FEEDBACK CONTROL OF SURGE IRRIGATION SYSTEMS[1]

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ABSTRACT

An automated irrigation control system is described which uses real-time feedback information transmitted by infrared telemetry from runoff sensors to control intermittent or surge irrigation. Flow runoff sensors monitor water depth in a measuring flume at the end of a field. Runoff data are transmitted via an infrared transmitter and receiver to a portable microcomputer located at the upper end of the field. Inflow data from a flow meter in the supply line are also fed to the computer. Using the feedback data and field parameters provided by the operator, the computer controls a surge valve for the advance phase of irrigation and determines cycle times during the cutback or post-advance phase to limit runoff and total application depths to target values set by the operator. All system components are battery-powered. Results from preliminary field tests confirmed the ability of the system to control irrigation by real-time feedback.

Keywords: Irrigation, surge, feedback control, automatic, infrared telemetry.

SUMMARY AND CONCLUSIONS

Un système de contrôle d'irrigation automatisée est expliqué et utilise des données en retour en temps réel transmises par télémétrie infrarouge par les détecteurs d'écoulement pour contrôler l'irrigation par impulsions ou l'irrigation intermittente. Grâce à l'irrigation par impulsions, l'eau peut être poussée à l'extrémité d'un sillon plus rapidement qu'en utilisant des jets d'arrosage continu. L'écoulement peut être contrôlé en modifiant les temps de répétition lors de la phase d'avance ultérieure d'irrigation ou de réduction. Les détecteurs du débit d'écoulement surveillent le niveau de l'eau du caniveau de mesure situé à l'extrémité du champ. Les données d'écoulement sont transmises à un micro-ordinateur portatif situé à l'extrémité supérieure du champ par l'intermédiaire d'un émetteur-récepteur infrarouge. Les données d'affluence de l'hydromètre de la conduite d'alimentation sont aussi transmises à l'ordinateur. En utilisant les données en retour et les valeurs des paramètres du champ fournis par

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l'opérateur, l'ordinateur contrôle une valve génératrice d'impulsions pour la phase d'avance d'irrigation et détermine les temps de répétition lors de la phase d'avance ultérieure pour maintenir les niveaux d'écoulement et d'application totale dans les limites fixées par l'opérateur. Tous les composants du système sont alimentés par des batteries. Le système automatisé a été mis à l'essai sur trois différents champs en 1991. Les diagrammes des résultats sont présentés ci-après et montrent les intervalles du cycle d'irrigation à impulsions et les taux d'écoulement actuels et de visée lors de la phase de réduction pour un champ d'alfafa avec un taux d'infiltration élevé et pour un champ d'haricot avec un taux d'infiltration faible. Les taux de moyenne totale du niveau de visée de l'écoulement contrôlé de 10 et 22 pour-cent furent obtenus. Les résultats des tests préliminaires sur site confirment les capacités du système de contrôler l'irrigation en utilisant les données en retour en temps réel.

Surge irrigation is the intermittent application of water to surface irrigated furrows or borders in a series of relatively short on and off time periods. The concept of surge irrigation was introduced by Stringham and Keller (1979) who also coined the term "surge flow". They found that the soil intake rate was generally reduced by applying water intermittently during the advance phase of an irrigation. A direct consequence of reducing the infiltration rate was more rapid advance. Intake opportunity time between the upper and lower ends of the furrows was more uniform than with continuous-flow systems and this resulted in more uniform water distribution.

Feedback control involves automatically sensing irrigation performance parameters such as water supply rates, tailwater runoff, and/or stream advance rates and modifying the irrigation application to improve performance. Feedback control allows a surface irrigation system to automatically respond to variations in infiltration rate, slope, and row length. Feedback control of surface irrigation systems normally tends to be somewhat complicated and costly because of the need to interconnect sensors and controllers distributed throughout a field. Since surge systems have one upfield control point, the surge valve, it is possible to vary irrigation set time by changing the duration of the surge cycle. If all the runoff from a field exits at one point, a degree of feedback control is feasible since runoff is readily measurable and only one downfield control point with sensors and a communication link between the upfield and downfield control points is required.

