RECEIVED

MAR 10 1997

OSTI

DOE/ID/13314--71

**INDUSTRIAL ENERGY CONSERVATION-
CENTER-PIVOT SITE SPECIFIC IRRIGATION**

Final Report for the Period January 95 - December 96

By

Ian R. McCann, Bradley A. King & Randall Brady

December 27, 1996

**Work Performed Under Contract No. DE-FC07-94ID13314
(LD-96-468)**

**Prepared for Department of Energy
Idaho Operations Office
Idaho Falls, Idaho 83401**

**Precision Irrigation Control System, Inc.
Soda Springs, Id. 83276**

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

at

*Bill
Givins*

TABLE OF CONTENTS

ABSTRACT	III
INTRODUCTION	1
METHODS	2
Figure 1. Field location near Aberdeen, Id.	3
Figure 2. Field map showing pump, pivot tracks and rock outcroppings.	3
Figure 3. Elevation map (ft.) of research site.	4
Figure 4. Application map for non-irrigated zones over rock outcroppings	4
RESULTS AND DISCUSSION	5
OTHER	7
Table 1. Sprinkler and Center-Pivot	8
Figure 5a. Pressure at the pivot for scenario 1	9
Figure 5b. Measured and theoretical flow for scenario 1	9
Figure 6a. Pressure at the pivot for scenario 2	10
Figure 6b. Measured and theoretical flow for scenario 2	10
Figure 7a. Pressure at the pivot for scenario 3	11
Figure 7b. Measured and theoretical flow for scenario 3	11
Figure 8a. Pressure at the pivot for scenario 4	12
Figure 8b. Measured and theoretical flow for scenario 4	12
Figure 9a. Comparison of measured and theoretical flow for scenario 1 - complete cycle	13
Figure 9b. Comparison of measured and theoretical flow for scenario 3- complete cycle	13
Figure 10a. Target application along center-pivot at 9 degrees	14
Figure 10b. Target application along center-pivot at 18 degrees	14

Figure 11a. Measured flow rate vs. rotation angle for all four scenarios	15
Figure 11b. Pressure at the pivot point vs. rotation angle for all four scenarios	15
Figure 12a. Power consumption vs. rotation angle for all four scenarios	16
Figure 12b. Cumulative energy consumption vs. rotation angle for all four scenarios	16

REFERENCES	17
-------------------	-----------

ABSTRACT

This project was to aid in the development and commercial transfer of site specific technology to industry and farmers. This report contains the results of data collected during the fall of 1996 on a site near Aberdeen, Id. This site was equipped to apply water at variable rates predetermined by a digital control map that resided in a computer controller. The flow rates were then adjusted to maintain desired pressure with an Adjustable Speed Drive. Energy consumption was monitored during implementation of site specific irrigation practices and normal irrigation practices. This final report covers the impact that site specific irrigation has on energy use on a irrigated small grain crop near Aberdeen, Idaho. 20 figs., 1 tabs.

INTRODUCTION

Irrigated agriculture is a major industry in the U.S. which, like many others, requires substantial energy, water and chemical inputs. Unlike other major industries however, production is not concentrated in a relatively small number of facilities but rather is spread across vast areas of the country with a large number of individual producers. The two major forms of irrigation are surface (gravity) systems, and sprinkler (pressurized) systems. In recent years, there has been a slight decline in total irrigated acreage and a significant conversion from surface to sprinkler systems.

There are a number of different types of sprinkler systems, characterized primarily by whether the sprinklers remain stationary (stationary systems) or whether they move (continuous-move systems) during the irrigation process. The center-pivot, in which the sprinklers are mounted on a pipe which rotates about a fixed point, is the most important example of a continuous-move system. The acreage under center-pivot irrigation has been increasing substantially in recent times. Center-pivot acreage has increased approximately 40%, or 4 million acres, during the past decade, and this trend is showing no signs of decreasing.

The ten leading states in terms of center-pivot acreage are shown in table 1, along with the percentage of systems powered by the three primary energy sources, namely electricity, diesel and natural gas or liquid propane. Electricity is by far the predominant energy source in the northwest. The leading states of Nebraska and Texas are more evenly split between these three energy sources. Together, these ten states account for approximately 77% of all center-pivot irrigated acreage.

