# Surge Irrigation : 2. Management*

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**Abstract** : General management guidelines for using surge irrigation to improve irrigation efficiency are summarized. Furrow irrigation is managed to complete the advance phase with a minimum volume of water using non-erosive streams. The post-advance phase is managed to prevent excessive runoff and to satisfy irrigation requirements of the root zone. Three methods of managing the post-advance phase are discussed. Improving irrigation efficiency with surge irrigation can, in some areas, help control vector-born diseases by reducing pools, puddles, seepage areas, and the use of low-velocity unlined ditches with their associated aquatic vegetation.

**Résumé** : Diverses techniques visant à améliorer l'efficacité de l'irrigation par intermittence sont discutées. L'irrigation par rigoles se fait de façon à ce que la phase d'avancement soit complétée tout en minimisant l'érosion et le volume d'eau utilisé. La phase post-avancement est exécutée de manière à minimiser le ruissellement excessif et à satisfaire aux besoins en eau de la zone des racines. Trois méthodes d'implantation de la phase post-avancement sont discutées. L'environnement résultant d'une telle amélioration de l'efficacité d'irrigation (réduction du nombre de surfaces et de flaques d'eau et de zones de suintement) aide à prévenir la propagation de maladies. Un autre avantage de cette méthode est l'utilisation de rigoles non revêtuesî favorisant ainsi la présence d'une végétation aquatique.

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* **Irrigation par intermittence : II. Gestion**

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Manuscript received 20 November 1989

## Introduction

Surge irrigation has the potential to significantly improve irrigation application uniformity and efficiencies and provide greater versatility for the irrigator compared to using continuous streams. However, it requires a higher level of management than a continuous-flow system. This paper summarizes general management guidelines for using surge irrigation in furrows to improve irrigation efficiency. This is the second of two papers. The first (Humpherys, 1989) presented an overview of surge irrigation including principles and theory, surge models, systems and equipment, and field experience.

## Management Guidelines

The ultimate irrigation management goal is to achieve high application efficiencies by minimizing deep percolation and tailwater losses while satisfying water storage requirements of the root zone. Surge irrigation can help accomplish this by advancing water to the ends of furrows in the shortest time possible, without excessive erosion, and by providing a means for post-advance management to minimize runoff. Because several management parameters must be considered, many management options or alternatives are possible. Using a kinematic wave model, Alemi and Goldhamer (1988) developed a mathematical optimization procedure to determine the optimum combination of parameters which would result in the maximum application efficiency for various irrigation strategies. With this technique, they investigated five surge management approaches to maximize efficiency for two soils, Oxalis silty clay and Flowell sandy loam. They concluded that for a given irrigation strategy, the optimum number of surges, inflow rates, and on-times varies depending upon field conditions and irrigation requirements. For the conditions and approaches studied, surge followed by continuous cutback streams gave the highest maximized irrigation efficiency.

Surge management is considered in two parts : the advance phase of irrigation and the post-advance or cutback phase. Management of the advance phase is usually more critical with coarse-textured and high intake rate soils where rapid advance is important, while management of the post-advance phase is usually more critical with fine-textured and low intake rate soils where runoff is important.

### Advance phase

The irrigation advance phase should be managed to complete advance in the shortest time possible with a minimum volume of water using non-erosive streams. The parameters to be chosen are : the maximum non-erosive stream size, surge cycle on and off-times, and number of cycles.

**Streamsize.** Since surge irrigation will generally be used on currently irrigated lands, the trial stream size can be that normally used for continuous flow. Furrow irrigation guidelines used for continuous flow can be used to establish maximum non-erosive stream sizes length of run, and cross slope for surging (Jensen, 1981;USDA - SCS, 1983). The non-erosive stream size for non-wheel track furrows should be selected as a starting point; the inflow rate into wheel-packed furrows can be reduced to achieve uniform stream advance. The USDA Soil Conservation Service (SCS) (1986) has also developed guidelines for surge irrigation system design and management.