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

BACKGROUND

Surge irrigation has the potential to improve irrigation application uniformity and efficiencies compared to continuous-flow systems. However, a higher level of management is required. Surge irrigation can be managed in two components: (1) the advance phase before runoff begins and (2) the post-advance or cutback phase during runoff. For coarse-textured and high intake rate soils, management of the advance phase is the most critical. In contrast, management of the post-advance phase is the most critical for fine-textured and low intake rate soils which tend to produce considerable runoff. Without careful management, surging can actually increase runoff, as some irrigators have discovered.

The most practical approach for post-advance control in many situations is to use cycle on-times based on the advance time through previously wetted furrows and the same size streams as during advance. As a general guide, water supply to a furrow during a post-advance cycle can be cut off when the water front reaches about three-fourths the furrow length downstream. Water stored in the furrow supplies the volume of water necessary to advance the front to the end of the furrow. Thus, only a relatively small amount of runoff need be produced. When the water supply to one set of furrows is cut off by a surge valve, the water supply is diverted to the companion set of furrows where the cycle is repeated. McCornick (1987) noted that for high intake rate soils, a cutoff time of as much as 1.3 times the wet advance time instead of 0.75 may be required. The higher value would be needed to allow water to reach the end of the furrow and provide a sufficient intake opportunity time at the end of the furrow. Thus, the on-time for post-advance surges ranges from approximately 0.75 to 1.3 times the wet advance time as intake rates vary.

SURGE FEEDBACK CONTROL

A surge feedback control system was developed primarily to provide a means of post-advance management to minimize runoff and to increase intake opportunity time at the lower end of a field. This type of feedback control is relatively easy to automate. A constraint for the system is that tailwater exit the field at one location without excessive delay. The operator preprograms the surge cycle times for advance utilizing one or more of the methods commonly used (Humpherys, 1989), and programs the depth of water to apply, and the desired or target rate of runoff. The desired runoff rate should be sufficient to ensure that an adequate amount of water is applied to the lower end of the furrows and is determined by experience. After startup, the surge valve operates as pre-programmed during the advance phase of the irrigation. When runoff approaches or reaches the desired target rate, the cycle time is reduced in steps to decrease runoff. If the cycle time is reduced too much, such that the runoff subsequently drops below the pre-programmed desired rate, the cycle time increases to increase the runoff rate.

Thus, as furrow intake rates change during an irrigation, feedback control provides a means of controlling water application to maintain a desired near-constant average runoff rate. The control limit is reached (usually only with low intake rate soils) when the cycle times become so short that water runs off both half-sets continuously. This condition represents the control limit but still provides a means of achieving cutback furrow streams without reducing the inflow supply.

System Components (Hardware)

Components for the surge feedback control system consist of an inline mechanical surge valve, an inflow measuring device and sensor, an outflow or runoff measurement structure and sensor, communication system between the outflow sensor and the controller, and a Tandy Model 102[3] or similar microcomputer to process the data. Since all of these units are powered by batteries, an external power source is not necessary.

Inflow measurement: An inline flow meter with a dry switch pulse transmitter is used to measure inflow. The pulse meter emits an electrical pulse after a calibrated volume of water passes through the meter. A two-digit counter installed in the computer interface records the inflow volume.

Surge valve: A commercial, electrically-powered, mechanical surge valve, configured in the form of a tee, is located in the center of a gated pipeline to form a split-set layout. The valve diverts water alternately from side to side as shown in Figure 1 when electrical command signals are received from the computer interface.

Runoff sensor and measurement: A pressure transducer mounted on a flow measurement flume (Trout, 1986) installed in a tailwater ditch at the field exit point is used to determine water depth in the flume. The rate and volume of water which leaves the field is determined from the sensed depth..

