IRRIGATION MANAGEMENT
SERIES

Surge Irrigation

Danny H. Rogers
Extension Agricultural Engineer

William M. Sothers
Extension Assistant

Cooperative Extension Service
Manhattan, Kansas

About one-half of all irrigated acres in Kansas are irrigated using surface irrigation. Many surface irrigation systems are designed and/or managed in such a manner that irrigation efficiency is low. Some of the problems associated with furrow irrigation methods are: 1) loss of water to runoff and deep percolation, 2) low uniformity of water application, and 3) high labor and management requirements. Irrigators must fit irrigation practices into busy schedules, resulting in irrigation changes being made at convenient time intervals and not when changes would need to be made for high efficiency.

The current trend is to replace surface irrigation systems with center pivot systems. Although this generally improves efficiency and reduces the amount of labor associated with irrigation, it also requires a large initial expense for equipment and installation.

An intermediate option that can be considered is the use of surge valves. Surge valves can increase the overall efficiency of surface irrigation by increasing application uniformity and decreasing runoff and deep percolation. The surge valve controller can also reduce the amount of labor associated with set changes. Surge valves can be used with existing gated pipe systems, sometimes with little additional investment, but certainly much less initial expense than converting to a sprinkler irrigation system.

Table 1 presents irrigation terminology that is used in the following discussions.

## INTRODUCTION TO SURGE IRRIGATION

Surge irrigation is the intermittent application of water to a furrow. This intermittent application of water is accomplished by alternating the application between two irrigation sets through the use of an automated valve. During continuous furrow irrigation, as soon as water is applied to the furrow, it begins to infiltrate downward and laterally throughout the root zone of the crop. Initially the advance rate is fast, but as the water advances down the furrow the advance rate slows. Water infiltration can be much greater at the top end of the field than the bottom because of the longer opportunity time at the top end. This results in water being lost to deep percolation at the upper end of the furrow.

When surge irrigation is used, the furrow is allowed to partially dry between water applications. Normally, when soil is wetted, the initial intake rate is high. As the application of water is continued, the intake rate decreases until it eventually becomes constant dependant on soil texture (See Extension Bulletin L-904, "Soil, Water and Plant Relationships", for additional details). While the furrow is drying between surge applications, the surface soil particles consolidate and a seal is formed in the furrow. When water is reintroduced to the furrow, the intake rate is lower and the water advances through the wet part of the row faster. The difference in intake rates between continuous and surge

Table 1. Terminology used in furrow and surge irrigation.

Infiltration Rate—	The rate at which a particular soil type will soak up available water. Different soil types have different rates.
Phases of Furrow Irrigation	
Advance Phase—	The phase in which the dry furrow is wetted.
Out Time—	The time required for water to reach the end of the furrow.
Soaking Phase—	The phase in which the required application depth is infiltrated.
Soaking Time—	The time it takes the required application depth to infiltrate.
Recession Phase—	The phase that starts when application of water to the furrow is stopped, and ends when water disappears from the soils surface.
Opportunity Time—	The total time that water is present at each point in the furrow. The goal is to have equal opportunity time at each point in the row.
Surge Terminology	
On-Time—	The time water is applied to one side of the surge valve before it is switched to the other side.
Off-Time—	The time water is not applied to one side of the surge valve. Usually the same as on-time.
Cycle-Time—	The time required to complete on 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.

Figure 1. Comparison of infiltration rates for surge and continuous irrigation.