The maximum non-erosive stream size may not always provide the best cutback stream size since the most feasible cutback stream for the post-advance phase is half the advance stream size, as discussed later. Therefore, a different criteria can be used to determine the advance stream size if the basic infiltration rate of the soil is known. The continuous cutback stream necessary to maintain flow to the end of the field during the post-advance phase with only a small amount of runoff can be calculated from the infiltration rate. Since the continuous cutback stream size is half the advance stream, the advance stream size is double the calculated cutback stream size. This approach (Izuno and Podmore, 1986) can be used for surge irrigation because the initial infiltration rate is reduced by surging to a value near the soils's basic intake rate. Thus, during the post-advance or cutback phase, water infiltrates at or near the basic intake rate throughout the furrow length. Therefore, the optimum cutback stream size can be determined by :

$$q = \frac{1000\ CLW}{60} \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \qquad (1)$$

where

q = cutback furrow stream size in liters per minute, L/m.

C = basic infiltration rate, mm/hr.

L = furrow length, m.

W = furrow spacing, m.

This method may be particularly useful for fine-textured or consolidated soils with low infiltration rates or for short fields which would normally produce considerable runoff. For these conditions, controlling runoff may be more important than rapid advance, and the advance stream size is chosen with the objective of using surge and the equipment available to control runoff. Stream sizes calculated by this method still must not exceed the maximum non-erosive stream size for the furrow.

**Cycle on-times.** Most commercial surge controllers contain internal algorithms which require only the "out-time" as an input parameter from which the controller provides suggested cycle on-times and number of cycles to complete advance. The "out-time" is the time required for water to advance to the end of the field with continuous streams and is determined from past experience. The out-time is the basic criterion used because it integrates many field factors into one number and is usually known. Most controllers allow times to be adjusted for local conditions. If a data base is available for local conditions, kinematic wave computer models can be used to simulate advance, recession, runoff, etc., for various on-times and stream sizes.

In the absence of either commercial controllers or models, a field trial can be used to determine management parameters. Since most surge systems use the split-set configuration (Humpherys, 1978) with two equal blocks of furrows, the on-time equals the off-time and the cycle ratio is 0.5. The on-times should progressively increase for each subsequent surge advance. The first surge should be as short as feasible to achieve a reduced infiltration rate as soon as possible and thereby reduce water intake at the head of the furrow. The initial on-time can be determined by measuring the time required for water in 75% of the furrows of the trial set to advance approximately 100 m (USDA-SCS, 1986) or 20 to 30 per cent of the total furrow length (Israeli, 1988). Another consideration for the initial on-time is that it should be long enough to allow the irrigator to adjust stream sizes for uniform advance in all furrows of the set. This will depend upon the number and type of gates used and the time required for the streams to stabilize. As a general guide, 10 minutes are needed for every 40 gates adjusted (McCornick, 1987). Another general rule-of-thumb guide for estimating the initial on-time, from field experience in Texas (U.S.A.), is given by the USDA-SCS (1986) when 4 to 6 surge cycles are used to advance water to the end of the furrow. Four cycles are usually considered adequate for furrows up to 400 m long, while 4 to 6 cycles are used for furrows over 400 m. For furrows 400 m or less :

$$\text{Initial on-time} = \frac{\text{out-time for continuous flow}}{8}$$

For furrows over 400 m long :

$$\text{Initial on-time} = \frac{\text{Out-time for continuous flow}}{12}$$

For most situations, the on-times will be in the range from 20 minutes to about two hours or less, depending upon soil conditions and length of furrow.

The on-time for the second surge can be determined from the field trial by measuring the time required for water to advance through the portion of the furrow wetted by the first surge plus an additional 100 to 150 m of dry furrow. Or, alternatively, add to the initial on-time the time required for water to advance through the furrow which was wetted during the first surge. The time for water to advance through previously wetted furrows is the wet advance time. A rule-of-thumb for this is 2 to 5 minutes per 30 meters over bare soil and 4 to 8 minutes when close growing crops are growing in the furrow (USDA-SCS, 1986). This process is continued to determine the on-times during advance for the remaining surge cycles up to the last. The times required for water to advance through previously wetted portions of the furrows should be recorded with their corresponding distances from which to determine the average wet advance rate. This rate is nearly constant for a given field and flow rate. Wet advance rates can also be simulated by kinematic wave models.