The electro-mechanical systems used for alignment and speed control have changed little since the introduction of center-pivots over thirty years ago. These systems are reliable and cost effective, and so there is little impetus for major change. The major management control is the speed at which the system rotates around the circle, which determines the depth of water applied to the ground because the water inflow is constant (typically 800-1200 gpm). Irrigation depth is minimum when the rotation speed is maximum, and is proportionately increased as the system is slowed down. Programmable micro-processor based controls have recently become available to replace manual control settings, enabling the rotation speed and direction to vary automatically for different sectors of the circle. The primary energy input is that required by the pumping plant to lift and pressurize the water in the system. Lift, operating pressure and efficiency vary tremendously between different systems and locations.

Current center-pivot technology has gone about as far as it can go. Operating pressures have been reduced, and application uniformity has been increased, both now approaching their practical limits. Programmable microprocessor control of speed, direction and chemical injection is the best commercially technology, and enables variable application to entire sectors of the circle. Regardless of location, almost any center-pivot irrigated field will have spatially varying production potential. The variability may be due to fixed factors such as soil type, soil depth and topography, or variable factors such as soil fertility, irrigation management or pest infestation. This variability is unlikely to conform in shape to complete sectors of a circle. Systems are not currently available which can account for variability of any shape, and so producers have to make uniform water and chemical applications to non-

uniform fields. Uniform application to an entire field or a sector is a one-dimensional approach to a two-dimensional problem. The next major improvement in center-pivot irrigation will come from systems which can automatically vary application to areas of any shape, and this requires a control system in which irrigation amount can be varied along the length of the mainline. Site Specific Crop Management (SSCM) is a term commonly applied to such systems. Most of the work in developing SSCM has been in variable rate fertilizer application from ground based machinery such as tractors, spreaders and sprayers. We have focused on developing systems to enable SSCM using center-pivots rather than ground based machinery because of the inherent advantages of center-pivots in terms of precise application of chemicals as well as water. A benefit of enabling SSCM is more efficient use of resources, including energy.

The rate of energy used for pumping is a function of flow rate and pressure. Reducing flow rate requires control of the sprinklers, and reducing pressure requires control of the pump. In conventional systems, the flow rate is constant and the pump is operated at a fixed speed to provide a set pressure and flow rate, which should provide sufficient pressure and flow to the center-pivot. However, in order to provide sufficient pressure at all times, it is usually necessary to provide excess pressure. A simple example is a field with varying topography. If the outer end of the center-pivot is at a higher elevation than the pivot point, then pressure at the end will be reduced by the an amount equal to the elevation difference head. To overcome this additional loss of pressure, the pressure at the pivot point will need to be sufficiently high to maintain end pressure at an acceptable level. This pressure will need to be provided for the entire rotation of the system because there is no control of the pump. Thus, the pressure may be higher than necessary at other locations in the field as the system rotates. Another simple example is the use of an end gun on a center-pivot. These are used to help irrigate the corners of a square field, and is turned on as appropriate during the rotation cycle. When they are on, flow is increased and therefore pressure may be reduced. This will need to be taken into consideration when the pump is sized, so that sufficient pressure for the entire system is available when the end gun is on. However, this necessitates higher than necessary pressure when the end gun is off.

A control system for center-pivots which enables flow to vary as required has been developed by PICS, with assistance from this project. To achieve energy savings also requires an Adjustable Speed Drive (ASD) to vary the speed of the pump to match changing pressure and flow needs during a rotation. This project has enabled the PICS control system to be integrated with an ASD to explore the energy aspects of variable rate irrigation. Because the system was controlled by microprocessors, appropriate software also was required, along with means for mapping variability. This report will primarily concentrate on the energy aspects of the development, particularly field results obtained from installing a control system and ASD on a commercial center-pivot.

METHODS

We identified and evaluated several potential control systems which might meet the required performance criteria for this application and, after testing and evaluation, eventually selected the most promising system. This control system (Echelon Corp.) is a commercially available

and uses a power line interface to send and receive signals over the existing center-pivot power cable. This control system and its application to this project is described in Wall et al. (1996, 3rd International Conference on Site Specific Crop Management, Bloomington, Minnesota.). It was extensively evaluated and tested in the laboratory prior to its implementation in the field.