TIME (hours)
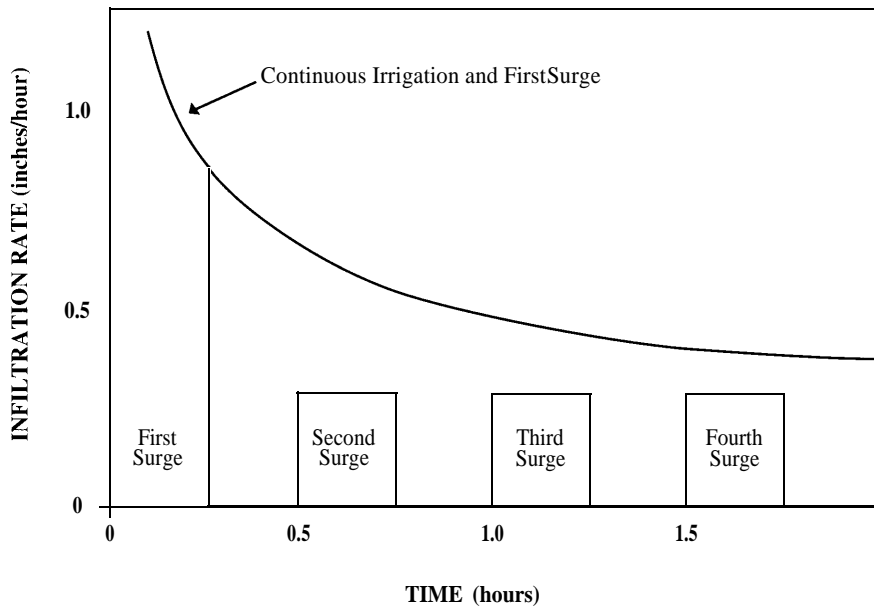
irrigation is illustrated in Figure 1. The formation of a seal reduces the amount of water that infiltrates into the soil in the upper part of the furrow, providing a more uniform application of water (Figure 2).

Another advantage that surge irrigation has over continuous flow irrigation is that it can reduce the amount of runoff by automatically cutting back the stream size once the water has reached the end of the furrow. In continuous flow irrigation, stream sizes are large to push water through the furrow as fast as possible to even out the time that water is present at both ends of the set. This results in a more uniform application. Excessive runoff will

occur if this large stream size is continued after water has reached the end of the furrow. Runoff can be reduced by reducing or cutting back the stream size when water reaches the end of the furrow. If no one is present to make these changes at the out-time, continuous flow irrigation will produce excessive runoff, which greatly lowers irrigation efficiency. When using surge irrigation, the controller can be programmed to automatically reduce the stream size when the out-time has been reached usually by rapidly cycling the water between the two sets. The rapid cycle length is selected so water never drains from the furrow until the irrigation is complete. (Figure 3).

Figure 2. Comparison of water infiltrated and distribution of surge and continuous irrigation.

DISTANCE DOWN FURROW
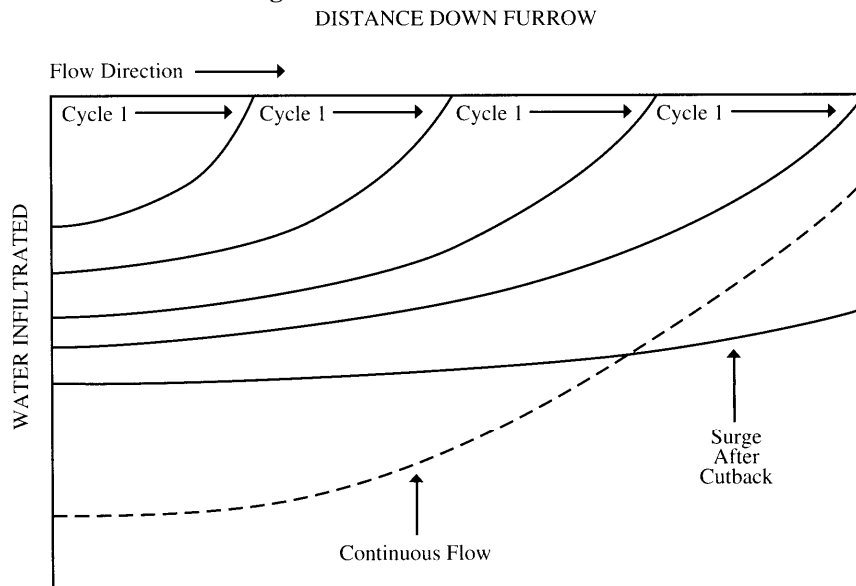
Surge irrigation may not be effective in all situations. The University of Nebraska evaluated surge irrigation in a series of trials on a variety of soils and field conditions (NebFacts 94-177). Surge irrigation was never less effective than continuous flow irrigation when compared in terms of advance time reductions. The average reduction in the time required to advance water to the downstream end of the field using surge irrigation compared to continuous flow was approximately 17 percent with a range of 0 to 52 percent. In almost half of the trials, no difference between surge and continuous flow advance time was detected. Most of the tests were conducted during the first irrigation, where the average advance time reduction was approximately 18 percent. Four tests were conducted during the second irrigation and two of those resulted in a significant decrease in advance time using surge irrigation. Only one in four tests on hard (wheel traffic) furrows resulted in a reduced advance time. The advance time for surge irrigation may not be an improvement on soils that initially have low intake rates, and on fields with relatively large slopes. Soils that crack when dry also are less likely to produce a favorable response to surge irrigation. It is up to the irrigator to evaluate the system and determine whether surge provides any benefit. Even though advance time may not be improved, the benefits of reduced runoff and reduced labor may still prove surge irrigation to be worthwhile.
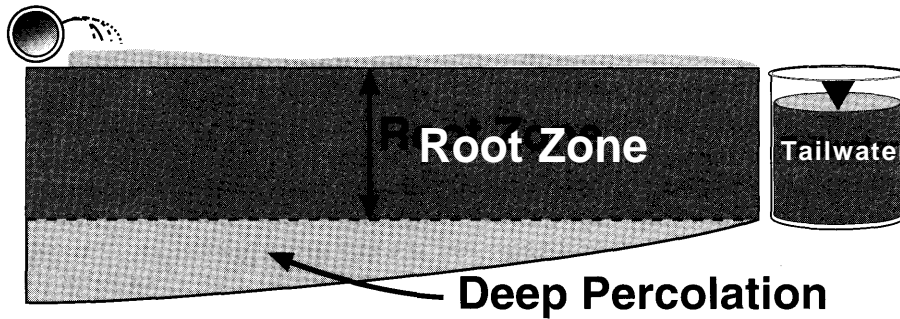
APPLICATION OF SURGE IRRIGATION