The wet advance time for the entire furrow length is used to determine the on-time for the last surge. This field wet advance time can be estimated by extrapolating the previously determined average wet advance rate to the end of the furrow. The on-time for the last surge of the advance includes advance time over the previously wetted furrow sections and needs to be near the field wet advance time to minimize runoff. For high intake rate soils where the advance may need to be "pushed" to the end of the furrow, McCornick (1987) determined that the last on-time needs to be about 1.3 times the field wet advance time. For low intake rate soils where the advancing front "rolls-on" after cutoff, the last on-time may need to be only 0.75 times the wet advance time. Some judgement based on local experience is usually needed to determine the on-time for the last surge. The empirical values shown may need to be adjusted based on experience for a particular field. It may be necessary to allow some runoff from the last surge of the advance phase to provide sufficient intake at the lower end of the field and to optimize distribution uniformity. Water can be applied more effectively by providing additional opportunity time under the higher initial or transition intake rate conditions of the advance phase than under the lower intake rate conditions of the post-advance phase, even though a limited amount of runoff may occur for a short period of time.

The advance phase of the first irrigation set should be monitored to provide a base for optimizing or fine-tuning the on-times and number of cycles for subsequent sets of the irrigation. By varying the streamsize, cycle times and number of cycles, a minimum volume, V min, to advance water to the end of a specific field can be determined. The volume of water applied is the cumulative on-time multiplied by the furrow inflow rate. In the absence of a local data base or more technical approaches, an irrigator may need to "experiment" with the first surge sets of a field to determine V min and times for subsequent sets to minimize runoff. McCornick (1987) presented procedures for estimating the minimum volume of water for advance for several physical and management parameters.

This discussion emphasizes the variable on-time approach for managing the advance phase. For some conditions, such as with relatively short field lengths, the constant on-time/variable-distance approach is used. Some researchers have also studied this method (Alemi and Goldhamer, 1988; Izuno and Podmore, 1986). With this latter approach, the on-times for all surge cycles are the same, while the length of dry furrow wetted with each subsequent surge decreases. The cycle on-time is the time required for water to advance approximately 35 to 45 % of the total furrow length (USDA-SCS, 1986) and is the same for each surge. The cycle time chosen should allow the design non-erosive stream to advance about 75% of the dry furrow length that was wetted during the previous surge. Unless carefully monitored, this approach could result in excessive tailwater runoff after the water reaches the end of the field. The optimized simulations of Alemi and Goldhamer did not clearly indicate that either the variable or constant on-time approach was the best; however, most practitioners prefer the variable on-time approach.

#### Post-advance or cutback phase

Since the field intake rate is reduced to near the basic rate by surging, continued surging, as during advance, produces excessive runoff. Thus, furrow stream sizes need to be cutback or reduced during the post advance phase to match the reduced furrow intake rate. Reduced infiltration rates require a longer post-advance irrigation time period than with continuous irrigation to apply a given amount of water.

A number of different management options can be used for this phase of the irrigation. Izuno and Podmore (1986) examined six approaches and concluded that, for their simulated conditions, continuous cutback streams which satisfy the basic furrow intake rate should be used. It is not usually practical to reduce stream sizes to other than those that are half the advance stream size which can be readily obtained by simultaneously opening both sides of a surge valve. Thus, by this means, the total inflow becomes equally distributed to the two blocks of furrows on either side of the valve.

The last surge of the advance phase could be prolonged so as to also comprise all or part of the post-advance phase to take advantage of the differences between the reduced infiltration rates of the previously wetted soil and that of the last surge at the lower end of the field. This would compensate for the normally shorter intake opportunity time at the lower end of the field and could potentially increase the distribution uniformity. However, this would require that the supply inflow be reduced to prevent excessive runoff, and it is not usually feasible to adjust the supply inflow during each irrigation set.

Considering the commercial equipment that is available, the three most common and practical approaches for post-advance management are :

1. Splitting the inflow at the surge valve to provide continuous 50% cutback stream sizes.

2. Cycling the surges with short on-times.

3. Cycling the surges with on-time which approximate the wet advance time.

The first method may not provide stream sizes large enough to reach the ends of the furrows on high intake rate soils. It is also limited to fields with little or no side slope. Uniform distribution is difficult to achieve with side slope because the lowest end of the pipe receives the most water. This is usually not significant during the advance phase when the pressure head in the pipeline is relatively large because the gate openings can be adjusted to compensate for elevation differences. However, during the cutback phase, elevation differences may be large in relation to the head. This causes significant differences in flow and it is not often practical to readjust the gates during cutback. Also, water may not reach outlets at the upper end of the pipe. Elevation differences up to about one-half or two-thirds of a pipe diameter can be compensated for by rotating the pipe lengths to lower the outlet gates on the high end and raise them on the low end to bring them to about the same elevation. However, even with this compensation, the side slope for this approach is limited to approximately 0.2% or less. However, splitting the inflow is usually the most efficient method where the above factors are not significant and the cutback furrow streams closely match the basic furrow intake rate. The streams need to be such that they reach the ends of the furrows without having to adjust the supply inflow, which is usually not feasible.

