing or determining the uniformity of water application to minimize over and under application.

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When evaluating existing systems, the major factors that can change a systems performance are a change in nozzle size due to wear, changes in pumping plant efficiency, water supply changes (particularly with ground water decline), system leaks and changes in roughness of the supply and lateral pipe lines. Evaluations should be performed when new systems are installed or when existing systems are modified with new sprinkler packages, to assure they operate as designed.

CURRENT EVALUATION PROCEDURES

The most common procedure for evaluating the uniformity of center pivot irrigation systems is to measure the application depth with catch cans. ASAE S346.1, (1999) and National Engineering Handbook, (1983) are the most commonly used standards in the US, and internationally for evaluating the uniformity of center pivot irrigation systems. The ASAE standard recommends two radial lines of catch cans with the outer end of the rows not more than 50 m apart. The NRSC recommends a single line of catch cans. Both standards recommend calculating the uniformity with the Heermann and Hein (1968) modified equation for the Christiansen (1942) uniformity coefficient. The NRCS includes other measures and performance parameters in their procedure.

The ASAE recommendation to run evaluations at night is often not practical. The requirement for low wind velocity at the time of evaluation is also difficult to satisfy, particularly when attempting to evaluate a number of systems. A wind tunnel study (Livingston et. al. 1985) showed that the divergence from 2.5 to 6.2 m/s wind speeds resulted in decreased catches of 5 - 25%. Losses of this magnitude can easily lead to the conclusion that a center pivot system is very inefficient. Evaporation from the catch cans before they are measured also introduces an error in the technique. Both the ASAE and NRCS standards were developed when impact sprinklers were typically used on moving systems. The current ASAE standard is modified for systems equipped with spray nozzles having significantly smaller pattern radii. The newer spray sprinkler heads often are installed on drop tubes having a wetted diameter of six m or less. The 3 to 4.6 m catch can spacing is not adequate for this small wetting pattern. A typical 380 m system would require more than 400 catch cans for the double row test to satisfy the ASAE standard. This results in evaluation of systems with the newer type sprinkler heads being extremely time consuming and resource intensive. A procedure or process that would provide the needed evaluation information with minimal sampling and use of human resources is an attractive alternative.

EVALUATION REQUIREMENTS

The current standards provide a single estimate of the CU at the time of the test. They require documenting the test and climatic conditions that should be considered when comparing tests between systems. The test however does not provide an insight to the performance of the system as it moves around the circle that is irrigated. The effect of topography and water supply characteristics should also be evaluated.

Field catch can data are an excellent way of observing the operating status under field conditions. One major problem is the inability to repeat the test and obtain identical evaluations in terms of depths caught and the resulting calculated uniformity.

ALTERNATIVE EVALUATION PROCEDURE

Computer simulation of the center pivot sprinkler performance was first presented by Heermann and Hein (1968). A user friendly simulation program Center Pivot Evaluation and Design (CPED), an enhancement of this work, is currently being used by the NRCS to evaluate center pivot systems. The required inputs and options for the model were presented by Heermann (1990). Simulation programs for evaluating different characteristics of center pivot systems have been written by Edling (1979), James (1984), and Bremond and Molle (1995). The distinct advantage of computer simulation over field tests is that a large number of design options and operating conditions can be compared with limited time and resources. The evaluation is also repeatable.

Suggested Protocol for Alternative Procedure

Manufacturers and distributors of center pivot and/or sprinkler heads use computer models to design the vast majority of new or renozzled center pivot systems. Most system designs will provide a uniform irrigation if nozzles and sprinklers are installed according to the design, and operated within their intended flow and pressure. The manufacturer's computer design inventory provides the majority of the inputs needed to run a simulation to obtain the potential uniformity of the system. The major manufacturers and distributors of center pivot sprinkler packages have written programs that will output their design packages to the CPED data file format and significantly reduce potential errors and the time of entering the center pivot design for evaluation.

The model documents the uniformity of the system as designed, however a key element to verify performance would be to go to the field and perform a physical and visual inventory of the system. The size and length of all pipes, sprinkler model, nozzle sizes, pressure regulators, and location of each outlet should be compared with the design chart and inventory. The elevation of the pivot and each tower is needed to accurately solve for the pressure distribution on the system. It is desirable to use pump and drawdown curves but the model can be run with constant pressure or discharge. An approximation of the pipe roughness is needed to run the simulation. With the system operating, pressure and discharge measurements should be taken along the lateral line and compared with the calculated pressures and discharges. A word of caution when running CPEDlite for pressure regulated systems. The current version of CPEDlite does not change the pressure as a function of line pressure with pressure regulators. For these systems it is recommended that the pivot pressure be specified. Pressure-regulated systems may lead to difficulties in matching a regression fit of pump curve data.

