Management Considerations in Surged Flow Irrigation

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Since the inception of surged flow irrigation in the late 1970's, the technique has evolved as one having great potential for enhancing the effectiveness of furrow irrigation systems. Many researchers, extension personnel, and irrigators have documented successful increases in application efficiency and uniformity upon converting continuous flow systems to surged flow. Others, however, have noted cases where surged flow irrigation showed no advantage in terms of distribution uniformity or application efficiency when compared to continuous flow. It is these cases that point to the need for continued investigations concerning surged flow irrigation, and perhaps more scrutiny of the role that management factors play in the effectiveness of surged flow systems.

University of Nebraska Field Trials

From 1983 to 1989 researchers at the University of Nebraska conducted many field scale trials to document the effect of surged flow on the performance of furrow irrigation systems (Yonts et al., 1991). The cumulative on-time required to advance water to the end of the furrow under surged flow was compared to that under continuous flow. A constant flow rate was used on all furrows within each field trial. The on-time was used as an indicator of effect because increased water advance rates infer a reduction in infiltration rates. The trials were conducted at several sites having different soils, during the first through third irrigation events of the season, and on hard and soft furrows.

The results of the trials were mixed, as indicated in Table 1. For all trials combined, approximately half (54%) indicated that water advanced to the furrow end in less time when flow was surged than with continuous flow. The highest success rate occurred during the first irrigation (59%) and on soft furrows (59%). Regardless of how the information is grouped, surged flow effectively reduced advance times in approximately half of the cases studied. When significant reductions in advance time occurred, the average reduction was 30%. When all trials are combined, thus including cases where no reductions occurred, the average reduction in advance time was 16%.

A review of the results of the University of Nebraska trials is optimistic in that a significant number of irrigation systems could be enhanced using surged flow. Conversely, the blanket application of a device that shows a 50% success rate may be questionable, and further indicates the need for site specific observations prior to the permanent installation of a surged flow system.

Table 1. Summary of the University of Nebraska surged flow irrigation trials (1983-1989).

Case	Number of Trials	Success Rate[1]	Average Reduction[2]	Average Significant Reduction[3]
All Trials	26	54%	16%	30%
First Irrigations	17	59%	19%	33%
Second Irrigations[4]	6	50%	12%	26%
Third Irrigations	2	50%	7%	14%
Soft Furrows - All	22	59%	18%	31%
Hard Furrows - All	4	25%	5%	20%

[1] Percentage of trials in which reductions in advance time occurred due to surged flow.
[2] Average reduction in advance time due to surged flow, including those cases where no reduction occurred.
[3] Average reduction in advance time due to surged flow, including only those cases where reductions occurred.
[4] Two of the second irrigation trials were re-ditched following the first irrigation.

University of Nebraska researchers also compared the effectiveness of surged flow irrigation with mechanical furrow packing. In general, it was found that both techniques had approximately the same success rate. Using both techniques together, surged flow on packed furrows, was not any more effective than either technique used alone. This reinforces informal observations that surged flow irrigation tends to be more effective on soft (non-traffic) furrows than on hard furrows.

Advance Time as an Indicator of Success

The University of Nebraska trials measured changes in advance time as indicators of the success of surged flow irrigation. While accelerated advance may be a general indicator of success, there are some concerns that should be voiced.

The advance time trials that were used to document the effect of surged flow irrigation are a result of the logic:

if: advance times are reduced,
then: infiltration rates are reduced, and
infiltration amounts are reduced, and
applications are more uniform, and
deep percolation is reduced.

The flaw in this logic is that a simple decrease in infiltration rates does not guarantee a decrease in infiltration amounts. Infiltration amounts depend on infiltration rate and opportunity time. Many locations in the furrow will have increased opportunity time as a result of surged flow irrigation. Increased opportunity time result from the accumulation of several recession times, instead of only one. Any decrease in infiltration rates must be of significant magnitude to offset increases in opportunity time that result from the increased recession times that surged flow generates. If changes in the infiltration rate occur, but not in significant magnitude to offset increased opportunity times, surged flow may result in increased infiltration, and potentially, increased deep percolation. This case is illustrated in Figure 1. In this example, surged flow advanced water to the end of the field in 14% less time than did continuous flow, but infiltration actually increased in many segments of the furrow.