Infrared transmitter and receiver: An Automata IRTR[4] infrared (IR) field station with transmit capability only transmits flow depth information from the outflow flume to the microprocessor. The IR transmitter accepts a serial electrical input from a pressure transducer attached to the flume and converts it to a serial optical output. An Automata IRRX, IR receiver senses the serial data stream, which consists of a modulated light beam from the transmitter, and converts the

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

[4]Automata, Grass Valley, California 95945 U.S.A.

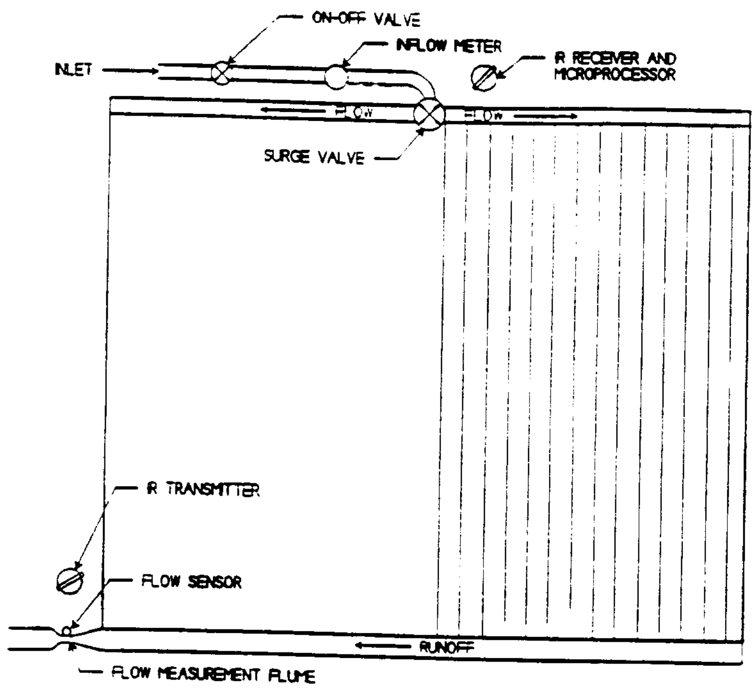

Figure 1. Schematic diagram of a surge feedback control system. (Diagramme schématique d'un système de contrôle d'irrigation à impulsions.)

optical signal to a serial electrical signal and feeds this to the computer through an RS-232 connector.

Microcomputer and interface: The Tandy Model 102 is a small, battery-powered microcomputer with 32K of random access memory and an 80C85 (8 bit CPU) coprocessor. 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.

A custom interface was assembled to decode information collected from the inflow meter and to operate the surge valve. The microcomputer is able to transfer data to the interface by reading and writing to an unused I/O CPU port connected directly to the interface. This port, normally used to operate an external tape driver, is used to read the inflow counter, operate the surge valve, or activate an on-off valve.

Microcomputer software: The microcomputer requires a program written in BASIC to operate the feedback system. The computer's internal clock is checked during each loop of the computer program. Depending on elapsed time, the position of the surge valve is changed or the on-off valve is operated. When the IR receiver receives a signal from the excitation relay of the outflow pressure transducer, the program is interrupted and the program flow is diverted to a special subroutine which calculates the runoff rate, reads the counter in the interface and determines the inflow rate, estimates the total intake, and calculates the next surge duration when the valve is in the second position of its present cycle.

Operator inputs to the program are: (1) number of surge cycles during the advance phase, (2) minimum surge cycle time, (3) estimated water advance time, (4) maximum irrigation time, (5) target flume depth or runoff rate to change to cutback, (6) target runoff rate in cutback mode, (7) target net application depth, (8) furrow length, (9) furrow spacing, (10) number of furrows (both sets), and (11) estimated distribution uniformity.