Model output includes the hydraulic operating pressures on the system, the sprinkler discharge, the application depth at requested positions and the coefficient of uniformity

(Christiansen). Differences between measured and computed pressures and discharges suggest that the system may not be performing as desired.

Potential causes of simulation errors are wear, age, or from initial input due to measurement or entry errors of the components. Factors that can change with age include the pipe roughness factor, pump characteristic curve, and nozzle size. Pressure regulators may have a hysteresis effect and could lead to differences between simulated and measured pressure. Age also can change the performance of flow control devices. Measurement is always a potential source of error. This could include measured pressures, discharges, distances and elevation, recognizing accuracy is ± 5% with most standard measuring devices for flow and pressure.

SIMULATION EVALUATION OF CENTER PIVOT SYSTEMS

The simulation model in this paper is based on the first model presented by Heermann and Hein (1968) which was verified with field data. Their simulation model required input of the sprinkler location, discharge, pattern radius and an assumed stationary pattern shape of either triangular or elliptical. The application depth versus distance along a radial line from the pivot was determined and application rates at a specified distance from the pivot were determined. The hours per revolution were input and each tower was assumed to move at a constant speed for the complete circle. Kincaid, Heermann and Kruse (1969) used the model to calculate potential runoff for different system capacities and infiltration rates. Kincaid and Heermann (1970) added the calculation of the flow resistance and verified with measured pressure distribution along the center pivot lateral. Chu and Moe (1972) studied the hydraulics of a center pivot system and developed a quick approximation for determining the pressure loss from the pivot to the outer end of the lateral as a constant (0.543) times the loss that would occur if the entire discharge flowed the total length of the lateral.

The model was adapted by Beccard and Heermann (1981) to include the effect of topographic differences in the resulting application depths along radii of the center pivot on non level fields. The model included the pump and well characteristics and calculated the hydraulic equilibrium point as the system moved to different positions on a rough terrain. The model was exercised to determine the uniformity changes when converting from high pressure to low pressure on rough terrain. Edling (1979), James (1982), James (1984), and James and Blair (1984) also used simulation models to study the performance of center pivot systems on variable topography and with different pressures.

The current simulation model has been expanded to include donut shaped stationary patterns which represent many of the low pressure spray heads.

EXAMPLE OF SIMULATION EVALUATION

The uniformity of application depths can be calculated by inventorying the sprinkler head models, nozzles sizes and distance from the pivot. The pump curve and drawdown, or pivot pressure, or pivot flow is also needed. Figure 1 illustrates a model simulation with nozzles installed as designed. The dashed line represents the distribution if the sprinkler heads were reversed between 2 towers at the time of installation. Note that the change reduced the CU by 3 percent.

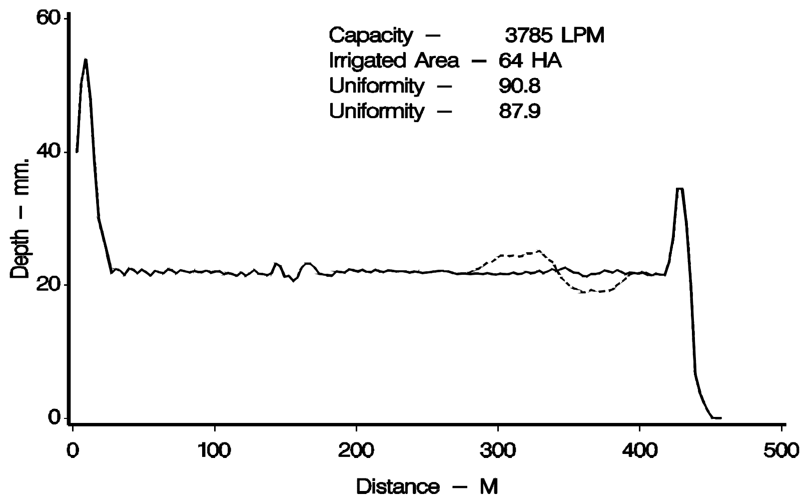

Figure 1 Typical center pivot as designed (CU = 90.8) and with 10 sprinkler heads incorrectly installed shown as a dashed line (CU = 87.9)

CPEDlite versus the full CPED model differs primarily in the selection of variable system parameters. The System file that contains system basics is identical for each simulation model. The System file consists of:

- Pump curve information, constant discharge or constant head with discharge estimate
- Total dynamic lift if using a pump curve.
- Length, inside diameter, resistance coefficient from pump to pivot hub
- Pipe diameter, distances and resistance coefficient along the lateral pipe.
- Pivot pad elevation, nozzle height and reference for specified pressures
- Number of towers, tower location from pivot and elevation relative to the pad
- Booster pump pressure increase, number of sprinklers beyond booster including big gun

- Distance, sprinkler brand, model # , size (64^{th} in.)of each sprinkler on the system, sprinkler application shape (donut, triangular, or elliptical
- Pressure control (specified pressure) on pressure controlled sprinklers.
- Start and stop angle for each part circle sprinkler.

Full description and detail of these elements are presented in the CPED users manual

Once the System File is complete, the simulation can be run after addition of a few more specific parameters. As previously stated CPEDlite limits the entries that can be changed.

1. Hours/Rev - The time needed to complete one revolution of the Pivot. This directly determines how much water is applied. (Both)

2. Sprinkler Number - All, Can not be changed. (CPEDlite)

3. Starting Distance for depth simulation (ft.). Is set to 12% of the total length, Cannot be changed. (CPEDlite)

4. Stopping Distance for depth simulation (ft.).Set to the end of the hardware but exclude the big gun, Cannot be changed. (CPEDlite)

5. Distance Increment - The distance between the simulated catch cans (ft.).Set to 1 foot, Cannot be changed. (CPEDlite)

6. The Minimum Depth for Uniformity (in.) Set to 0, Cannot be changed. (CPEDlite)

Once these parameters are entered, start the simulation.

RESULTS

As the simulation runs, depths vs distance are plotted on the monitor. On completion the uniformity range (in 5% increments), system Q, starting and ending evaluation distances, mean depth and irrigated area are displayed. An example monitor display is shown in Figure 4. The uniformity is in the > 95% uniformity range. The resulting depths have a large difference between the consecutive simulated points. The system has a 10 foot spacing of spray sprinklers. The large variation in depth is typical of what can be expected with the spray sprinklers with pattern radii varying from 10 to 16 ft. The variation decreases as the distance from the pivot increases with the larger pattern radii.

The CPEDlite is constrained on run time options to assure that repeatable results will be obtained for the same system. Industry, Government and University personnel determined that it would be appropriate for CPEDlite to report CU in 5 percent increments to assure repeatable results. The actual CU for the example system is 95.2%. If the spacing interval was changed from one to ten ft. the CU would increase to 97.7%. Spacing intervals from one to ten ft. by one foot increment were simulated with starting distances between 160 and 169 feet. The lowest CU (93.3%) resulted with a starting distance of 164 feet and a spacing interval of five feet (Figure 5). A CU of 98.1% was simulated with a starting distance of 161 feet and ten foot spacing (Figure 6). Thus, a 4.8 % point change resulted with changes in the starting distance and spacing interval. It should be noted that the data points shown in Figure 5 and 6 are subsets of the entire data set in Figure 4 where application depths were simulated at one foot intervals. Figure 5 represents the envelope of the points in Figure 4 and thus reduces the CU. Whereas, Figure 6 is a set from the middle of the data in Figure 4 and thus a higher CU. The five percent increments in reported CU is nearly equivalent to the range in CU for a single system simulated.