Energy savings resulting from the use of the PICS system depend entirely on the individual field and the center-pivot system. A typical situation might be a field with varying slopes, soil texture and crop production potential. For example, fields with significant areas of rock outcrops would benefit from withholding irrigation entirely to these non-productive areas. We identified such a field near Aberdeen, in SE Idaho, on which to test the PICS system. Figure 1 shows the general location of the system, while figure 2 shows a more detailed map of the field and the location of the major components, including pump, ASD, pivot point and wheel tracks. The field was surveyed, using a total station system, to develop a topographic map prior to installing the PICS equipment. The locations of the rock outcrops were surveyed using a differential Global Positioning System. Figure 3 shows the topography of the field. It can be seen that there are substantial differences in elevation between the pump, the pivot and various areas within the field. These elevation differences will produce pressure variation within the system as it rotates around the field. Figure 4 shows the control map used to avoid irrigation on the rock outcrops.

We compared four different strategies to manage the operation of the center-pivot and pump system, with the aim of allowing a comparison to be made between energy usage at different levels of control. These strategies were:

1. No control over the pump. This represents the vast majority of systems. The pump was operated at a fixed speed regardless

Figure 1. Field location near Aberdeen, Id.

Figure 2. Field map showing pump, pivot tracks and rock outcroppings.

of pressure variation within the center-pivot and the flow requirements. This is the baseline scenario against which the other strategies can be compared. Because of energy losses by the ASD, there is a slight increase in energy use compared with the standard situation where no ASD is used.

2. Use the ASD to control the pump to just maintain minimum pressure at critical point(s) along the lateral. This allows for pressure changes due to elevation to be accounted for and may result in a reduction in overall energy use by reducing pressure requirements at the pump.
3. Use the irrigation control system to reduce irrigation (withhold irrigation to the rock outcrops in this case), and the ASD to maintain a minimum pressure (35 psi) at critical points.
4. Use the irrigation control system to withhold irrigation to the rock outcrops, and the ASD to control the pump to maintain a constant pressure (58 psi) at the pump.

In subsequent figures, these strategies will be referred to as scenarios 1 through 4 respectively.

Electronic pressure sensors were used at the following three locations along the center-pivot to periodically measure water pressure.

- At the pivot point (referred to in subsequent figures as "Pivot")
- At the sixth tower, which is approximately in the middle of the system (referred to in subsequent figures as "Middle")
- At the end of the system (referred to in subsequent figures as "End")

The measurements of pressure were made each time the angle of the system incremented by one degree during its rotation around the field. There were thus 360 measurements made during a complete individual irrigation (one complete rotation). The pressure data were transmitted over the power line back to the control computer at the pump where they were used to implement one of the four strategies above. Similarly, an electronic flow meter (IDTech EFC 1000) was used to measure total pump flow at the same time as the pressure measurements. The energy use of the system was obtained from the electrical utility supplying power to the system (Idaho Power Co.), integrated over

Figure 3. Elevation map (ft.) of research site.

Figure 4. Application map for non-irrigated zones over rock outcroppings.

consecutive 15 minute periods throughout the irrigations comprising the different scenarios. The water application of the system was measured using catch cans located under the outermost span, where no reduction in application rate occurred.

RESULTS AND DISCUSSION

After identifying the control system hardware and developing the software, the proof of the system lies in its field performance. The results presented here are from the field installation for several irrigations corresponding to the above four scenarios.

Figures 5a and 5b show results for a single irrigation under scenario 1, as a function of rotation angle of the center-pivot. Figure 5a shows pressure at the three measured points along the system, while figure 5b shows the theoretical and measured flow rates. The theoretical flow rate is computed from the sum of the nominal discharge of all the sprinklers.

Variation in flow rate in conventional center-pivot systems is largely due to the operation of the end gun, which may be separately turned off. Figures 6a and 6b, 7a and 7b, and 8a and 8b show the corresponding results for scenarios 2, 3, and 4 respectively. In scenarios 1 and 2, there is no on/off control of individual sprinklers, and so the variation in flow is largely due to the operation of the end gun. In scenarios 3 and 4, individual sprinklers may be turned on or off as required by the application map, and so total flow may vary considerably. Figures 9a and 9b show measured flow rate compared to theoretical flow rate, for scenarios 1 and 3 respectively. Scenario 1, which approximates conventional systems, shows the variability of measured flow about the two major theoretical flow rates, corresponding to flow with the end gun on and off. Other comparisons between measured and theoretical flow rates should be evaluated against this level of variability. Scenario 3 represents the best attainable management using a PICS system. The average deviation of the measured flow rate from the theoretical flow rate in scenario 1 is 7% of the theoretical rate, while in scenario 3 the corresponding value is 8%. It can therefore be seen that there is approximately the same degree of variability of flow rate in the two scenarios, implying that the PICS system was able to control a varying flow requirement with about the same variation from the intended target as flow rate in a conventional system with a uniform target.