Several factors need to be determined when implementing surge irrigation. These factors include positioning of the surge valve, determining furrow stream size, determining number of surge cycles, and determining surge on-times.

POSITIONING OF SURGE VALVE

The positioning of the surge valve will largely be determined by pre-existing field properties. Figures 4–8 show positioning of the valve for different field characteristics. An ideal situation would be when the water supply, or irrigation well, is located near the middle of the pipe line (Figure 4).

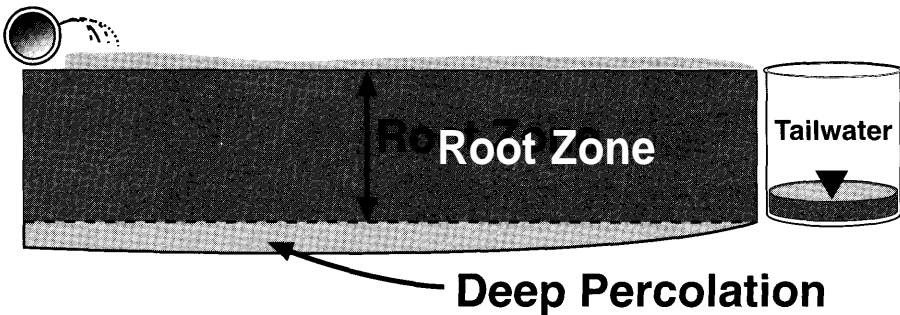**Figure 3. Comparison of Continuous and Surge Irrigation Losses.**

Continuous Large Furrow Stream

Root Zone

Tailwater

Deep Percolation

Continuous Small Furrow Stream

Root Zone

Tailwater

Deep Percolation
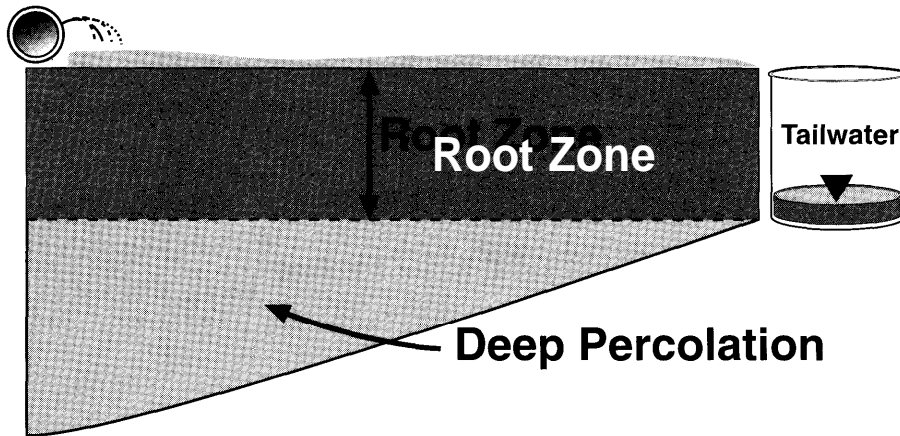
Surge: Large Initial, Small Cutback Furrow Stream