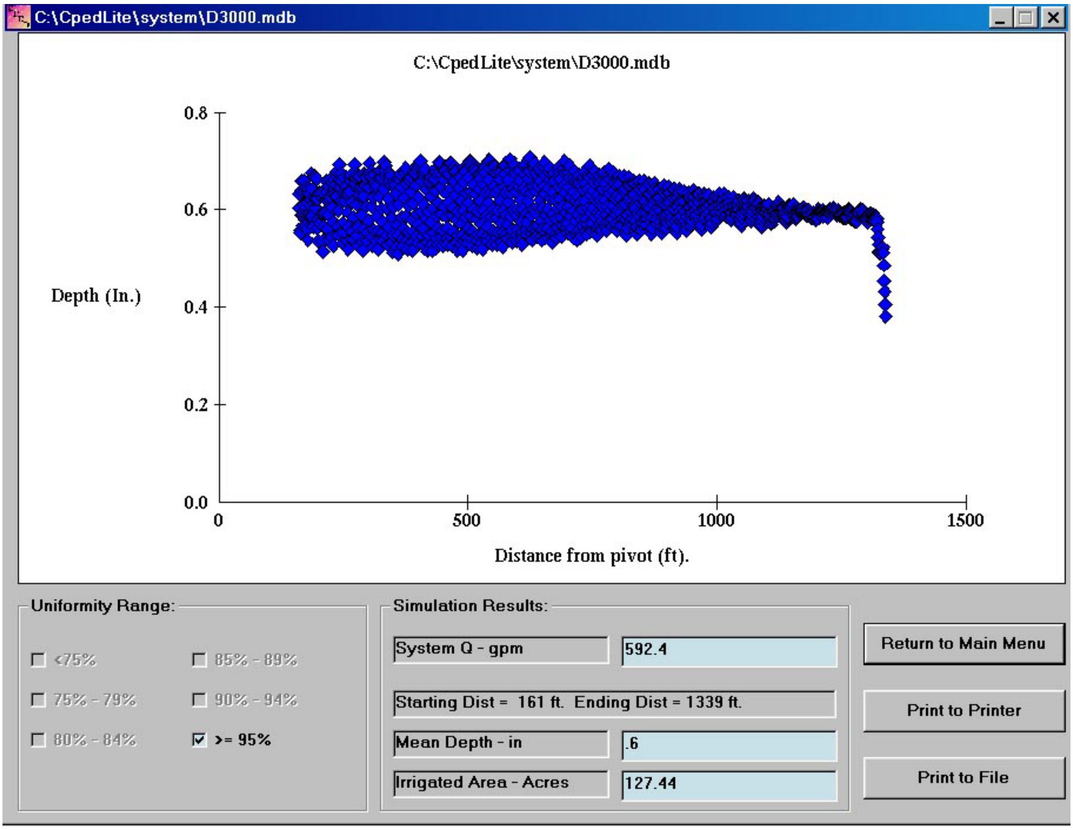

Figure 4. Example Monitor output from CPEDlite for D3000 system.

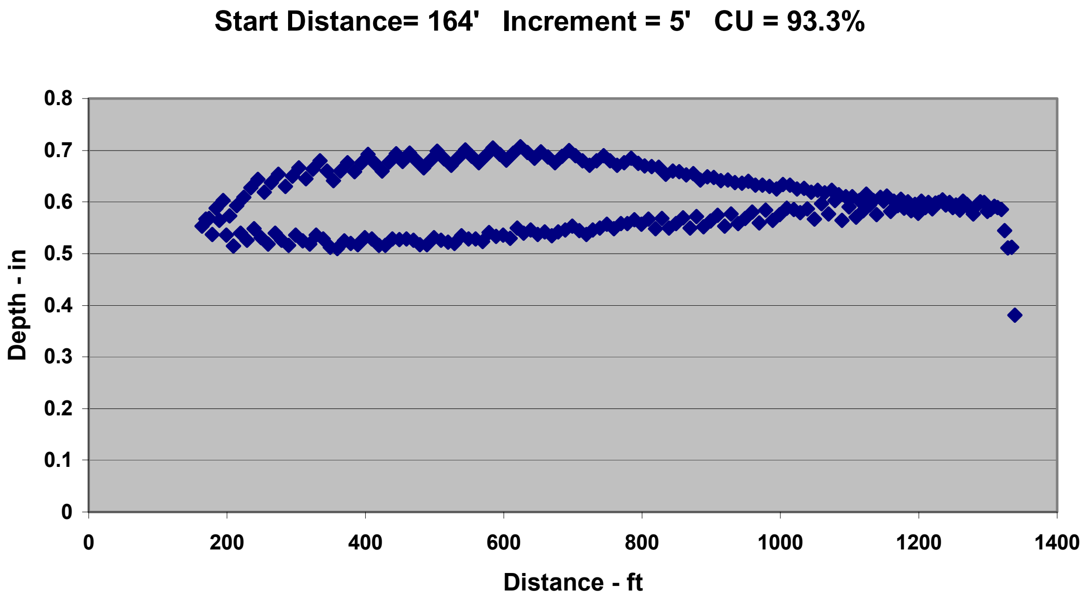

Figure 5. Simulation of D3000 with depth measurements at 5 foot intervals.