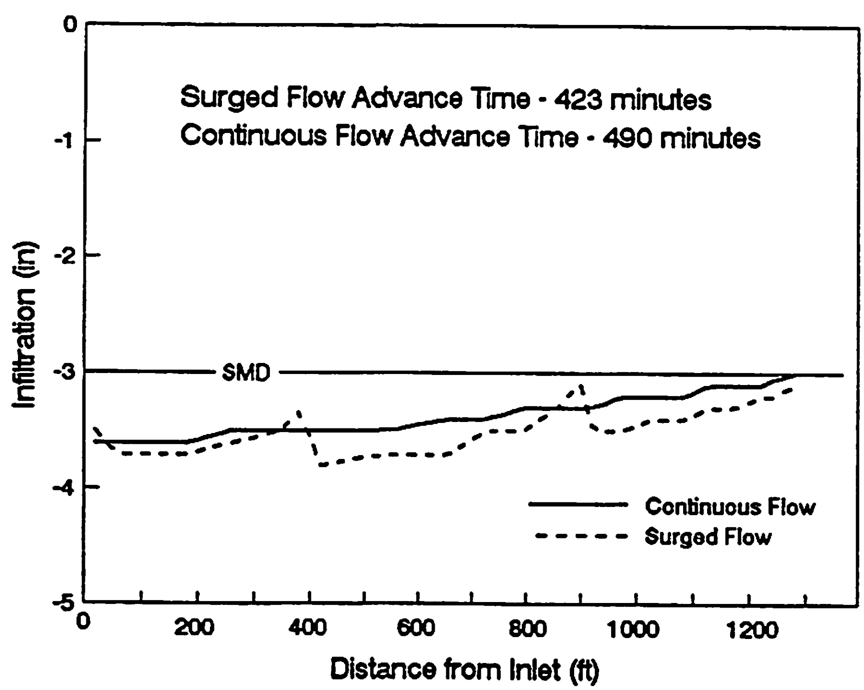

Figure 1. Model results showing a case where decreases in infiltration rates are offset by increases in opportunity time, resulting in increased deep percolation due to surged flow.

The graph of Figure 1 was developed using the SRFR model (Strelkoff, 1990), which simulates furrow irrigation events for a single furrow based on physical descriptions of soil, field, and management characteristics. The characteristics of the example of Figure 1 are fairly representative of conditions in South Central Nebraska. Physically, the example is one having 36 inch furrow spacing with 1/4 mile (1320 ft) furrow lengths. The flow rate used was 9 gpm in a furrow channel assumed to be a symmetric trapezoid, with a 10 inch base, 8 inch maximum depth, and 1.4:1 side slopes (vertical:horizontal). In both cases, water flowed into the furrow for a total of 24 hours, resulting in a gross application of 5.3 inches to replenish a 3 inch soil moisture deficit.

Perhaps the most important assumptions used to generate Figure 1 are associated with the infiltration characteristics of the soil. The SRFR model uses a modified Kostiakov equation to represent cumulative infiltration as a function of opportunity time (time water is present on the soil surface, not real time):

$$F = kt^a + bt + c, \tag{1}$$

where: F = cumulative infiltration (in),
t = opportunity time (hr),
k,a,b,c = empirical constants for a given soil location at a given time.

Observed values of the empirical constants from University of Nebraska field trials were used, taken from evaluations on a Hastings silt loam soil having conventional tillage (disk and surface plant) during the third irrigation of the 1983 crop year. The parameters used in the analysis to generate Figure 1 were:

$k = 0.853$ in/hr^a,
$a = 0.262$
$b = 0.536$ in/hr,
$c = 0$.

A second assumption describes the effect of surged flow irrigation on the infiltration characteristics of the soil. Many researchers have found reductions in infiltration rates upon re-wetting of a particular section of the furrow. For this analysis, the model of Izuno et al. (1985) is assumed valid. With this technique, the infiltration rate drops to steady state after the first surge. That is, the infiltration is described by the power function of Equation 1 during the initial wetting, but upon re-wetting infiltration is described by:

$$dF/dt = b_o. \tag{2}$$

A conservative approach would be to assign b_o as the first derivative of Equation 1 evaluated at an arbitrarily large value of t, perhaps t = 12 hours. This is the technique used for the example of Figure 1. This results in $b_o = 0.102$ in/hr.