Root Zone

Tailwater

Deep Percolation

In this case, the valve is located with equal land area on each side of the valve. However, most situations require the water to be brought to the proper location using mainline pipe (Figure 5). An alternative to locating the valve in the middle of the pipeline would be to place the valve at the water source. This still requires extra mainline pipe (Figure 6). For irregular shaped fields, there are two methods of placing the valve. The first method is to place the valve so that there are an equal amount of acres on each side of

the valve. With this option the cycle times are the same for each side of the valve, but the number of rows irrigated for each set is indirectly proportional to the furrow length of that set. For example, if the furrow length is 500 feet on the left set, and 1000 feet on the right set, there would be one-half as many furrows irrigated per set on the right side (Figure 7). The second method is to place the valve in the middle of the pipeline and have different cycle times for each side of the valve. The goal for this method is to

apply the same amount of water to each set (Figure 8).

DETERMINING STREAM SIZE

The stream size for the advance phase of surge irrigation should be the maximum non-erosive stream size to advance the water through the row as quickly as possible.

The Soil Conservation Service (SCS) Surge Flow Irrigation Field Guide suggests the stream size can be estimated by:

$$Q(gpm) = L(feet) \times 0.02$$

where Q = Stream size in gallons per minute

L = Furrow length in feet

However, the upper limit for a non-erosive stream size under the best slopes and soil types is around 40 gpm. The minimum stream size probably would not be less than what the irrigator currently uses for a continuous flow irrigation, and more likely higher, if possible. Another equation suggested for surge irrigation stream size determination is for the cut-back stream size. This is the stream size used after water has been advanced through the row, and the soaking phase has begun. This stream size will advance water to the end of the field while reducing runoff. This equation requires the basic intake rate of the soil be known. Intake rates for soils are available in the county soil survey and the SCS Irrigation Guide. If the intake rate is known, the cut-back stream size can be determined by:

$$Q = \frac{C \times L \times B}{96.25}$$

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 the advance phase of surge irrigation can then be taken as twice the cut-back stream size.

