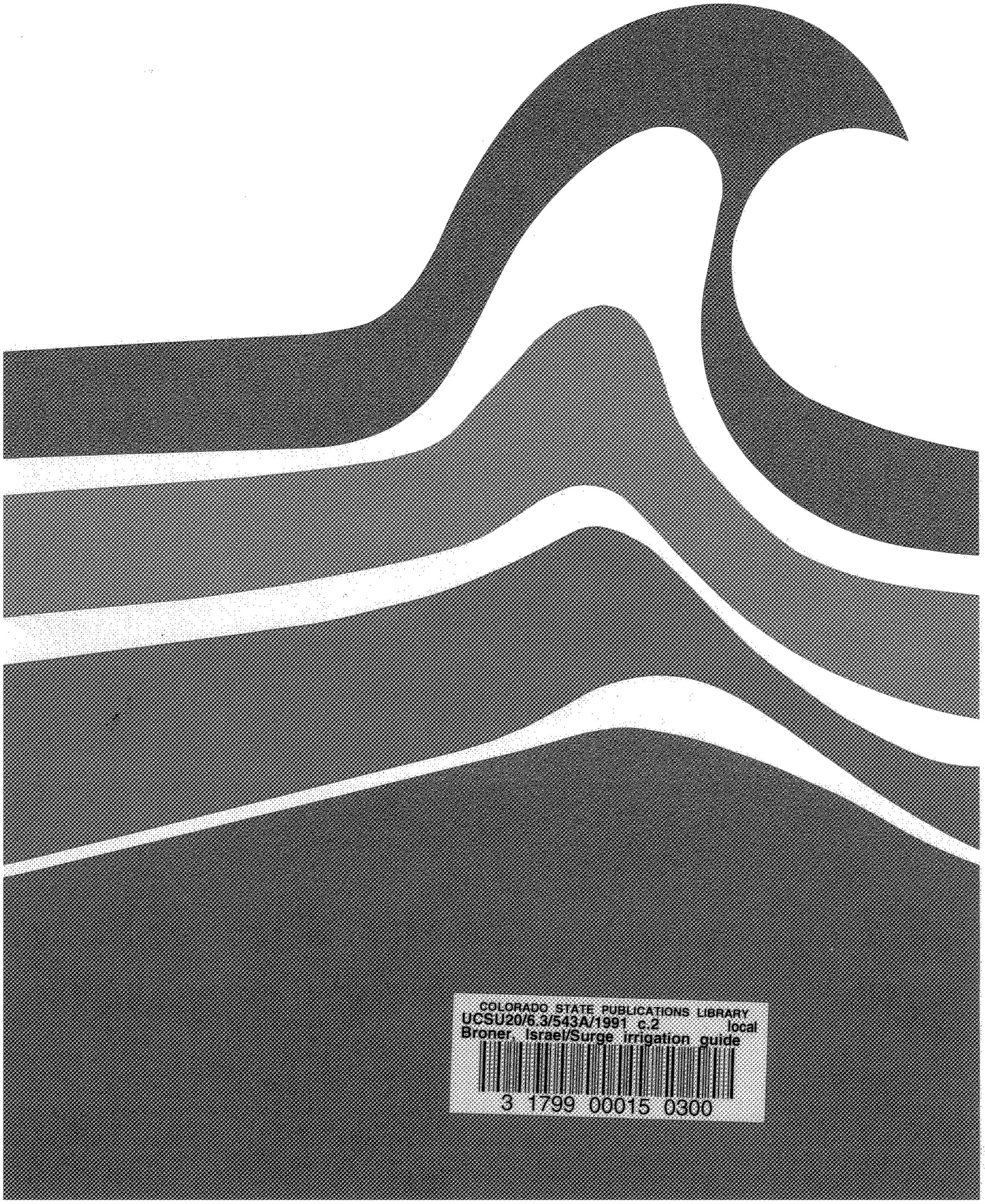
SURGE IRRIGATION GUIDE

Bulletin 543A



Colorado State University Cooperative Extension

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Surge Irrigation Practices

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Table of Contents

Continuous Furrow Irrigation

Phases of Furrow Irrigation

Furrow irrigation can be divided into three basic phases for practical applications.

Advance Phase: the phase in which the dry furrow is wetted. A good practice is to complete the advance as fast as possible to prevent excessive deep percolation at the upper end of the field.

Out Time: the time it takes the water to reach the end of the furrow;from the beginning of irrigation until water reaches the end of the field.