Perhaps the case shown in Figure 1 is the exception rather than the rule, in many cases reduced advance rates do correspond with reduced infiltration depths. The example is presented here to demonstrate that increases in the rate of advance may indicate a decrease in infiltration **rate**, but do not always decrease the infiltrated **depth**, because of increases opportunity times in certain segments of the furrow.

Flow Rate Effect

The flow rate used to compare surged flow to continuous flow may be a factor that ultimately affects the outcome of the trial. The difference in advance time between two furrows at one flow rate may be significant, while the same test under an increased flow rate may show relatively little difference in advance times. This is a result of the non-linear relationship between advance time and distance. The point chosen as the furrow end may also affect significance of difference. A more formal analysis may require a complete regression significance test imposed on the advance curves for the two treatments to assess significance of differences in advance rates.

Managing the Post-Advance Phase

Many researchers have concentrated on the advance phase of surged flow irrigation. The post-advance phase may be equally important, where the goal is to continue to fill the root zone to the desired amount as uniformly as possible. In some cases minimizing runoff flows is also a consideration.

Recent research (Ganapathy, 1992) indicates that a modification of the on-time factors used in post advance flow would result in more efficient water application. The study used field trials and the model of Izuno and Podmore (1985) to determine the post advance factor (PAF) that resulted in the maximum low quarter application efficiency (LQAE). The PAF is defined as the ratio of the duration of one post advance surge to the total duration of all advance surges.

Table 2. Post advance factors used in a sample of commercially available surged valves and those recommended by University of Nebraska researchers.

Source	PAF
P&R	0.15
Waterman	0.11 - 0.23
Yonts et al., 1991	0.16 - 0.23
Ganapathy, 1992	0.10

This study would indicate that the PAF that results in the maximum efficiency is actually less than that previously recommended by the University of Nebraska, as well as the values that are programmed into two of the commercially available valves (Table 2). A PAF of 0.10 indicates that the on-time for each advance surge should be one tenth of the sum of the advance surge on-times. The recommended PAF is higher, approximately 0.20, if a re-use system is used.

This study confirmed early results indicating that a cutoff ratio (advance inflow time divided by total inflow time) of 0.5 is a reasonable target. This infers that furrow irrigators should try to advance water to the end of the field in one half the total on-time. Then a PAF of 0.10 should be used to finish out the set using post advance (often called cutback or soak) cycles.

Goals of Surged Flow Irrigation

As with any technique, success should be judged based on the expectations and goals of the user. One irrigator may be interested in reducing gross applications, while another may be concerned only with increases in uniformity of application. An irrigator may also be concerned with runoff volumes, or the amount of labor time that is required to irrigate a given acreage.

Reduced Applications

Reducing annual application amounts in a furrow irrigation system can be accomplished **only** by changing the set time, the set size (number of furrows) or by altering the irrigation schedule. This is true whether surged or continuous flow is used, and these items may be changed singly or in combination.

The set size and time, assuming that the source flow rate is relatively constant, are the only two management parameters that affect the application amount for a single irrigation. Simply changing to surged flow **will not** reduce application amounts **unless** the set size and/or time is adjusted. Any decrease in set time must more than offset a decrease in set size if the gross application is to be reduced. This is illustrated in Figure 2, if a 900 gpm source is used to irrigate 36 inch by 1/4 mile furrows.

A change in the annual gross application may be accomplished by irrigating less frequently. In the case of a transition from continuous flow to surged flow, if both were fully irrigated then no change in schedule should be expected. If the continuous flow system was irrigated frequently based on a portion of the field that was inadequately irrigated each time, and the surged flow system provide a higher degree of uniformity, then less frequent irrigations may be possible. In any case it is difficult to forecast a decrease in annual application resulting from less frequent irrigations that may be a result of a transition from continuous to surged flow.

Increased Uniformity

Regardless of goals concerning the gross application for each irrigation event, an irrigator may be interested in applying a more uniform application. This may be the case if a continuous flow system under-irrigates the downstream end of the field, resulting in yield losses or requiring a large average application to compensate for the poor uniformity. Surged flow irrigation has the potential to result in more uniform applications, but only if infiltration rates decrease sufficiently. Uniformity is difficult for the irrigator to judge, but irrigation advance times, runoff volumes, post irrigation soil probing and even crop yield may indicate successful changes in application uniformity.