Possible energy savings can best be illustrated by examining particular areas in the field where there are varying flow and/or pressure requirements in detail, because the rate of energy use at any time is a function of flow rate and pressure. One such area is the sector of the circle from 0 degrees to 30 degrees, which contains a rock outcrop requiring appropriate sprinklers to be shut off while they are over it. At the beginning and end of the sector (0 degrees and 30 degrees) there is no reduction in flow rate required. Figures 10a and 10b show the target relative flow rate for this area at positions corresponding to 9 and 18 degrees respectively, for each span, compared with a constant target (i.e. flow control vs. no flow control). Scenarios 1 and 2 have no flow control, while scenarios 3 and 4 implement flow control. Because of the relatively small area (and therefore low flow required), span 1 was controlled as a single unit. The area under each span progressively increases the further the span is from the pivot point. Spans 2 and 3 were controlled in two sections, i.e. the sprinklers in the inner half of the span could be turned on or off independently from the sprinklers in the outer half. Spans 4 through 10 were controlled in three sections, i.e. an inner, middle and outer third. Span 11 is the

relatively short overhang at the end of the system, and this was controlled as a single unit. Thus, in figures 10a and 10b, span 1 has a single value, spans 2 and 3 have two values, spans 3 to 10 have three values, and span 11 (the overhang) has 1 value. As the center-pivot progresses from 0 through about 7 degrees, the target flow is not reduced. As the system progresses, the target flow is progressively reduced from about 8 degrees through 18 degrees as more of the system is over the rock outcrop. From about 19 degrees onwards, target flow progressively increases as more of the system completes its pass over the outcrop.

Figures 11a and 11b show measured flow rate and pressure at the pivot point within this area for all four scenarios, respectively. In figure 11a, scenarios 1 and 2 show essentially constant flow while scenarios 3 and 4 show reduced flow in part of the sector, as the control system implements the irrigation targets shown in figures 10a and 10b by turning appropriate sprinklers off. Similarly, in figure 11b, pressure at the pivot point varies according to expectations under each of the four scenarios.

The most important result from an energy point of view is how the various flows and pressures are reflected in energy use. Figure 12a shows the rate of energy use, in kW, for fifteen minute intervals during the time the center-pivot was irrigating this particular area, for each scenario. Scenario 1 shows essentially constant power input because flow and pressure were also essentially constant. Scenario 2, (pressure control only) shows reduced power input because the ASD was able to reduce pressure in the system without affecting flow. In parts of the field where pressure cannot be reduced without affecting flow, the power input would be the same as in scenario 1. An example of this could be where the outer end of the center-pivot is at a significantly higher elevation than the pivot, requiring pressure to be increased to maintain sufficient pressure at the outer end.

Power input under scenario 3 (both pressure and flow control) shows the benefits of reduced power when pressure alone can be reduced, as it is from 0 to 7 degrees, and when pressure and flow are reduced, as they are from 8 to 30 degrees. In the former, power input is essentially the same as in scenario 2. In the latter, power input is progressively reduced from 8 to 18 degrees as more of the center-pivot passes over the rock outcrop and increasing numbers of sprinklers are shut off. From 19 to 30 degrees power input progressively increases as sprinklers start turning on again once they are past the outcrop, until at 30 degrees all the sprinklers are on again and power input is the same as under scenario 2.

Power input under scenario 4 (flow control only) is similar to scenario 1 from 0 to 7 degrees because no flow reduction occurs. From 8 to 18 degrees, and from 19 to 30 degrees, power input progressively decreases and then increases as under scenario 3. However, because pressure is higher than required, the power input is higher than under scenario 3.

Figure 12b shows power input integrated over time to show total energy used (kW-hr) under the four scenarios, for the same sector of the field. As shown in figure 12a, the highest energy use is under scenario 1 and the lowest is under scenario 3. Compared with the baseline (scenario 1), scenario 3 used significantly less energy in this sector (203 kW-Hr compared to 280 kW-Hr, a 28% reduction).