FIELD TESTS

Field installations

The feedback control system was tested in three different fields. These fields had varied run lengths, slopes, row spacings, and crops. The soil was a uniform silt loam. The system is semi-portable and the components were moved from field to field for the tests. These preliminary tests were conducted to gain background information and experience in setting target values, to monitor the system's ability to reach and maintain target values, and to make adjustments in the program. Further tests will be made to fine tune the program.

Performance

Output diagrams for irrigations on two fields representing two diverse conditions are shown in Figures 2 and 3. Irrigation data for an alfalfa field with a high water infiltration rate and a slope of 0.3 percent are shown in Figure 2 while that for a bean field with a low infiltration rate and 1.0% slope are shown in Figure 3. The diagrams show the actual outflow or runoff rate Q, target runoff rate Q_1 which signals completion of the advance phase, maximum target runoff rate during cutback Q_2, average controlled runoff rate Q_{avg}, and surge time interval T_s. Target values for Q_1 were set high enough to assure that advance would be completed in most of the furrows, while Q_2 was chosen to limit the amount of runoff.

During advance, the computer operates the surge valve according to operator-programmed cycle times and receives transmitted runoff data (zero during advance). When runoff begins for the first half-set, the computer recognizes that advance is complete and subsequent cycle times are determined by an algorithm in the software which uses feedback information. The algorithm attempts to adjust for the lagtime between commands and system response and anticipates the approach of Q to Q_2. If the runoff fails to reach or is slow to approach Q_2, then the cycle time is increased. Conversely, the cycle time is decreased if Q exceeds Q_2. This process is depicted in Figure 2 where the advance phase ended at about 475 minutes; runoff was slow in approaching Q_2 because of the alfalfa field's high intake rate and the computer increased the cycle time at 530 minutes. Runoff still did not reach Q_2, so the

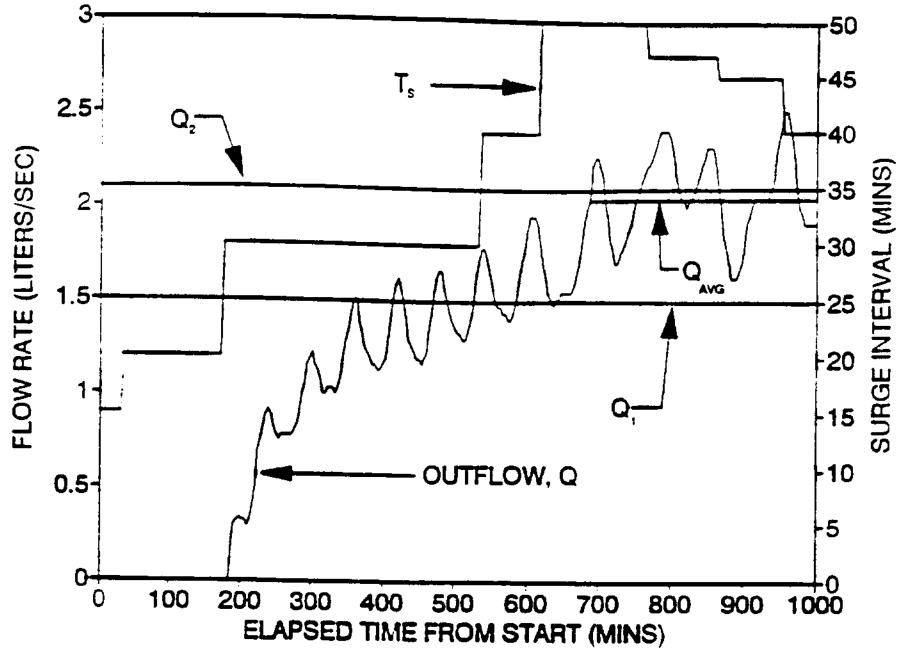

Figure 2. Output diagram which shows surge cycle intervals and actual and target runoff rates during cutback for an alfalfa field with a high water infiltration rate. (Diagramme des résultats illustrant les intervalles du cycle d'irrigation à impulsions ainsi que les taux d'écoulement actuels et de visée lors de la phase de réduction d'un champ d'alfafa avec un taux d'infiltration élevé.)