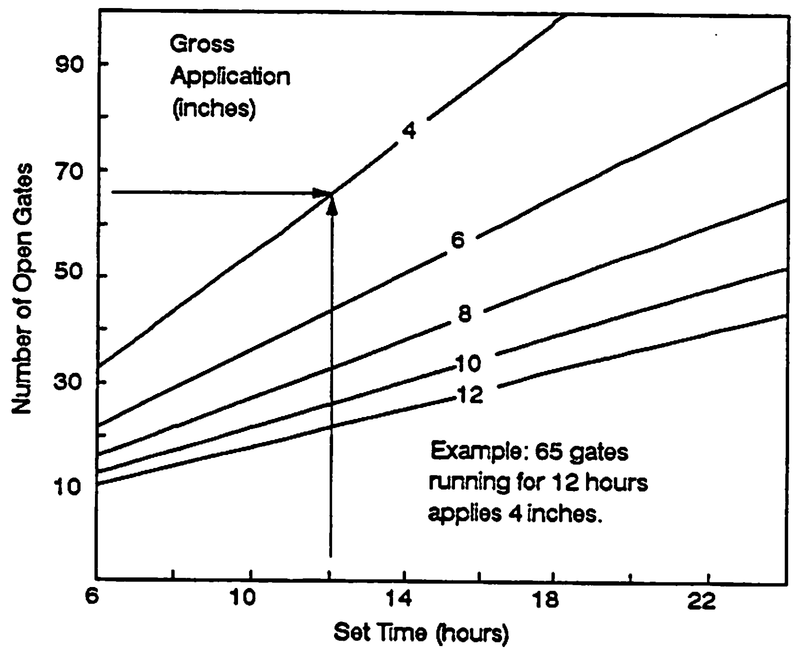

Figure 2. Average gross application resulting from combinations of set time and number of gates open for a 900 gpm source irrigating 36 inch by 1/4 mile furrows.

Reduced Tailwater

Some irrigators may have goals concerning decreased tailwater. Surged flow may help accomplish this, but there is an important factor to bear in mind. Decreases in tailwater without corresponding decreases in application amounts translate into increases in infiltration. If a system had some deep percolation to begin with, and tailwater were reduced, then deep percolation would increase unless the tailwater loss was reflected in the change in gross application amounts.

Labor Management

Some irrigators may be interested in surged flow irrigation as a labor management tool. Commercially available surge valves may reduce the number of trips to the field by at least half. The same amount of time would be spent opening and closing gates, but the seasonal travel time to and from the field would be reduced. While at the field, the irrigator may find himself spending slightly more time as he programs the surge valve. Semi-automated systems with multiple risers and surge valves may further cut labor requirements, however, many proposed systems of this type may degrade irrigation effectiveness as the irrigator no longer has the flexibility to alter his set size based on field conditions. Also, complex system designs with buried lines and multiple risers and surge valves are not likely to be cost effective based on labor savings alone.

Conclusions

Surged flow irrigation has emerged as the only new technology in surface irrigation that has a widespread opportunity to enhance application efficiency and uniformity. However, like any new device or technology, the suitability of surged flow irrigation depends on site specific conditions as well as the management regime under which it is used. Field trial results in Nebraska indicate a success rate of approximately 50 percent. This should be viewed optimistically; a 50 percent success rate represents incredible opportunities in terms of acres impacted compared to having no alternative at all. Advance time as an indicator of success in surged flow irrigation should be used cautiously. Reductions in infiltration rates must more than offset increases in opportunity time if uniformity is to be enhanced. Recent work has indicated that the cycle times in the post advance phase should be of shorter duration than those previously recommended. Finally, the success of a conversion to surged flow irrigation should be judged in light of the irrigators goals.

