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FEEDBACK CONTROL OF CABLEGATION SYSTEMS

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Cablegation is an automated furrow irrigation system (Kemper et al.,1981; Kemper et al., 1985; Kemper et al., 1987) fabricated from gated-pipe, a plug that blocks water flow and slides through the pipe, and a controller that reels out cable to regulate the rate of plug movement. The pipe, with open outlets located near the top of the pipe, is placed on a uniform grade. Water flows through the pipe below the level of the outlets until it reaches the plug where it backs up and flows out of the outlets. Outlets nearest the plug flow at the highest rate, while those further upstream flow at decreasing rates (Figure 1). As the plug moves, the flow is cut back to each furrow. Since each furrow is in a different phase of irrigation, tailwater runoff is fairly constant after an initial starting period.

Feedback control involves automatically sensing information about irrigation performance such as stream advance rates or tailwater runoff rate and modifying the application to improve performance. Such controls permit a surface irrigation system to automatically respond to variations in infiltration rate, slope, and row length. Feedback control of surface irrigation systems tends to be complicated and expensive due to the need to distribute and interconnect sensors and controllers throughout a large field. Trout and Kincaid (1987) proposed that cablegation would be ideal for feedback control since it has a steady runoff rate and set times are determined by plug speed. Thus, using runoff rate to adjust set time requires only one sensor and one controller.

The objectives of this paper are, (1) to describe the hardware and the operating procedure for a furrow cablegation feedback control system, and (2) to present initial field evaluations from the experimental systems.

BACKGROUND

On many fine-textured soils the infiltration rate decreases rapidly as they absorb water. These soils have a tendency to crack when dry and to swell and "seal up" when wet. Consequently, much of the irrigation water infiltrates during the first few minutes after furrow flow advance. Therefore, uniformity of application down a furrow is usually high if water advances to the end of the field. Most of any additional water applied runs off. Thus, runoff is an important controllable component of water loss on these soils.

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System Components (Hardware)

The components of the feedback control system are a flow measurement structure with a sensor that determines whether the runoff rate is within an acceptable range, a Tandy Model 102[2] or similar microcomputer to process the data, an information communication system between the sensor and controller, and an electronically-activated cablegation plug speed controller (Figure 2). An external source of AC power is not necessary since all of the equipment can be powered by batteries.

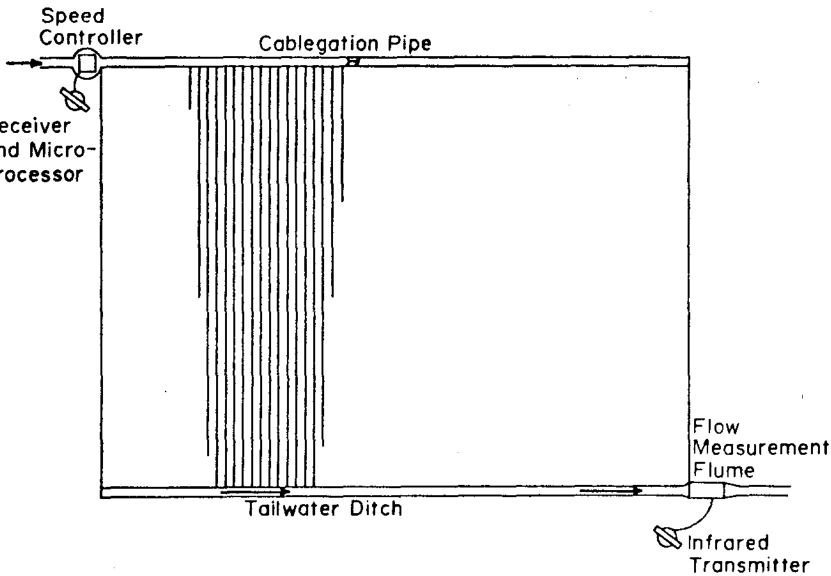

Figure 2. Schematic of cablegation plug speed feedback control system (after Trout and Kincaid, 1987)