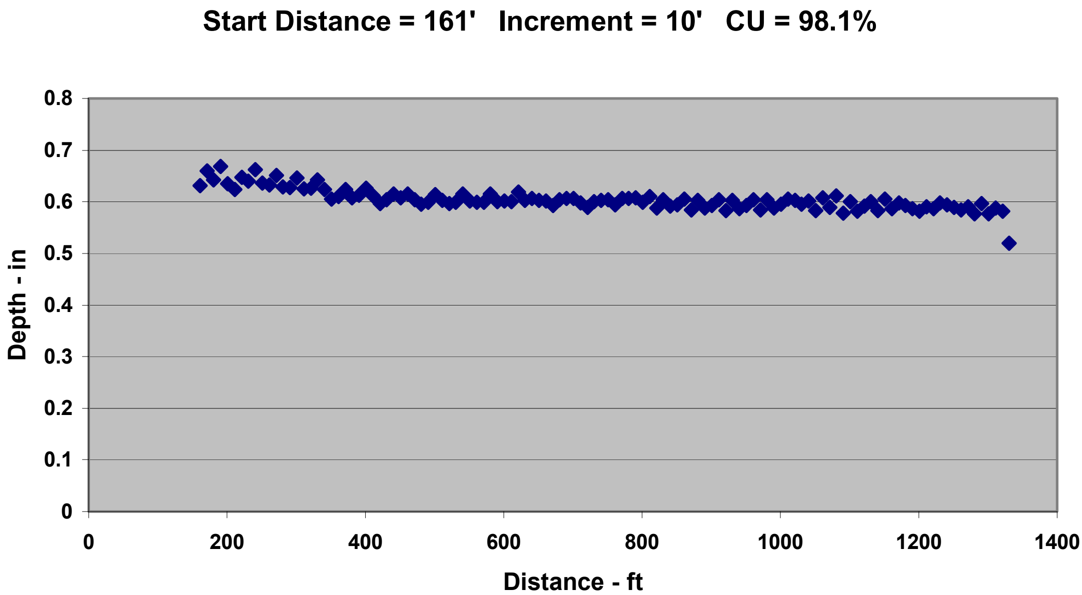

Figure 6. Simulation of D3000 with depth measurements at 10 foot intervals.

The simple example and comparisons demonstrates the validity of reporting the uniformity in 5% uniformity bands. It also points out the potential problem of measuring with catch cans when a four to five percent difference in CU is possible with different starting distances and simulated catch can spacings.

Other information that can be printed or saved in a file for each sprinkler is:

1. The line pressure - psi
2. The nozzle pressure - psi
3. The discharge - gpm
4. The pattern radius - ft

DISCUSSION OF EVALUATION PROCEDURES

Evaluations of center pivot simulations were compared against catch can spacing (Heermann and Spofford, 1998). Catch can data had significantly more variation than the simulated but approximately the same average depths. The sprinklers were spray nozzles with deep grooved pads producing distinct streams and large drop sizes. The catch can test was repeated on the same system by replacing the pads with smooth pads. The catch can CU increased by 10% when changing from the deep grooved pads to the smooth pads. The distinct streams are not measured correctly with small (10-20 cm) catch cans.

The particular objective for evaluating a center pivot system should be considered when selecting the evaluation procedure. If the objective is to consider modifications to improve the uniformity, there is a distinct advantage in using the simulation model procedure. Once the distribution uniformities are calculated with the existing system, it is quite simple to propose changes and simulate the improvements.

Disadvantages of catch cans

- Wind
- Night Testing
- Evaporation
- Difficulty in catching streams from grooved pads
- Small pattern radii – large number of cans
- Extreme care to set cans level and at proper distance
- Labor intensive

Advantages of catch cans

- Provides real field data from actual conditions
- Simple to install
- More readily accepted by user or system owner
- Does not need a computer

Disadvantages of Simulation

- Difficult to obtain pump curves
- Difficult to obtain elevation data.
- Requires labor to verify field installation
- Need drawdown water level
- Must have understanding of running models
- May need additional measurements if simulation disagrees with field data
- Need to know pattern shapes for application devices

Advantages of Simulation

- Less labor intensive to obtain field pressure and discharge data
- Wind is not a problem
- Provides a complete hydraulic analysis for comparison with field data
- Measurement errors of catch cans eliminated
- Modification of design can easily be evaluated
- Used to analyze for potential problems
- Aids in identifying pump problems
- Allows analysis of changing drawdown
- Successive runs with water table changes
- Can be used to recommend design changes
- Analyze effects of elevation changes for a particular field
- Analyze effect of big-gun operation

CONCLUSION

Simulation models can effectively be used in the evaluation of center pivot systems. The advantage of a simulation procedure is the speed of evaluation of an existing system and system modifications. The simulation model can also be used to determine the distribution over the entire field as the topography varies and big gun sprinklers are turned on and off. It also can be an effective tool for diagnosing distribution problems of a center pivot system. Procedures need to be developed to effectively use the simulation for detecting and interpreting the cause of differences between the field measured and simulated system pressure and discharge.

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