Soaking Phase: the phase in which the required irrigation depth (application depth) is infiltrated or "soaked." During the soaking phase, the goal is to apply a stream size that will satisfy the soil intake rate and therefore minimize tail water.

Soaking Time: (Application Time) the time it takes the required application depth to infiltrate. This soaking time can be calculated if the soil intake characteristics are known.

Recession Phase: the phase that starts when the water stream to the furrow is cut off and lasts until water disappears from the soil surface.

Opportunity Time: the total time that water stands on the soil surface at any point (each point along the furrow). The opportunity time is the time difference between recession and advance. The goal is to have an equal opportunity time at all points in a furrow.

"Cut Back" Practice

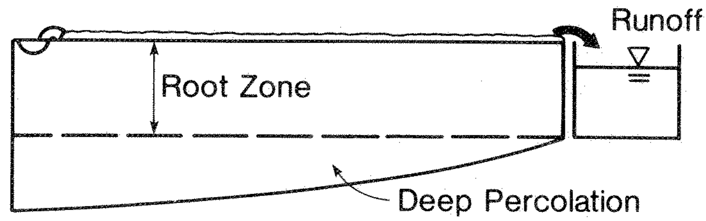
A large stream is needed to advance the water rapidly from the upper end of the furrow to the lower end. This practice reduces the opportunity time at the upper end of the furrow and minimizes differences in application depths between the upper and lower ends of the furrow. Therefore, deep percolation at the upper end of the furrow is minimized. After the advance is completed, the large stream should be cut back to reduce runoff at the lower end of the furrow. This practice is termed "cut back."

Different soil types pose different challenges to the irrigator. Light soils have a high rate of water intake, therefore a large stream is needed to speed the advance. In heavier soils that have a low rate of water intake, a small stream size is needed during the soaking phase to reduce tail water. Figure 1 illustrates the relationship between stream size, deep percolation and runoff. A proper practice in furrow irrigation is to start with a large stream until advance is complete and cut it back for the soaking phase. This practice is labor intensive and difficult to implement because the flow relieved by the cut back is only sufficient for advance on a partial set. The fact that this practice has not been accepted by irrigators is the best proof to this claim. However, researchers and field personnel continue to seek ways to automate the "cut-back" practice to improve efficiencies of furrow irrigation.

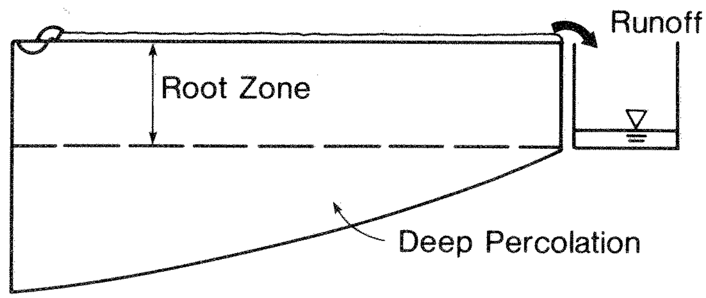
Figure 1: Relations between stream size deep percolation and runoff.

Why Cutback?