Runoff sensor and flow measurement: The purpose of the sensor is to determine whether the runoff is too high or low. Although a continuous analog signal, such as from a pressure transducer, would provide more information; it was decided to reduce costs by using only two depth limit switches. The sensor is constructed from three brass rods (Figure 3). The rods are suspended at adjustable heights over the flow monitoring point. One rod is lowered to the bottom of the device and acts as a common ground for the circuit. The bottom end of the other two rods are set at the desired lower and upper runoff water depth. The premise of this simple sensor is that when the water level reaches the middle or upper rod, the circuit shorts.

In the experimental system, the sensor was placed in a flow measurement flume equipped with a pressure transducer (Trout, 1986) installed in the tailwater ditch. The transducer and flume made it possible to determine how well the system responded to flow variations and calculate the net depth of water applied. The

[2]Names of equipment manufactures and suppliers are provided for the benefit of the reader and do not imply endorsement by the USDA.

Infiltration, and thus runoff, varies spatially and temporally. Spatial variation results from differences in soil texture and structure, tillage methods, wheel traffic, and topography. Temporal infiltration variation results from soil structural changes caused by tillage consolidation and surface sealing. Because infiltration is variable and difficult for the irrigator to predict, efficient surface irrigation requires frequent checking of performance and system adjustment.

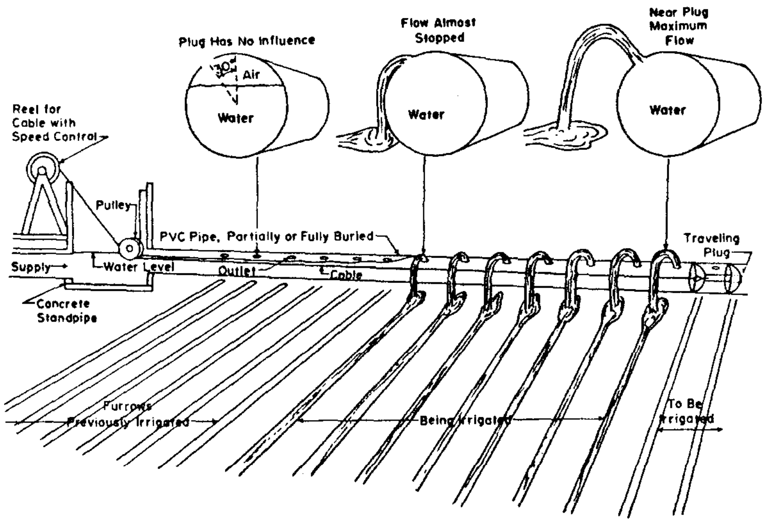

Figure 1. A cablegation automated furrow irrigation system (Kemper et-al., 1981)

The purpose of feedback control is to automatically make the required system adjustments. With cablegation feedback control, the operator need only determine the amount of runoff required to ensure that adequate water is applied to the lower-ends of the furrows. The set time is easily regulated by adjusting plug speed. When runoff is too great, set time is reduced by increasing plug speed. When runoff is inadequate to ensure complete advance on most furrows, set time is increased. This provides only partial control, since irrigation set time is the only modification possible and furrow flow rates must be manually set. However, irrigation performance is fairly insensitive to furrow flow rates on soils with high initial and low final infiltration rates (Trout and Kincaid, 1987). The irrigator also gives up control over gross application depth. This is generally not a disadvantage since net application depth on this type of soil is primarily determined by the soil infiltration capacity (i.e. is insensitive to irrigation time and gross application). Since runoff is controlled, percent runoff is constant and the net application depth is easily calculated from gross application.