DETERMINING NUMBER OF SURGE CYCLES

The number of surge cycles required to advance water to the end of the furrow is determined by the furrow length. For furrows one/fourth of a mile (1,320 feet) long or less, the number of cycles required is usually 3 or 4.
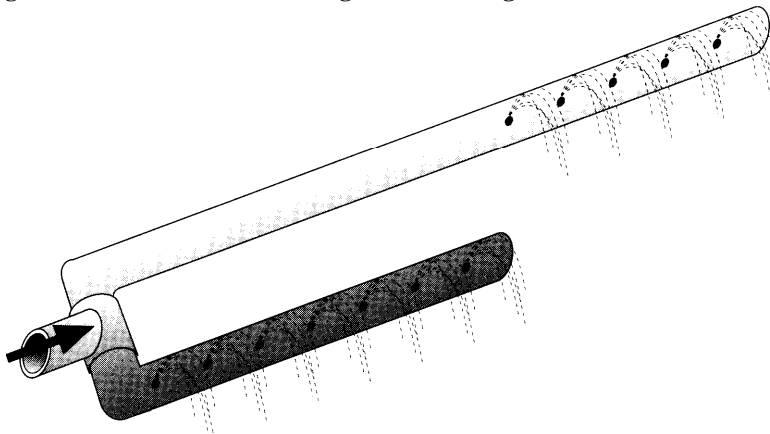
Figure 4. Water Source and Surge Valve in Middle of Pipeline.
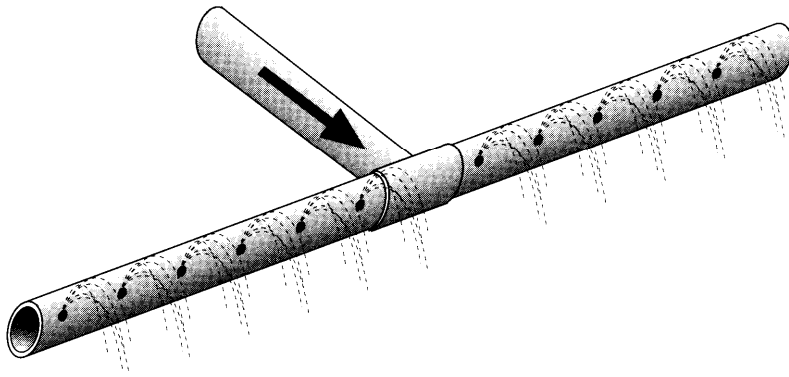
Figure 5. Water Source at Edge of Field, Surge Valve in Middle of Pipeline.
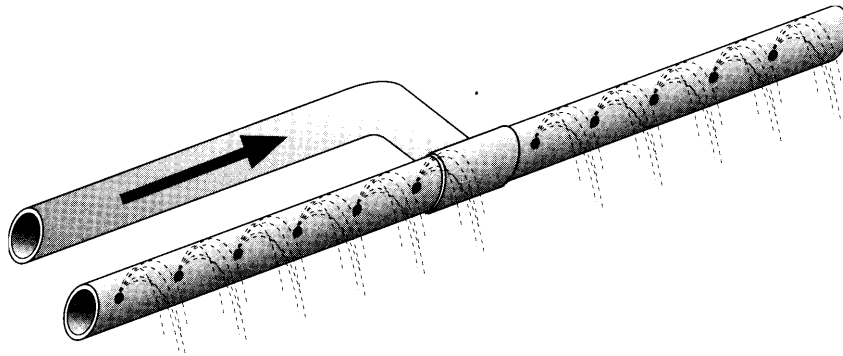
Figure 6. Water Source and Surge Valve at Edge of Field.

For furrows over one/fourth of a mile long, the number of cycles is between 4 and 6. The exact number of cycles required for a particular field is determined by watching the irrigation of the first set and making necessary changes to correctly irrigate the following sets. Additional surge cycles will be required during the soaking phase.

DETERMINING SURGE ADVANCE PHASE ON-TIMES

The determination of the on-time for surge irrigation is mostly a "rule of thumb" process. Most of the controllers available with surge valves come with at least two basic programming options. The first option is to manually program the controller for each surge on-time. The second option is an automatic option. The automatic option asks for only one input, such as out time, and automatically determines surge on-times. The automatic option is a good starting point for surge irrigation, but the best results are achieved by watching the surge process and using the manual programming option to set up each individual field. There are two methods for determining surge on-times for the advance phase of the irrigation.

Variable On-Time/Constant Advance. The first method is to vary the surge on-times so that a constant advance is achieved for each surge. For this method, the first surge on-time is set to the time required for water to advance 1/n x 100 percent (where n is the number of advance surges being used) of the furrow length. The subsequent surge on-times will be equal to the amount of time it takes for water to advance over the previously wetted portion of the furrow plus the amount of time required for the water to advance another 1/n x 100 percent of the furrow length. During the advance phase, the off time must be long enough to allow the water in the furrow to completely soak in.

For example, if four (n=4) surge cycles are used to advance the irrigation water across the field, then the cycle time should be selected so the first cycle advances the water 25 percent of the furrow length and each subsequent cycle advances an additional 25 percent. The irrigator can determine the required times by observation of the first irrigation set. Surge irrigation research at the University of Nebraska provides an estimate of on-time for surge irrigation, shown in Table 2. The advance time for the first surge still must be determined, then the on-time ratios from Table 2 could be used to determine the on-times for the remaining surges. An example is shown in Table 2.

**Table 2. On-Time Ratios for Surge Irrigation**

Cycle Number	On-Time Ratio
1	1.00
2	1.97
3	2.64
4	3.20
5	3.70
6	4.15

Example: Calculate the on-times for four surges if the on-time required to advance the water one-quarter of the field length is 20 minutes.

Cycle Number	On-Time (minutes)
1	20
2	20 x 1.97 = 39
3	20 x 2.64 = 53
4	20 x 3.20 = 64

Source: Yonts, C.D. and D.E. Eisenhauer. 1991. "Impact of surge irrigation on furrow water advance." American Society of Agricultural Engineers Paper 912125.