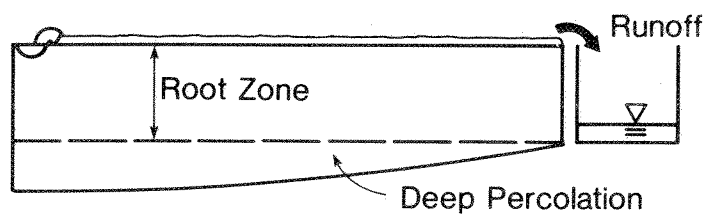
Continuous Large Furrow Stream



Continuous Small Furrow Stream



Large Initial, Small Cutback Furrow Stream



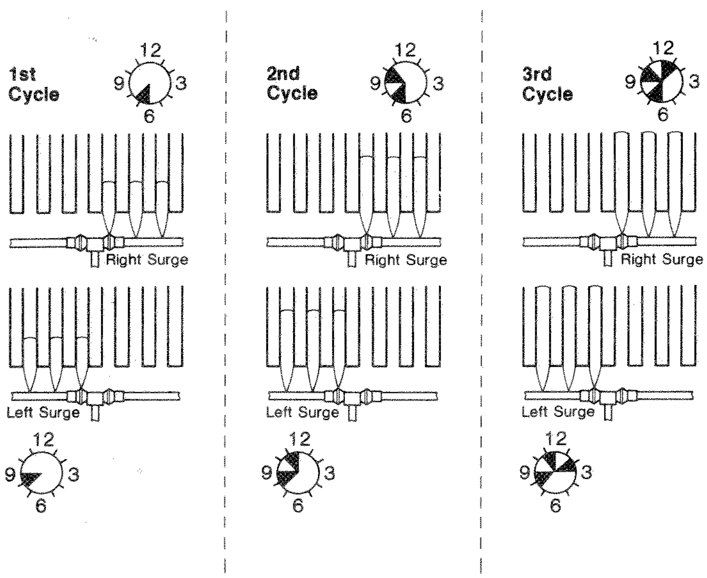
Introduction to Surge Irrigation

What is Surge Irrigation?

Surge irrigation is the intermittent application of water to furrows in a series of surges of constant or variable time spans. Usually the water is alternated between two sets of furrows until the irrigation is completed. Surge irrigation, in its modern form, is a relatively new irrigation technique and was first introduced by Utah State University (Stringham and Keller, 1979). However, the phenomenon of surge has been known to irrigators for more than two decades. Many irrigators found it impossible to complete the advance phase of furrow irrigation following a major cultivation because of the high water intake rate. They discovered that the advance phase could be completed by interrupting the stream furrow flow and then reapplying it hours or days later – practice sometimes called "bumping."

Surge irrigation can be applied manually by alternating water between two sets of furrows. However, labor is prohibitive in most cases because usually more than a few surges are needed. In today's typical installation, surge irrigation is applied through the use of an automatic "surge valve" located between two sets of gated pipes (Figure 2). Water is alternated between the right and left sides of the surge valve. Therefore, for each set of furrows, a series of on and off time periods is created as depicted in Figure 2. For example, a furrow on one side of the surge valve receives water for 40 minutes and then water is shut off for 40 minutes. This furrow will receive the second surge of water after one hour and 20 minutes (80 minutes). The second surge duration can again be 40 minutes or longer according to the particular program used. This process continues until the advance is completed.

Figure 2: Surge cycles and water advance.



Cut back for the soaking phase in surge irrigation can be done in two ways. The first way is to divide the flow between the two sets which reduces the stream size by 50 percent. The second way is to continue to alternate the water between the two sets of furrows on a short time interval which cuts back time and the average stream size.

Advantages

1. Faster water advance to the end of the field reduces deep percolation at the upper end of the field.
2. Automatic cut back reduces tail water.
3. Allows lighter applications of water.
4. More uniform water distribution along the furrow.
5. More opportunities to save water and energy.

Disadvantages

1. Requires a higher level of management (may be a problem when using unskilled labor).
2. Surge equipment must be maintained properly just as any piece of machinery.
3. Additional cost of the surge valve and gated pipe if not already used.

Why Surge Irrigation?

To properly apply furrow irrigation, some cut-back method is needed. Simple automatic irrigation valves only can turn water on or off, not half on or half off. Surge irrigation is automation of the "cut back." Instead of cutting back or reducing the continuous stream size, surging reduces the average stream size that the furrow receives.

Furthermore, early trials of surge irrigation showed the surge phenomenon (alternating water between two sets of furrows) has more advantages than just automation of the "cut-back" practice. Reduced infiltration rate is a major phenomenon associated with surge irrigation. Several explanations have been suggested for the reduced infiltration rate, however, few have been scientifically verified. As a consequence of the reduced infiltration rate, advance is completed even faster, and deep percolation at the upper end of the furrow is reduced even more than by just cutting back. Runoff is reduced mainly because of the "cut back."

Converting from continuous gated pipe irrigation to surge irrigation is straight forward and will be explained in the sections that follow.

Surge Terminology

On-Time: the time water is applied on one side of the surge valve before it is alternated to the other side.

Off-Time: usually the same duration as the on-time and is the time that water is not applied on one side of the surge valve.

Cycle Time: the time to complete a full on/off cycle; on-time plus off-time.

Cycle Ratio: the ratio between the on-time and the cycle time. A cycle ratio of 0.5 is prevalent today; on-time = off-time.

Management of Surge Irrigation

Phases of Surge Irrigation

Managing surge irrigation requires higher levels of management skills. However, surge offers management flexibilities that continuous furrow irrigation lacks. The management parameters for surge irrigation are furrow stream size, surge on-times and number of surges. Appropriate values of these parameters are dependent upon field length, furrow slope size and shape, soil characteristics, and surface debris. In general, stream sizes and surge on-times should be larger for light textured soils as well as long and clogged furrows. For heavy soils and short, small, clean furrows, smaller stream sizes and shorter surge on-times should be used. Different management strategies are needed for the advance phase and the soaking phase of surge irrigation.