time interval was again increased at 618 minutes. This caused the runoff to reach and exceed the target value so the time interval was then decreased for subsequent cycles, as shown by the T_s curve. A constant average runoff rate near the target rate Q_2 was achieved during the remainder of the irrigation as the field's intake rate decreased. This response can also be seen in Figure 3 where the surge cycle time interval increased until the target rate Q_2 was reached at 240 min, after which the cycle time was progressively decreased to limit runoff as the field's intake rate decreased. In this case, the field's low intake rate resulted in a relatively high runoff for the inflow supply used. The system decreased the cycle time until the limit condition of 50% cutback continuous streams was approached. At this limit condition, it is best to put the surge valve in its center position to split the inflow equally between the two half-sets. This provides continuous cutback furrow streams one-half the size of the original streams.

During the cutback phase, the computer receives inflow data from the flow meter and, by subtracting out the runoff, calculates the average depth of application. When the calculated application depth, using the assumed distribution uniformity value, reaches or exceeds the target depth, or when the irrigation time exceeds the maximum allowed irrigation time, the computer terminates irrigation and closes the on-off supply valve. The computer continues receiving runoff data until runoff ceases. The inflow, outflow, and other operational data form a history of the irrigation which are stored in a cassette recorder.

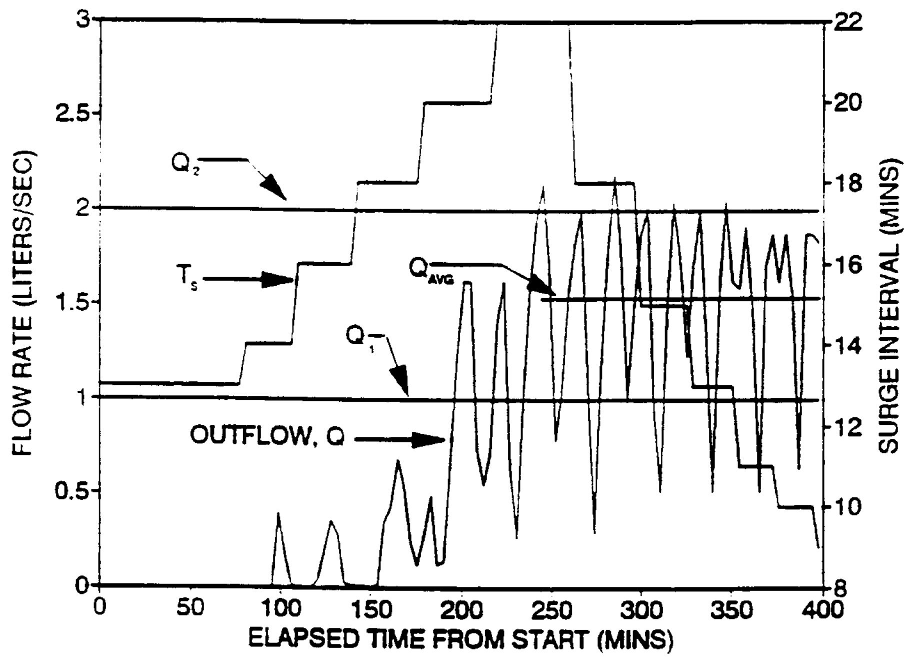

Figure 3. Output diagram for a bean field with a low infiltration rate. (Diagramme des résultats pour un champ d'haricot avec un taux d'infiltration faible.)

Runoff for the two irrigations represented in Figures 2 and 3 was 10 and 22% respectively. Runoff from surface irrigated fields under similar conditions with conventional methods typically ranges from about 25 to as high as 49% (Trout, 1988). The automated feedback system provides a means to optimize furrow irrigation by reducing both tailwater runoff and deep percolation using the surge technique. Sediment production from highly erodible soils can also be reduced.

The computer program and additional system details can be obtained from the authors.

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