Figure 7. Irregular Shaped Field, Surge Valve in Pipeline so Equal Area on Each Side Using Different Stream Sizes for Each Side.
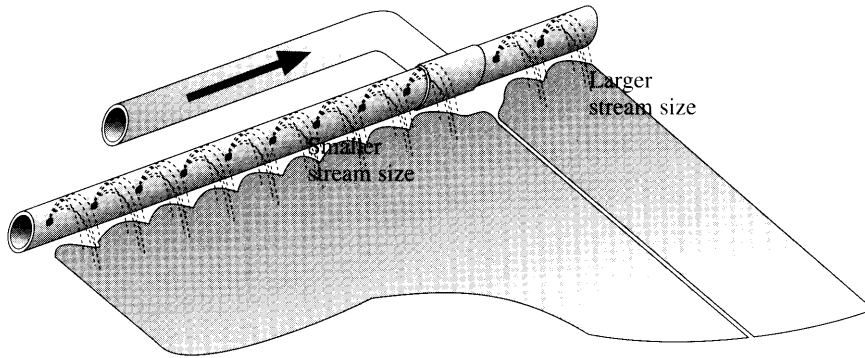
Figure 8. Irregular Shaped Field, Surge Valve in Middle of Pipeline Using Different Cycle Times for Each Side.
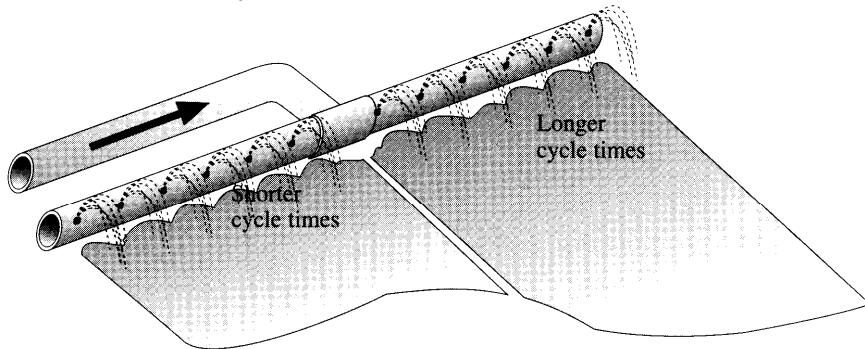
Whether using the pre-programmed on-times or those determined using Table 2, water advance should be monitored in the field to adjust to specific field conditions. The field conditions also change between irrigations, especially between previously undisturbed furrows and previously watered furrows.

Constant On-Time/Variable Advance. The second method uses a constant on-time for each surge, advancing the water over less distance for each surge. For this method, the on-time is set so that the initial advance is approximately 35 to 45 percent of the total furrow length. Each subsequent advance should be 75 percent of the previous surge's advance. Today's valves allow for variable on-time programming which is the preferred method.

SURGE SOAKING PHASE ON-TIME DETERMINATION

Once the water has reached the end of the furrow, the surge on-time is reduced (cut-back) to reduce the amount of runoff. A rule of thumb suggested by the SCS is to set the soaking phase on-time to the time that it takes water to advance approximately 75 percent of the furrow. It is important to monitor first irrigation sets during the soaking phase so that adjustments can be made to the on-times. The objective is to minimize the amount of tailwater while still allowing enough soaking at the lower end of the field. On-times that are too long will result in excessive runoff, and on-times that are too short will result in excessive water on the upper end of the furrow while the lower end of the furrow does not receive enough. Once the best soaking phase on-time has been achieved, the surges should be continued until the desired application depth is achieved. A soil probe or soil water blocks can be used to determine when the application depth has been reached.

USING SURGE IRRIGATION'S BENEFITS

If surge irrigation does result in improved advance times on a field, the irrigator would then be able to take advantage of surge by being able to apply smaller application amounts uniformly. The following comparison of continuous and surge irrigation will illustrate this benefit.

Continuous irrigation system: Continuous irrigation of 100 acres at 750 gpm and 51 30-inch (2.5 feet) rows per set. The length of the rows are ¼ of a mile (1320 feet). The sets run for 12 hours.

The applied application depth for these conditions would be 5.18 inches and take 13 days to complete one irrigation cycle. The calculation of the application depth and irrigation cycle is shown in figure 9.