Advance Phase

Stream Size Selection

Stream size selection for surge irrigation is no different from selecting the stream size for continuous furrow irrigation. A good approach for surge irrigation is to select the maximum non-erosive stream size, which can initially be approximated using an empirical equation suggested by the SCS Surge Flow Irrigation Guide.

$$Q \text{ (gpm)} = L \text{ (feet)} \times 0.02$$

where, Q = Stream size in gallons per minute
L = Furrow length in feet

If the soil's basic intake rate is known, a different approach unique to surge irrigation can be taken. The proper cut-back stream size for the soaking phase necessary to advance to the field end while maintaining negligible tailwater can be calculated. This stream size is the one needed for the soaking phase when the entire field is at or very near the basic intake rate. This stream size can be determined by:

$$Q = \frac{CxLxB}{96.25}$$

where, Q = Stream size for cut-back phase (gpm)
L = Furrow length (ft)
B = Furrow spacing (ft)
C = Basic intake rate (in/hr)

The furrow stream size needed for surge irrigation is then twice the cut-back stream size. Manual adjustments of the stream size to each furrow should be conducted at the beginning of the irrigation to account for variations between hard and soft furrows and other local conditions.

On-Time Determination

Two management approaches are available to determine the surge on-times for the advance phase of surge irrigation.

1. Variable time/constant distance. Set the time needed for an advance of 20 percent to 25 percent of the furrow length per surge cycle. With this approach, the on-time of the next advance surge will be slightly longer than the previous surge. The on-time of the next surge will be the time needed to advance over the dry portion plus the time needed to advance over the previously wetted portion of the furrow.

2. Constant time/variable distance. On-time for the advance surges is constant. The on-time should be set so that the first surge will wet about 30 percent to 35 percent of the furrow length. Following surges will wet shorter portions of the dry furrow.

Knowledge of advance rates of water over dry and previously wetted soils is needed to determine the surge on-times. Advance rate over dry soil usually is available from experiences with continuous furrow irrigation. Advance rates over previously wetted soils can be measured during the second surge of the first irrigation. In addition, the following rules of thumb can be used.

First advance surge (first approach) on-time for furrows one-fourth mile long or less is one-eighth of the continuous irrigation out-time, and for furrows longer than one-fourth mile, it is one-twelveth of the continuous irrigation out-time. The advance time over previously wetted soils is two to five minutes per 100 feet of wetted furrow over bare soil and four to eight minutes when close growing crops are being irrigated. In general, the advance time is shorter for steeper slopes and low intake rate soils and longer for flat fields and higher intake rate soils. Advance time also is affected by the stream size and soil cover. The advance time is shorter for large stream sizes and longer for smaller stream sizes. The number of surges for the advance phase will be determined by the management approach used.

Example: Given a field of 1200 ft length:

From past experience with continuous furrow irrigation, it was determined that the out-time is four hours. Therefore, the dry advance rate is 240 min/12 = 20 minutes per 100 feet. Since the field has a moderate slope and a low water intake rate, it was assumed that the wet advance will be three minutes per 100 feet. Surge on-times for the advance phase using the two management approaches will be:

1. Variable time/constant distance. To advance 300 feet of dry soil, the needed on-time is 60 minutes. Therefore, the first surge on-time will be 60 minutes and the advance at the time of cut-off will be 300 feet. Assuming that after cut off water will continue to advance about 30 percent of the dry advance, total advance will be 400 feet. The on-time for the second surge will be 60 minutes plus the time needed to advance over the wet portion which is 3 x 4 = 12 minutes. On-time for the second surge is 72 minutes, and it will advance a total distance of 800 feet. On-time for the third surge will be 84 minutes [60 + (3 x 8)], and the advance will probably be completed during the third surge. Therefore, three surges will be needed to complete the advance phase, as shown in Table 1.

Table l: Advance on-times. (Variable time/constant distance)

Surge No.	1	2	3
On-time(min)	60	72	84
Total distance advanced (ft)	400	800	1200 *

*Watered out

2. Constant time/variable distance. The first surge should wet 400 feet, which is 33 percent of the furrow length. Therefore, surge on-time is 20 x 4 = 80 minutes. The total advance of the first surge will be about 530 feet if you assume that after cut off, advance will continue to about 30 percent of the length of dry advance. From the 80 minutes on-time of the second surge, 16 will be needed to advance over the previously wetted portion. Therefore the dry advance will be 320 feet and the wetted front will advance a total of 416 feet. During the second surge the total advance will then be 946 ft. The advance will then be completed in three surges, as shown in Table 2.