PLUG SPEED FEEDBACK CONTROL SYSTEM

The feedback control described here, outflow evaluation-plug speed adjustment, is easy to automate since only one sensor in the tail water ditch and one control point at the field inlet are required. The only major requirement for this system are that all runoff exit the field at one location and without too much delay

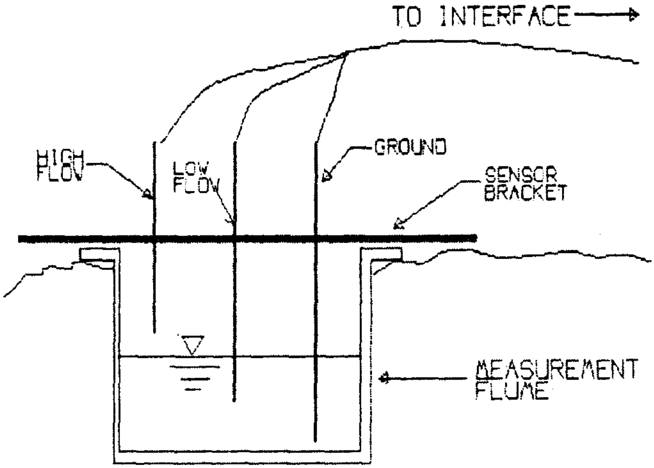

Figure 3. Cablegation feedback runoff sensor.

sensor can be placed in any structure (or even a ditch) with a head:discharge relationship.

<u>Microcomputer and Interface:</u> The Tandy Model 102 is a small, battery powered microcomputer with 32K of random access memory and an 80C85 (8 bit CPU) co-processor. The Model 102 features include: an eight-line liquid crystal display, full keyboard, an RS-232 connector, a 40 pin external bus signal interface, and an external cassette interface. The microcomputer is programmed in BASIC.

A custom interface was assembled to decode the runoff sensor signal and to activate the transmitter. The microcomputer reads the runoff sensor signal and transmits data by reading and writing to an unused I/O CPU port (#112 in the Model 102) that is connected to the interface. This port number is normally used to operate an external tape drive. The computer reads a latch decoder in the interface which is connected to an 8-bit memory read bus. An electric current is sent through the sensor from the bus. If both sensors are short-circuited, the computer reads a 0; if one sensor is submerged, the computer reads a 2; and if neither sensor is submerged the computer reads a 3.

The controller release signal is sent from the computer through the latch decoder to an 8 bit memory write bus. The signal from the bus activates a transistor which switches on the infrared transmitter.

<u>Infrared transmitter and receiver:</u> An Automata IRTX infrared (IR) transmitter were used to convey control signals to the controller. The IR transmitter accepts a switch electrical input from the transistor connected to the memory write bus in the interface and converts the signal to a switch optical output. At every plug release interval, the computer and the interface send a one-quarter second signal to the IR transmitter. The transmitter then beams an IR light switch closure signal for one-quarter second.

Automata's IRRX, IR receiver senses the switch optical input from the receiver and converts it to an electrical signal. The electrical signal drives a mechanical relay that closes the circuit of a 12-volt battery connected in series

Electronic cablegation controller: An electronic cablegation plug-speed controller manufactured by Cablegation Controls Inc. was used with the feedback system. These controllers are normally supplied with an electronic timer that operates the solenoid-activated release mechanism. With the feedback system, the timer was replaced with a battery connected in series with the relay from the receiver. When the receiver accepts an IR signal from the transmitter, the mechanical relay closes the circuit with the battery and activates the solenoid which releases the latch. Thus the plug advances one cable reel circumference with each release signal.

Microcomputer Software

A BASIC computer program was written to run on the Tandy Model 102. An external electronic switch cycles the program loop approximately once each minute to reduce power consumption. The computer's internal clock is checked each loop of the program. An elapsed time (minutes) from the beginning of the irrigation is calculated. Depending on elapsed time, the sensor is read or the release signal sent and the read or release times updated accordingly.

The five inputs to the program are: (1) delay time for start up, (2) initial plug release interval, (3) delay time to initial runoff, (4) sensor scan interval, and (5) release interval change. The operator can change the plug release interval while the program is running.

The delay time for start up is used to hold the plug stationary for an initial period of time. It's purpose is to begin an irrigation on the first set of furrows for systems which aren't equipped with a bypass (Kincaid and Kemper, 1984). This delay is needed regardless of feedback.