The 12 hour per set interval meets the irrigator's need to reasonable and regular set times, the application amount is very large and, even if applied uniformly, would likely be low irrigation efficiency due to deep percolation. The irrigation cycle also takes 13 days which would likely result in stress in the last part of field receiving maturity. Since the application amount is large, the irrigator may wish to adjust the number of rows watered for each cycle of the surge system to reduce the total application amount.

Surge irrigation system: Using the same field and flow characteristics from above, but this time using surge to water 70 rows (35 rows on each surge cycle), in 12 hours (6 hours per surge cycle).

The applied application depth for these conditions would be 3.78 inches and take 9.5 days to complete one irrigation cycle. The calculation of the irrigation depth and irrigation cycle is shown in figure 10.

The surge irrigation system reduces the gross application amount and would most likely better match soil water capacity and maintain better soil water levels due to a more frequent irrigation.

In order to obtain an improvement from surge irrigation, it will most likely be necessary to either adjust the number of rows being irrigation in a given set or change the set time.

DETERMINING IF SURGE IRRIGATION WILL WORK FOR YOU

When trying to determine whether or not surge irrigation will improve your irrigation efficiency, it may be a good

idea to conduct your own test, especially if you have a field you can conveniently visit multiple times during an irrigation set. Manually surge several rows of a set next to continuously running rows. Compare the amount of time that each method requires to reach the end of the field. If the time for the manually surged rows is significantly lower than the continuous rows, then surge irrigation will probably improve irrigation efficiency.

When using a new irrigation method for the first time it is important to monitor the application. It is useful to know such things as depth of infiltration, amount of water used to achieve correct application depth, etc.

A useful tool used in monitoring applications is the soil probe. By taking soil samples, it can be determined whether or not a more uniform application is being achieved by using surge irrigation. This is done by comparing soil samples of the upper end of a furrow to soil samples of the lower end. It is also a good idea to compare samples of different sets.

Surge irrigation will not always reduce advance times. Advance times over fields that already have low intake rates or relatively high slopes will probably not decrease with the use of surge irrigation.

Keep in mind, even if surge irrigation does not reduce advance time, it will help reduce labor by decreasing the number of set changes by half, and also will reduce the amount of water lost to runoff by implementing an automatic cutback cycle.

Figure 9: Calculation of irrigation rate, set size, application amount, and interval for continuous flow irrigation example

$$\text{Application Rate} = \frac{750 \text{ gpm}}{450 \frac{\text{gpm}}{\text{acre-inch/hr}}} = 1.67 \ \frac{\text{acre-inch}}{\text{hour}}$$

$$\text{Acres per Set} = \frac{2.5 \text{ ft/row x } 51 \text{ rows x } 1320 \text{ ft}}{43560 \text{ ft}^2/\text{acre}} = 3.86 \text{ acres}$$

$$\text{Gross Application Amount} = \frac{12 \text{ hours/set x } 1.67 \text{ acre-inch/hour}}{3,86 \text{ acres/set}} = 5.19 \text{ inches}$$

$$\text{Irrigation Interval} = \frac{100 \text{ acres}}{3.86 \text{ acres/set}} = 25.9 \text{ sets or } 13 \text{ days}$$

Figure 10: Calculation of irrigation rate, set size, application amount and interval for surge flow irrigation example.

$$\text{Application Rate} = 1.67 \text{ acre-inch/hour (as before)}$$

$$\text{Acres per Set (2 surge cycles)} = \frac{2.5 \text{ ft/row x } 70 \text{ rows x } 1320 \text{ ft}}{43560 \text{ ft}^2/\text{acre}} = 5.30 \text{ acres}$$

$$\text{Gross Application Amount} = \frac{12 \text{ hours/set x } 1.67 \text{ acre-inch/hour}}{5.30 \text{ acres/set}} = 3.78 \text{ inches}$$

$$\text{Irrigation Interval} = \frac{100 \text{ acres}}{5.30 \text{ acres/set}} = 18.9 \text{ sets or } 9.5 \text{ days}$$

COOPERATIVE EXTENSION SERVICE, MANHATTAN, KANSAS

L-912　　　　　　　　　　　　　　　　　　　　　　　　　　July 1995

File: Engineering 4-3 Irrigation