Table 2: Advance on-times. (Constant time/variable distance)

Surge No.	1	2	3
On-Time (min)	80	80	80
Total distance advanced (ft)	530	946	1200 *

*Watered out

Soaking Phase (Post-Advance)

Management Alternatives

When the water reaches the end of the furrow, the soaking (post-advance) phase starts. To minimize tailwater losses, some cut back methods are needed. Four management alternatives are available for the post-advance phase of surge irrigation.

1. Cut back of the on-time (continue to cycle surges). The on-time of the last advance surge is reduced to the point where the furrow infiltration absorbs most of the water with some tail water to insure soaking of the end of the furrow.

2. Further cut back of on-time. On-time is cut back until individual surges combine creating a steady flow at a reduced (cut back) rate.

3. Prolong the last advance surge. The last surge is prolonged until irrigation is completed. This takes advantage of the differences in infiltration rates between dry and previously wetted soil.

4. Stream size cut back. Using this alternative, the flow is divided between the two sets on both sides of the surge valve to create a reduced continuous cut back. This is possible provided that the surge valve has a middle position. This approach has been highly recommended by some researchers. However, other researchers did not find this approach practical in most field applications, especially when the gated pipe is laid on a cross slope.

Alternatives (1) and (2) are more common and used in most applications. Some scholars claim that using alternative (3) will result in generating more tail water than conventional irrigation. The cross slope usually is a limiting factor when considering alternative (4) because dividing the flow in half between both sides results in uneven water distribution along the gated pipe. The gates on the up-slope side of the surge valve will apply less water than those on the down-slope side of the surge valve.

Cut Back On-Time Determination

On-time for the soaking phase depends on the desired management alternative. For example, if alternative four (cut back of the stream size) is chosen then the irrigation becomes continuous on both sides of the surge valve and on-time is not a factor any longer. Actually on-time is not a factor for management alternatives three and four. For the two first management alternatives, on-time needs to be determined. Basically these two alternatives require cut back of the on-time of the last advance surge. The question is how much to reduce the on-time. A rule of thumb suggested by the Soil Conservation Service is to set the on-time to the time that it takes the water to advance 70 percent to 80 percent of the furrow length. This time initially can be estimated using the rule that concerns the advance time over previously wetted soil. For the example of the 1200-feet field, a cut back on-time that can advance 900 feet (75% of 1200 feet) is needed. Using the assumption of three minutes per 100 feet of previously wetted soil advance time, the initial cut back on-time is 3 x 9 = 27 minutes. However, it is recommended to observe first irrigations and to adjust on-times. Adjusting on-time of the cutback (soaking) phase to the basic soil intake rate is crucial to minimize tailwater or prevent under-irrigation in the lower end of the field. It is recommended to experiment with the cut back on-times. By trying different on-times, the irrigator can fine tune the cut back on-time to an optimal on-time that will minimize tailwater and still allow for enough soaking at the lower end of the field. In general, for low intake rate soils, on-times should be shorter than high intake rate soils. Reducing cut back on-time to a very short duration is not recommended because short on-times (five to 10 minutes) will cause a significant time loss on refilling the gated pipe and create small furrow stream during pipe emptying. These small streams and short durations will increase deep percolation at the upper end of the field and result in under irrigation at the lower end of the field.

Application Time (Soaking Time) Determination

Advance estimation of the required application time is not feasible or practical in most situations. If soils in the field are uniform and the infiltration characteristics are known, the following equation can be used to estimate the application time for the soaking phase:

$$Ta = \frac{Dr - k(Ton)^a}{c}$$

where, Ta = Required application time (min)
Dr = Desired application depth (in)
Ton = On-time of the last advance surge (min)
k,a,c = Parameters of the infiltration function
($Z = k\, T^a + c$)

This infiltration function is the "modified Kostiakov" in which the term "c" is the basic water intake rate. The infiltration function can be found from field tests described in SCS Irrigation Guide. There are several complicated computer simulation models that can be used to determine the application time by trial and error. One of these models was fitted for surge irrigation by the USDA Agricultural Research Service and the SCS and can be found in most SCS offices and some Colorado State University Cooperative Extension county offices. This model predicts the advance and water depth applied for a given application time, soil and field characteristics. A more advanced and comprehensive simulation model was recently released by Utah State University and is called "SIRMOD." This model is more suited for simulating surge irrigation. SIRMOD can be purchased from the Irrigation Software Engineering Division, Department of Agricultural and Irrigation Engineering, Utah State University. The most practical way to determine application time is for irrigators to use past experience to estimate application time and to monitor the soil water content to determine when irrigation is complete. A good way to monitor the depth of water infiltration and water content is by using the soil probe with the feel method. An explanation of how to use a soil probe with the feel method can be found in Service in Action sheet 4.700, Estimating soil moisture for irrigation.