The initial plug release interval is the duration between plug releases or the inverse of plug speed. The plug moves one reel circumference for each release interval. Gross application with cablegation systems is proportional to the plug release interval. The computer calculates a maximum and a minimum allowable interval proportional to the initial release interval.

The delay time to initial runoff is the time to wait for runoff to occur before the plug release interval is increased. The delay allows time for water to advance across the field and fill the tailwater ditch.

The sensor scan interval is the interval between runoff sensor readings. The release interval change is the percent the plug release interval is changed each scan if the sensed flow is out of range. These two parameters determine how quickly the system responds to variations in runoff rate. If the scan interval is too small or the release interval too large, the system may overshoot the correct response before the runoff can respond to system adjustments. If the scan interval is large and the release interval change small, the system response is slow which results in high or low runoff.

Computer Model

A computer model capable of simulating an operating cablegation feedback system is under development. The simulation model will be used to refine feedback control algorithms and determine optimum system response rate (sensor scan interval and release interval change) for varying field conditions.

System Costs

The approximate costs for installing a cablegation feedback control system are:

Flow Measurement Flume (Optional)	--	$ 300
Flow Depth Sensor	--	30
Infrared Transmitter and Receiver	--	550
Microcomputer	--	500
Weatherproof Case	--	50
Interface:		
Hardware and Connectors	--	30
Radio Shack Bus Connector	--	40
Assembly Cost (2 hours @ $15/hr)	--	30
Total Feedback Control System		$1530
Electronic Cablegation Controller	--	$ 550
Cablegation Inlet Structure, Plug, Cable, etc.	--	450
Gated Pipe, Outlets, and Installation (380m @≈$10/m)	--	3800
Total Cablegation System		$4800
Total Cablegation with Feedback		$6330

The total cost for a new feedback cablegation system for a square 16 ha (40 ac) field would be about $6400, or $400/ha ($160/ac).

FIELD TESTS

Site Descriptions

Two feedback control systems were installed and operated during the summer of 1989 on existing cablegation systems in north-eastern Colorado near Julesburg. One field covered 11.3 hectares and was rectangular in shape with runs of 3[illegible] meters and a uniform down field slope (0.5%). The other field encompassed 3.[illegible] hectares and was extremely irregular in shape and slope, with furrow lengths varying from 95 to 290 meters. Both fields were planted to corn.

Performance

Figure 4, shows the runoff rate, target runoff rate (between Q_L and Q_H) and plug release interval for part of one irrigation on the rectangular field. Inflow was constant at 43 liters/second (L/s). The runoff limits Q_L and Q_H are chosen by the operator by adjusting the runoff sensor rods. In general Q_L must be high enough to insure that most of the furrows complete advance and Q_H is selected primarily to limit runoff loss. In this figure, the feedback system was initially not in operation and field runoff was high. The initial release interval was 6 minutes and the maximum and minimum interval allowed was 18 and 2 minutes respectively. Sensor scan time was set at 6 minutes and the release interval change was 3%. The system properly began decreasing the release interval (increasing plug speed and decreasing set time). The runoff decreased in response and reached the acceptable range-then continued to decrease with no additional plug speed change. The continuing decrease was initially the result of runoff response lag but was also the result of the field infiltration variability (increased permeability). When the runoff dropped below the lower limit, the system slowed down the plug, resulting in increasing runoff. System response lag is primarily a function of surface water storage volume changes on the field. This flat field has a considerable amount of water stored on the field and in the tailwater ditch and responds slowly. Therefore, runoff response to plug speed variations is slow. However, during the time represented on the figure, net application depth (inflow rate minus outflow rate divided by plug speed) varied only between 14 to 16 mm