Splitting the inflow for cutback can also be used in areas where irrigation systems are manually operated. In this case, the benefits of surge irrigation can be achieved by using siphon tubes from an open ditch. Two siphon tubes are used for every other furrow such that their combined discharge does not exceed the maximum non-erosive stream size. The two tubes serve one pair of furrows and surging is accomplished by moving the tubes back and forth at the end of each surge on-time from the furrow being irrigated to the adjacent furrow. This is done without repriming the tubes. Surging is not affected by the time required to manually change the tubes if the irrigator always starts at the same side of the set and progresses in the same direction at each cycle. At the end of the advance phase, one tube of each pair is moved to the other furrow so that there is one siphon tube discharging into each furrow. This reduces the furrow inflow rate by half and provides a continuous cutback stream. This method is labor intensive. However, low-cost layflat tubing can be used instead of siphon tubes to eliminate most of the labor and still achieve the benefits of surging (Humpherys, 1988).

Method 2 uses short cycle on-times up to about ten minutes such that cutback is achieved by adjusting the on-time rather than the inflow. The time-averaged flow rate is half the inflow rate and produces surges that overlap and coalesce some distance down the furrows; the coalesced streams are similar to the continuous streams of the first method. This method is most feasible with single furrow valve control systems (Stringham, 1988) which use individually automated furrow outlets. The pipeline acts as a manifold with a near-constant pressure head and cross slope is not a factor. When this method is used with commonly-used gated pipe, the distribution is nonuniform even with short pipe lengths because filling of the pipe occupies a significant portion of the short on-time. Outlets near the valve start flowing immediately while those near the end do not flow until the pipe fills. Also, the small streams that result from the pipe emptying contribute to deep percolation.

The third method, with cycle on-times based on the wet advance rate, is the most practical approach for many situations. As a general guide, the on-time can be set for about 0.75 times the wet advance time. Thus, the cutoff will occur when water reaches three-fourths the distance downstream. This may be adequate for low intake rate soils where water continues to advance after cutoff. However, for high intake rate soils, the on-time may need to be as much as 1.3 times the wet advance time (McCornick, 1987). The on-time for the post-advance surges may require adjusting within this range, based on local conditions and needs. Because the intake opportunity time is less at the lower end of the field, a compromise may need to be made by the irrigator between under-irrigation at the end of the field and larger tailwater losses.

**System evaluation**

Feedback on the performance of a surge irrigation system is needed for effective management. Evaluation information can be used to improve performance, determine adequacy of the system design, compare different management options, or to compare to continuous flow systems under similar conditions. An irrigation system is evaluated for the depth or volume of water applied, water distribution uniformity in the soil profile and along the length of the furrow, and for the irrigation application efficiency. Evaluation of a surge system is more complicated and requires much more data than that for a continuous-flow system because instead of one advance, a series of surge advances must be monitored. Also, the soil's infiltration rate is modified by the surging process so that it cannot be described as a function of opportunity time only, as with continuous irrigation. Detailed procedures for evaluating continuous-flow furrow irrigation are described by Merriam and Keller (1978), Merriam et al. (1981), and by the USDA-SCS (1983). An adaptation of these techniques applied to individual surges cumulatively is usually followed for evaluating surge systems. The USDA-SCS (1983, 1986) presents detailed procedures and forms for evaluating both continuous and surge flow systems along with examples. Opportunity times determined from advance and recession curves along with soil intake rate curves are used to determine the water intake at each furrow station. Four methods are described for developing cumulative intake versus opportunity-time curves. In-field evaluation using these procedures does not require modeling and can be accomplished by trained technicians, but for surge irrigation, is time consuming and requires many calculations.