When and How Much to Irrigate

Deciding when to irrigate and how much water to apply is part of irrigation water management and is done in the same manner for all types of irrigation systems. Even if the application time is known, irrigation should be monitored to determine whether the desired depth was applied across the field. Soil variability and low water distribution uniformities make it even more complex to determine whether the desired depth of application was achieved.

Under surface irrigation systems, the decision of when irrigation is complete is more complicated because application time can only be estimated and distribution uniformities can be inherently low. Therefore, monitoring surface irrigation, including surge irrigation, is crucial. If surge irrigation is managed properly, then higher distribution uniformities can be expected, which can relax the need for monitoring. However, until enough experience is gained, the irrigator is encouraged to observe and monitor surge irrigation even more than continuous irrigation. A detailed discussion of when to irrigate, how much and when an irrigation is complete can be found in "Scheduling Irrigation: A Guide for Improved Water Management Through Proper Timing and Amount of Water Application." This guide is available at all Colorado Cooperative Extension county offices and Soil Conservation Service offices.

Implementation

Automatic surge valves are manufactured today by two large companies. A typical valve has a controller powered by a battery charged with a solar panel. Consequently no power source is required in the field. The valve usually is located in the middle of two sets of gated pipes as shown in Figure 2.

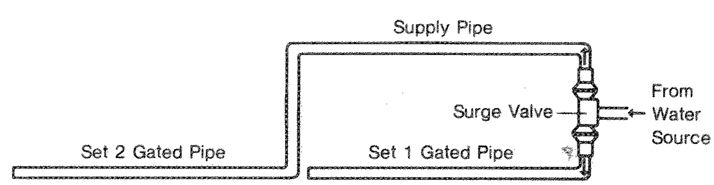
In a typical installation, the result is that the gated pipe on one side of the valve is on a down slope while the gated pipe on the opposite side is on an up slope. This situation does not pose a problem where the water source has enough pressure or there is a sufficient elevation difference to maintain uniform stream sizes on both sides of the surge valve. Sediment accumulation in the gated pipe on the up-slope side might cause a problem because water velocity is slower. When one set of gated pipes is on an up slope you should not use the post-advance management alternative that divides the flow between the two sets.(By cutting the flow in half, the last gates on the up-slope side might not get enough flow and, consequently, the distribution uniformity will decrease.) If collapsible tubes are used as the gated pipe then both sides need to be on a down slope. It is not necessary to locate the surge valve in the middle of the two sets. The valve can be located at the upper end of the field and a delivery pipe can be used to supply the lower set of gated pipes as shown in Figure 3. This configuration will allow both sets of gated pipes to be on a down slope.

Most of the controllers manufactured are capable of automatically performing several programs. Two basic options are available in most of the surge controllers. The first option is a manual control and the user can enter a sequence of surge cycles to be performed by the valve. The second option is referred to as the auto mode and it requires only one input, such as out-time of continuous flow irrigation or the length and slope of the field. The sequence of surges, advance on-time and cut-back on-time are determined by the controller. The auto mode makes the controller very easy to operate, but reduces the fitness of the surge sequence to the particular field conditions. By observing irrigations, one can find an optimal surge on-times sequence that completes the advance fast and minimizes tail water, and programs it in the controller using the manual mode. Programming these controllers is very simple and can be learned in a short time.

In-Line Surge Valve

An in-line surge valve was recently developed in Grand Junction, Colorado. This valve operates as a gate valve in the pipeline. Thus the valve is part of the pipeline. An elevation drop is needed in order for the in-line surge valve to operate. Hydraulically, the in-line surge valve operates as the surge gate depicted in Figure 4. When the in-line valve is closed, the gated pipe on the upstream side of the valve is irrigating. When the in-line surge valve is open, the water level in the gated pipie on the upstream side drops below the level of the gates. Thus, water doesn't flow through the open gates (Figure 4).