RECTANGULAR FIELD

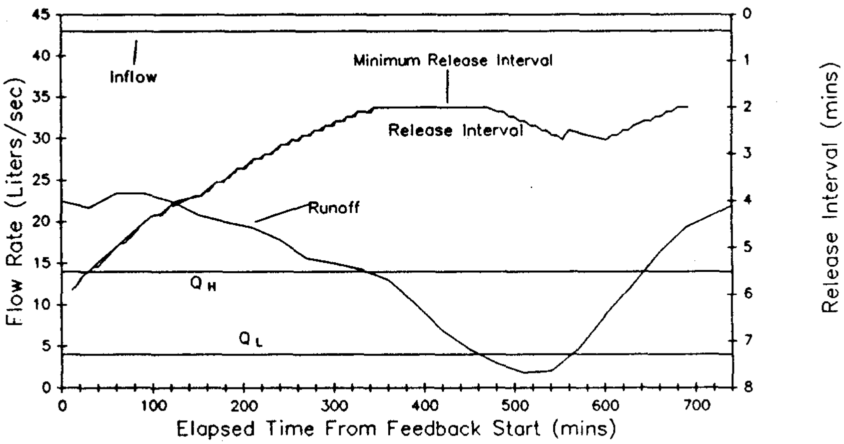

Figure 4. Plug speed feedback control and response on the rectangular field.

Figure 5, depicts system operation on the irregular field. The first 25 furrows in this field are only 95 meters long. The next 60 furrows vary from 200-290 meters in length. The initial release interval was 31 minutes, scan time was 30 minutes, and the release interval change was 5%. This cablegation system did not have a bypass, so the control program delayed 90 minutes before initially releasing the plug. The inflow into the system increased 100% at about 400 minutes (unbeknownst to the operator). The system was able to reduce runoff to an acceptable level within 400 minutes (6.7 hrs) in spite of the fact that row length was fluctuating during this time. On this field and tailwater ditch the system responded quickly (little surface storage change). A small modification in plug speed quickly caused a runoff change at the sensor.

With the initial low inflow and short run lengths, net application depth fluctuated between 40-50 mm. Within 500 minutes of the flow increase, net application and runoff had been reduced to initial levels.

SUMMARY

A cablegation feedback control system requires only one sensor location and one control point. There are four components to the system: (1) a runoff sensor, (2) a small microcomputer, (3) an information communication system between sensor and controller, and (4) an electronic cablegation controller. Two experimental systems were used in eastern Colorado during the summer of 1989. The system did not operate effectively on a flat field with widely varying infiltration, but responded quickly to changing row lengths and inflow rates on a steep field.

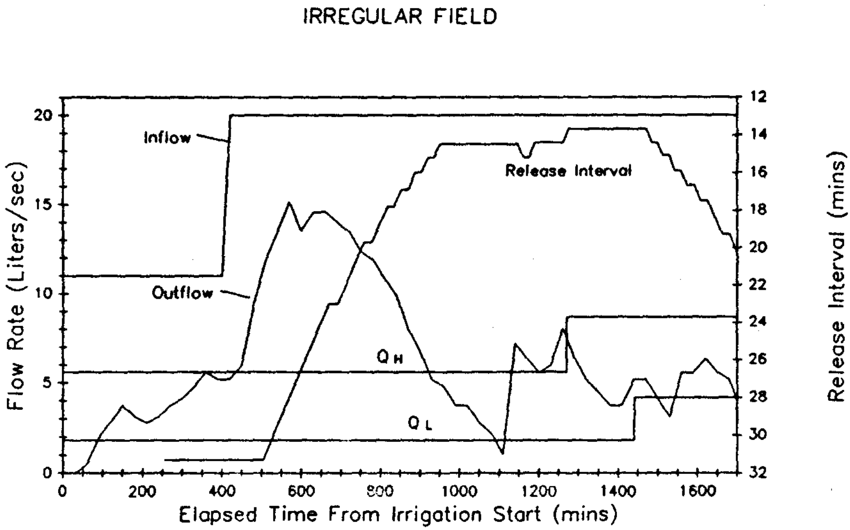

Figure 5. Plug speed feedback control and response on the irregular field.

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