References

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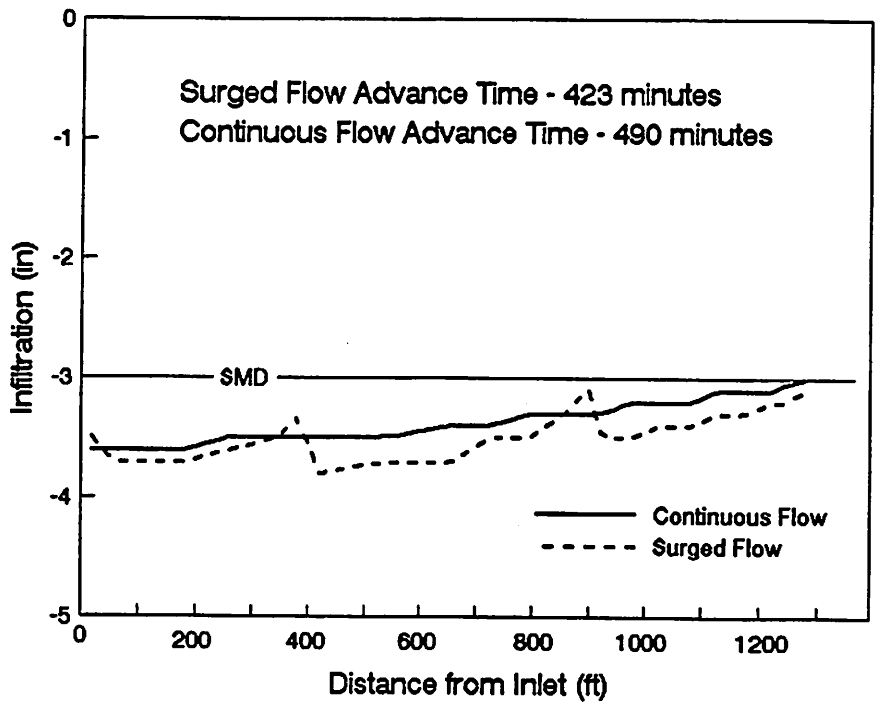
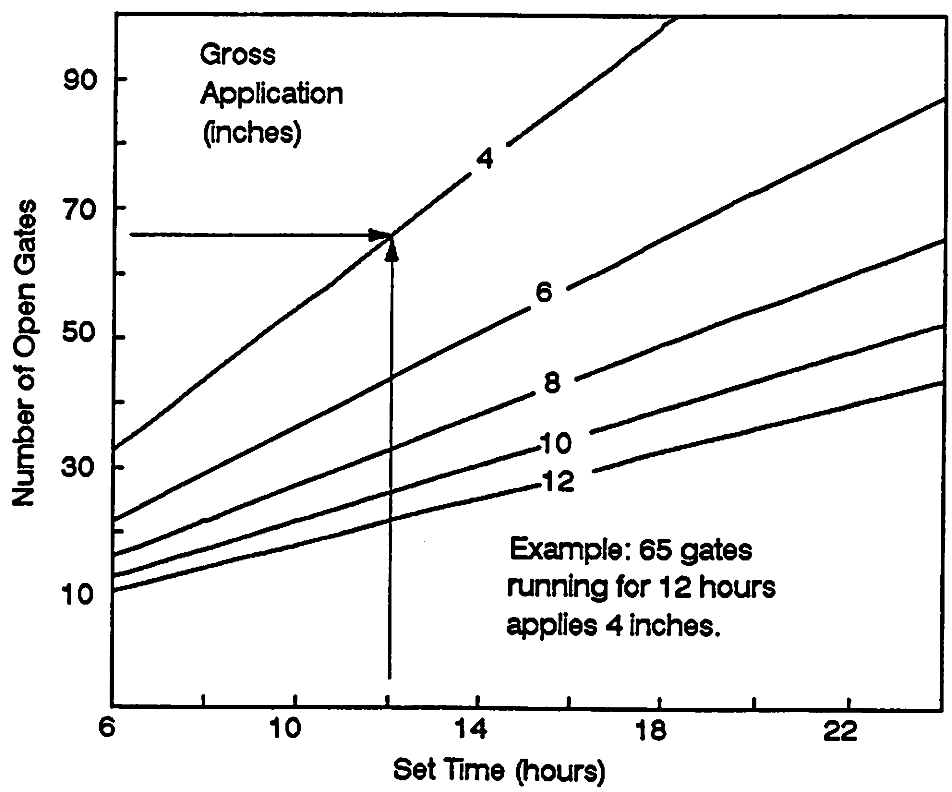


Surged Flow Advance Time - 423 minutes
Continuous Flow Advance Time - 490 minutes
Infiltration (in)
0
-1
-2
-3
-4
-5
SMD
Continuous Flow
Surged Flow
0
200
400
600
800
1000
1200
Distance from Inlet (ft)


Gross
Application
(inches)
4
6
8
10
12
Example: 65 gates
running for 12 hours
applies 4 inches.
Number of Open Gates
90
70
50
30
10
6
10
14
18
22
Set Time (hours)