To minimize the amount of time required and the amount of data to be collected, McCornick et al. (1988) presented a simplified procedure for evaluating the advance phase of surge irrigation. By reducing the number of data points required to describe the advance of each surge, this method eliminates much of the labor required. For each surge advance, the procedure requires the advance time to the point where the previous surge stopped, the advance distance at the time of cutoff, and the distance where the advance stopped. The advance curve is approximated in three linear segments. The recession is approximated as a linear function between the time of cutoff at the head of the furrow and at the point of maximum advance distance. Calculated infiltrated depths for each surge at each station are summed from which the distribution and application efficiency are determined. This procedure describes with a 95% probability the application efficiency within ± 2 percentage points and the distribution uniformity within ± 19 percentage points of the results obtained by measuring the advance every 25 m. The method is sufficiently accurate in many cases for service agency technicians to make on-site evaluations to demonstrate surge benefits and where precision data is not required. A computer program named EVALUATE(2) was developed at Colorado State University (Israeli, 1988) to evaluate surge irrigation using a kinematic wave model.

The time or date to irrigate and the amount of water to apply for surge irrigation is determined by the same methods as for continuous irrigation. If a complete evaluation is not conducted, an irrigator needs to take notes and monitor application depths by using a soil probe or other means to develop an experience base from which to adjust future surge irrigations to maximize uniformity and efficiency as much as possible.

**Surge management for vector control**

Poor on-farm irrigation management practices in some areas of the world contribute to vector-born diseases such as malaria and yellow fever. By helping improve irrigation efficiency, surge irrigation combined with other control measures could have a favourable impact in these areas. Surface irrigation, historically and because of its low cost, is the dominant irrigation method in those areas where vector-born diseases pose the greatest threat. Because surface irrigation is labor intensive, it is usually poorly managed with resulting low irrigation efficiencies. Deep percolation and runoff losses are usually excessive. Both of these losses increase the drainage requirement and contribute to the amount of surface water in pools, seep areas, and drainage ditches.

Grubinger and Pozzi (1985) discussed various water-associated vector-born diseases and the adverse effects of irrigation and drainage on the propagation of vectors such as mosquitos and snails. Irrigation management control measures include eliminating pools, puddles, seepage areas, and their associated aquatic vegetation. Small, low-velocity irrigation and drainage channels are also a problem because they

(2) This program may be obtained from Colorado State University, Department of Agricultural and Chemical Engineering, Fort Collins, Colorado, USA.

provide breeding places and a favourable environment for vector production, particularly when they are poorly maintained and aquatic vegetation is allowed to grow.

When vector control is a primary objective, some of the management criteria for surge irrigation may be different from that normally used. Managing the post-advance phase may be more critical than other management goals. For example, it may be more important to limit runoff than to completely satisfy the irrigation requirement at the lower end of the field. Thus, the post-advance cycle on-times can be chosen accordingly. Selecting furrow advance stream sizes based on the maximum non-erosive stream size may result in post-advance streams that are too large for low infiltration rate soils. Thus, where tailwater losses are more critical than rapid advance, cutback streams can be chosen to match the soil's basic infiltration rate as discussed previously. This criteria can also apply where surging may not be beneficial during advance but could be used to limit runoff during mid-to-late season irrigations or on compacted or low-intake rate soils which otherwise would produce excessive runoff. Field trials will usually be needed to provide a local data base for using models and as aids in determining the best combination of stream sizes and on-times.

Surge irrigation systems normally use closed conveyances such as gated pipe. From a vector control viewpoint, this is desirable because it reduces the length of open ditch conveyance systems with their accompanying adverse environmental effects. Surge irrigation is inherently more practical to implement when automated, and most systems use commercial mechanized valves to optimize labor inputs. Because surface systems are usually labor intensive, even partial mechanization can improve the level of management with resulting improvement in irrigation efficiency. Some benefits from surging can be realized by using the siphon tube method discussed previously, even though this requires open ditches and considerable labor. Layflat, flexible irrigation tubing (Humpherys, 1988) can provide a low-cost alternative to gated pipe. It eliminates the open ditches required for siphon tubes and eliminates most of the labor. For surging, the flow can be changed alternately back and forth between sets for surging by manually pulling a valve handle.

Surge irrigation may be beneficial on borders and basins, however, further research is needed to determine its effects on vector habitat with these systems. Limited field tests by Walker et al. (1981) and Westesen and Biglen (1986) indicated that surging could improve irrigation performance. Relatively short-period intermittent ponding on border and basin surfaces, as required by surging, will usually be more desirable than the longer ponding periods used in continuous irrigation, particularly if improvements in system performance with reduced losses could also be achieved.