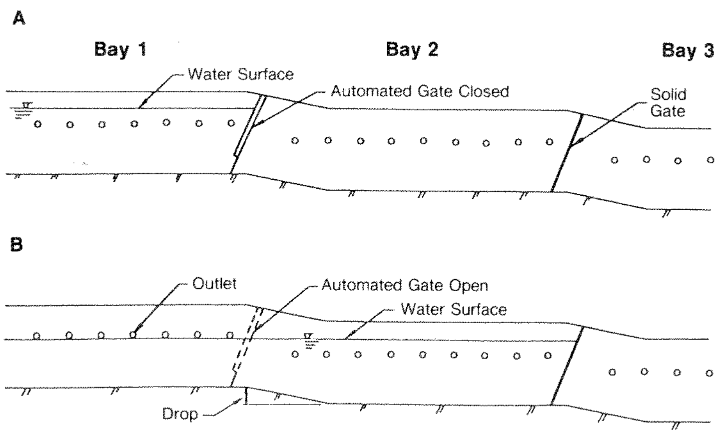
Figure 3: Locating the surge valve at the upper end of the field.



Ditch Implementation

Surge irrigation can be implemented in concrete ditches. Figure 4 shows the required layout of the concrete ditch. A surge gate that replaces the drop gate is needed for this type of installation. To control the gate, the same controller that is used for the surge valves can be used. Surge irrigation also can be implemented in graded concrete ditches by cutting out notches at different depths on each side of the surge gate. Implementation of surge irrigation in concrete ditches is being done in the Grand Valley area in Colorado.

Figure 4: Schematic diagram of applying surge in ported ditches.



Evaluation

What is Furrow Irrigation Evaluation?

Evaluation of furrow irrigation is the determination of how much water has been applied and where it has been applied. The performance of furrow irrigation is evaluated by estimating the following parameters.

Application Efficiency: the ratio between water stored in the root zone and total water applied. High application efficiencies mean less deep percolation and less tailwater.

Distribution Uniformity: describes water distribution along the individual furrows and in between the furrows. High values of distribution uniformity mean that different sections of the field received similar application depths.

Since furrow irrigation uses the soil as the water distribution system, application depths in different field sections depend on soil characteristics and are affected by soil variability. Therefore, it is important to evaluate the actual application depth in furrow irrigation. Evaluation of surge irrigation to determine the application depth and water distribution uniformity is more crucial since another parameter, the surge effect, is introduced.

Furrow irrigation evaluations, including surge, are composed of water inflow and outflow measurements and recording of advance and recession times along the furrow. Estimation of water intake rate by the soil can be done from advance data or by measuring furrow flows with flumes.

Recording Data in the Field

1. Water flow measurement. Outflows from the field usually are measured with a flume installed in the tailwater ditch. The water delivery system will determine whether inflows can be estimated or measured. If a water meter is available, it can be installed between the water outlet and the gated pipe. Where a well is used, you can estimate water inflows if you know the well discharge. In addition, to estimate inflows multiply the number of open gates by the average stream size. Use a bucket and a stop watch to estimate average stream size.

2. Advance and recession time. Stations should be marked with flags along the furrow length. For a detailed evaluation, the stations should be installed every 100 feet. However, the SCS Surge Flow Irrigation Field Guide recommends four stations spaced equally. Water advance and recession times at each station should be recorded on the field data sheets.

3. Soil water intake characteristics. A cumulative water intake **versus** time can be developed by using furrow flumes.

The SCS guide suggests a procedure based on measuring advance time to 100-foot stations. This procedure does not require the use of furrow flumes.

Tables to record information collected during an evaluation of irrigation in the field are provided at the end of this section. The tables have been designed to collect information needed for two evaluation procedures discussed in the next section and to help the irrigator make management decisions.

Evaluation Procedures

1. United States Department of Agriculture-Soil Conservation Service "Surge Flow Irrigation Field Guide." This procedure uses opportunity times from advance and recession curves with the soil water intake curve to obtain total water intake at each furrow station. There are four methods to develop soil water intake curves. One of the methods is based on advance data and does not require any flume measurements. The drawback of this procedure is that it is actually a modified evaluation procedure for continuous furrow irrigation and requires tedious calculations. The advantage of this procedure is that it is simple enough to be performed by a trained technician and does not require any computer modeling.