OTHER

The ultimate goal is to commercialize control systems for SSCM. In addition to the technical development which this project has accomplished, PICS has developed a close business relationship with a major fertilizer producer and distributor. We have already formalized a development agreement and are in the process of formalizing a joint production and marketing agreement which will result in systems being available commercially within 2 years. Thus, we have combined our experience and R&D expertise with a company with the resources to successfully commercialize and market the system. We have also been supported by other industries, including a manufacturer of ASDs, a manufacturer of chemical injection equipment, and the electrical power supplier for the area in which we have worked. Also, as a beginning to publicizing the system and eventually marketing it, we held a field day in July 1996 to demonstrate the prototype system to interested people, including farmers. The event was a success and has generated great interest.

State	Center-pivot area (1000 ac)	Total sprinkler area (1000 ac)	Center-pivot as % of sprinkler	Energy source			Avg. well depth (ft)
				EL ¹	DS ²	NAG ³	
NE	3808	4230	90	35	27	36	190
TX	1700	2156	79	35	30	34	250
KS	1487	1545	96	10	15	75	245
CO	780	872	89	75	5	19	240
GA	705	1227	57	23	60	5	300
ID	683	2325	29	98	1	0.5	250-300
WA	457	1508	30	99	0.5	0.3	250-400
MS	357	384	93	38	54	6	120-170
MN	349	492	71	65	35	0	110
SD	347	355	98	61	17	3	120
Total	10,673	15094	71				

¹EL is electricity

²DS is diesel fuel

³NG is natural gas or liquid propane

Table 1. Sprinkler and center-pivot acreage in the ten leading states in terms of area under center-pivots, together with leading energy source% of pumps). Source: Shank, 1992.

Figure 5a. Pressure at the pivot, in the middle (span 6) and at the end of the system for scenario 1 (no pump or flow control), vs. rotation angle of the system.

Figure 5b. Measured and theoretical flow rate for scenario 1 (no pump or flow control), vs. rotation angle of the system.

Figure 6a. Pressure at the pivot, in the middle (span 6) and at the end of the system for scenario 2 (pump control), vs. rotation angle of the system.

Figure 6b. Measured and theoretical flow rate for scenario 2 (pump control), vs. rotation angle of the system.

Figure 7a. Pressure at the pivot, in the middle (span 6) and at the end of the system for scenario 3 (pump and flow control), vs. rotation angle of the system.

Figure 7b. Measured and theoretical flow rate for scenario 3 (pump and flow control), vs. rotation angle of the system.

Figure 8a. Pressure at the pivot, in the middle (span 6) and at the end of the system for scenario 4 (flow control), vs. rotation angle of the system.

Figure 8b. Measured and theoretical flow rate for scenario 4 (flow control), vs. rotation angle of the system.

Figure 9a. Comparison of measured and theoretical flow rate for a complete irrigation under scenario 1 (no control). The average deviation of measured flow from theoretical flow is 7%.

Figure 9b. Comparison of measured and theoretical flow rate for a complete irrigation under scenario 3 (flow control and pump control). The average deviation of measured flow from theoretical flow is 8%.

Figure 10a. Target application along center-pivot at 9 degrees

Figure 10b. Target application along center-pivot at 18 degrees.

Figure 11a. Measured flow rate vs. rotation angle for all four scenarios

Figure 11b. Pressure at the pivot point vs. Rotation angle for all four scenarios.

Figure 12a. Power consumption vs. rotation angle, for all four scenarios

Figure 12b. Cumulative energy consumption vs. rotation angle, for all four scenarios.

REFERENCES

Shank, B.F. 1992. Annual Irrigation Survey. Irrigation Journal, Jan/Feb Issue, pp 19-47.

King, B.A., R.A. Brady, I.R. McCann and J.C. Stark. 1995. Variable rate Water application through sprinkler irrigation. Site-specific management for agricultural systems. ASA. Madison, Wi. pp. 485-493.

Wall, R.W., King, B.A. and McCann, I.R. Center-Pivot Irrigation System Control and Data Communications Network for Real-Time Variable Water Application. (1996, 3rd International Conference on Site Specific Crop Management, Bloomington, Minnesota). American Society of Agronomy.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.