## Concluding discussion and summary

Surge irrigation generally reduces a soil's infiltration rate such that furrow stream advance can be hastened and distribution uniformity increased compared to continuous irrigation. This results in less deep percolation. Surged furrow streams can often be advanced to the end of the field with half the volume of water required for continuous streams. Surging also provides a practical means of achieving cutback during the post advance phase to control runoff. Surge irrigation requires a higher level of management and operator skills than does continuous irrigation. Additional monitoring may be required to prevent under-irrigation. Because of reduced infiltration rates, improper management could actually increase runoff.

Management of surge irrigation is considered in two phases - advance and post-advance. The advance stream size is usually the maximum non-erosive stream. However, for some conditions, it is desireable to use a stream size that is based on the furrow intake rate during post advance. Several methods are used to determine the number of surges and cycle on-times. The two most commonly used and practical methods of managing the post advance phase are to (1) split the inflow to provide continuous streams that are half the advance stream size and (2) continue surging with on-times which approximate the wet advance time. Splitting the inflow is limited to fields with little or no cross slope. Managing the advance phase is usually more critical with high infiltration rate soils where rapid advance is important, while managing the post-advance phase is usually more critical with low infiltration rate soils which commonly produce considerable runoff.

Since several management parameters must be considered, many management options are possible. Kinematic wave models are useful in helping determine the optimum combination of parameters for various management approaches to maximize efficiency. Using model simulations, some of these approaches have been studied by researchers who have concluded that, for the approaches investigated, surge followed by continuous cutback streams gave the best efficiency (Alemi and Goldhamer, 1988; Izuno and Podmore, 1986). Although model simulations are helpful, the management alternatives to be investigated must be consistent with the constraints of a given irrigation system. For example, simulations that require changing the supply inflow during an irrigation may not be practical to implement in the field. An irrigator usually has a given stream size with which to irrigate, and if a surge management technique requires changing the supply inflow to obtain cutback streams, the irrigator must either waste the excess or find another place to use it during the post advance phase. This entails additional labor and irrigating with the smaller left-over stream for a short period of time is not feasible. Use of cutback streams with continuous irrigation to improve irrigation efficiency has been encouraged for a long time. However, because of the difficulty and inconvenience of reducing stream size during an irrigation, cutback streams have generally not been used. This same constraint can apply to surge irrigation. Therefore, the management option recommended must be within the capability of the irrigator to use, even though another alternative could produce a slightly higher efficiency. One of the advantages of surge irrigation and its associated equipment is that it can provide a means of managing the post-advance phase without increasing labor or inconvenience. The original intent of Stringham and Keller (1979) was to find a practical means of achieving cutback streams without having to reduce the supply inflow. The split-set technique (Humpherys, 1978) was also proposed for this purpose and is the configuration currently used in surge systems. Therefore, management approaches that use continuous cutback streams are most feasibly limited to those conditions where reduced stream sizes that are half the advance stream, obtained by simultaneously opening both sides of a surge valve, can be used or which can be obtained by time-averaging.

Field evaluation is needed for effective management of surge systems. Because a series of surge advances must be monitored, evaluation of surge irrigation is more time consuming and requires more data than that for continuous systems. Adaptation of continuous-flow techniques is commonly used and is described by the USDA-SCS (1986). McCornick et al. (1988) presented a simplified procedure to evaluate the advance phase which requires less data.

In addition to its potential to increase irrigation efficiency and uniformity, surge irrigation can provide other benefits. Increased irrigation efficiency will help preserve ground water quality and reduce energy costs for pumping. Researchers have reported significant decreases in the variability of stream advance by surging. By reducing irrigation water losses, surging can sometimes reduce the adverse environmental effects of surface systems which contribute to vector-born diseases. Surging provides greater versatility and management opportunities for the irrigator. For example, by hastening the advance, light irrigation applications are possible. Since automation is needed to fully implement surge irrigation, commercial equipment has become available which provides different management options and can optimize labor inputs. Although benefits from surging can be realized on most soils, the greatest benefits during the advance phase occur on coarse-textured soils and during the first irrigation of the season or following tillage when soils are loose. Benefits on fine-textured compacted soils having low infiltration rates may be best achieved during the post-advance phase by controlling runoff. Surging on basins and borders may be beneficial but further research is needed. An overview of surge irrigation including principles and theory, mathematical models, systems and equipment, and field experience was presented in a previous paper (Humpherys, 1989).

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