2. Colorado State University "Evaluation Procedures for Surge Irrigation." This procedure was developed especially for surge irrigation. A simulation of the irrigation event was obtained through the use of a kinematic wave model. The procedure was developed based on field experiments conducted in eastern Colorado during one growing season. The field data sheets can be used for data collection for the evaluation. Additional data are needed for the first advance surge, which is the distance advanced at half of the on-time. The evaluation is performed using a computer program called "EVALUATE" available from the Department of Agricultural and Chemical Engineering, Colorado State University.

Monitoring an Irrigation

A detailed furrow irrigation evaluation consumes time and labor. Surge irrigation evaluation is an even more tedious task. If a complete evaluation cannot be done, the irrigator is encouraged to monitor an irrigation and record as much data as possible. These data can be used for management decisions for the next irrigation. The use of a soil probe that can sample different sections of the field is a practical and recommended method to monitor irrigation. Through the use of the soil probe an irrigator can obtain information on water distribution and penetration depth along the furrow. A probe will give a quick indication whether or not distribution uniformity in the field is increased by the use of surge irrigation and whether the desired application depth has been achieved.

References

Izuno, F. T. 1984. Surge Irrigation: Characterization of Advance, Infiltration and Performance for Irrigation Management. Ph.D. Dissertation, Colorado State University. 279 pp.

Izuno, Forrest T.; Podmore, Terence H. 1986. Surge irrigation management. Agricultural Water Management. 11:279-291.

McCornick, P. G.; Podmore T.H.; and Duke, H.R. 1988. Field evaluation procedure for surge irrigation. Transaction of the ASAE 31.(1):168-176.

McCornick, P. G. 1987. Guidelines for the management and implementation of surge irrigation. Colorado State University Research Station Report.

Podmore, T. H.; Duke, H.R. 1982. Field evaluation of surge irrigation. ASAE Paper No. 82-2102. Presented at the 1982 Summer Meeting, Madison, Wisconsin. 15 pp.

Podmore, T. H.; Duke, H.R.; and Izuno, F.T. 1983. Implementation of surge irrigation. ASAE Paper No. 83-2018. Presented at the 1983 summer meeting, Bozeman, Montana. 20 pp.

Stringham, G. E.; Keller, J. 1979. Surge flow for automatic irrigation. Proc. 1979 Irrigation and Drainage Specialty Conference, ASCE, Albuquerque, New Mexico. 10 pp.

Sweeten, J. M.; Jordan, W.R. 1987. Irrigation water management for the Texas High Plains: a research summary. Texas Water Resources Institute, Texas A and M University. 339 pp.

Testezlaf, R.; Garton, J.E.; Cudrak A.J.; and Elliott R.L. 1985. An open-ditch surge flow furrow irrigation system. ASAE Paper No. 85-2069. Presented at the 1985 summer meeting, East Lansing, Michigan.

United States Department of Agriculture, Soil Conservation Service. 1986. Surge Flow Irrigation Field Guide. 32 pp.

United States Department of Agricultural, Soil Conservation Service. 1987. Ed. H. Duke. Scheduling irrigations: a guide for improved irrigation water management through proper timing and amount of water application. 85 pp.

Walker, W. R.; Skogerboe, G.V. 1984. The Theory and Practice of Surface Irrigation. Utah State University. 220 pp.

SURGE IRRIGATION FIELD DATA

Farm ______________________________ Crop ______________________________

Location ____________________ Observer ____________________ Date ____________________

Irrigation No. ______________ Crop Stage ______________________________

Furrow: Spacing ______________ ft. Length ______________ ft. Slope ______________ %

No. of Furrows per Side ______________________ Furrow Inflow Stream ______________________ gpm

Watermeter Reading*: Start ______________ cf End ______________ cf

Total Inflow ______________ cf

Total Outflow ______________ cf

	ADVANCE PHASE DATA					
SURGE NO.	1	2	3	4	5	6
On time (min.)						
Time taken to advance over wet portion (min.)						
Total distance advanced (feet)						
Advanced distance at completion of on-time						

* If applicable; if not available, estimate inflows.

SURGE IRRIGATION FIELD DATA

Time of Day Irrigation Started: ______________________________

STATION	DISTANCE	SURGE	ADVANCE*					CUTBACK*				
number	feet	number	1	2	3	4	5	6	7	8	9	10
1		adv.										
		rec.										
2		adv.										
		rec.										
3		adv.										
		rec.										
4		adv.										
		rec.										
5		adv.										
		rec.										
6		adv.										
		rec.										
7		adv.										
		rec.										
8		adv.										
		rec.										

* Time of day water advanced or receded at each station