EVALUATING AND FINE TUNING FURROW IRRIGATION SYSTEMS

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Many factors affect the performance of furrow irrigation systems, for example the soil texture and structure, furrow length, spacing between wetted furrows, crop residue and furrow slope. There are other elements that come into play that have more to do with the management of the system, meaning that changes can easily be made throughout the irrigation season. The set time and number of gates opened are examples of management factors, and are the primary tools that irrigators have to optimize performance given the physical features of the irrigation system. The set time and number of gates opened determine the gross application (the total amount of water applied) and also affect the distribution of water along the length of the furrow. The first item discussed here is a tool that uses easily measured irrigation information to estimate the infiltration distribution and overall performance of a furrow irrigated set. The second item is a tool that can be used to fine tune the infiltration profile once a suitable gross application amount is arrived at.

Volume Balance Model-Modified (VBMM)

The VBMM is a computer program that uses volume balance concepts to estimate the amount of water infiltrated at a series of points along the field. A detailed description of the mathematics used in the model can be found in Eisenhauer et al. (1993). For this presentation it will suffice to summarize the assumptions used in the model and the restrictions associated with the use of the model.

1. The model should be used only on continuous (**not** surged) flow furrow irrigation systems. If the ends are blocked, the model my be used up to the point that water ponds at the downstream end, where the runoff term will then include all water that passes that point.

2. It is assumed that the advance of water down the furrow and the cumulative infiltration with respect to time can be represented using simple power functions.

3. The subsurface shape factor (the shape of the infiltration profile at any time) is assumed constant and valid after advance is completed.

4. Users should keep in mind that within an irrigated set any disuniformity in field slope, furrow roughness, channel cross section, or soil characteristics will adversely affect the performance of the model.

5. An important assumption is that the exponent of the infiltration equation is related to soil texture. Users that are apprehensive about this assumption may avoid it by using, for example, the two-point method described by Smerdon et al. (1988) to estimate the exponent based on actual field observations.

6. Unless more detailed information is available, it is assumed that 50% of the runoff that enters a return (reuse) system is beneficially stored in a crop root zone and not counted against the system when calculating the application efficiency. In any case, all of the runoff is considered when calculating the gross application.

7. While the VBMM is ideally suited to single furrow evaluations, it may be used on an entire set. The input would then be based on average values for the set. The advance time used should be a weighted average based on the tillage equipment and irrigated furrow spacing. For example, if eight row equipment without dual tires is used and every furrow is irrigated, the advance time should be measured on randomly chosen furrows - two wheel (hard), five non-wheel (soft) and one guess furrow. If this is not possible, the next best option is to observe the median furrow to advance to the field end. This means that if thirty furrows are irrigated, the time at which the fifteenth furrow advances would be recorded and assumed to represent the weighted average.

8. Input to the model is easily observed in most on-farm settings. The input includes:

a) a description of the general soil texture (sand, loam or clay) unless the Kostiakov exponent is known, in which case it is input directly,
b) the pump or source flow rate (gpm),
c) the set time (hours),
d) the average time for water to advance to the furrow end (hours),
e) the average furrow length (feet),
f) the average down-furrow slope (%),
g) the furrow spacing (inches),
h) the average wetted furrow spacing (inches),
i) the number of gates open or tubes flowing,
j) and the estimated average soil moisture deficit, or SMD, (inches).

The wetted furrow spacing is also a weighted average. For example, if the wetted furrow pattern is two on, one off, two on, one off...., then the wetted furrow spacing would be 1.5 times the furrow spacing.

This presentation does not attempt to validate the VBMM model - that work is presented in Eisenhauer et al. (1993). The model was demonstrated in 1993 on several farms in south central Nebraska. A summary of the field conditions at each site are given in Table 1. Table 2 shows specific management conditions and the VBMM results for each unique run. Graphic summaries of the VBMM output for several sites are shown in Figures 1-7.

Figure 1 shows the VBMM results for the first irrigation at Bill Griffith's farm. This figure shows how changes in management can cause dramatic changes in application efficiency. For the first irrigation event the efficiency varied set-to-set from a low of 34% to a high of 70%. The primary reason for this variation is that Bill was experimenting with combinations of set time and number of gates open on each set. Bill noticed in the first set that water was advancing more rapidly than he anticipated. On the second set he opened twice as many gates for a slightly longer set time. The net result was that he reduced his application by 1.7 inches and increased his efficiency substantially. Note also that the second set had different soil conditions, as seen at the upstream end of the field where less water infiltrated even though the opportunity time was slightly greater. Another factor in the difference in efficiencies between sets is the change in soil moisture deficit (SMD). For the first irrigation, Bill probably irrigated all sets too early. He chose to do this because in prior years it took up to two weeks to get over this field. This year, however, his soil was more compacted due to a mechanical packing operation combined with weather factors. When coupled with guidance on appropriate set times and sizes, Bill was able to get over the field in 3 days. Thus, he never encountered a set that had a high SMD during the first irrigation. During the second irrigation (Figure 2), Bill waited until the SMD was larger to start irrigating, and his efficiencies reflect this. In Bill's case, light irrigations (less than 1.5 inches) are difficult to achieve.

Figure 3 shows the VBMM output for a field on Craig Welty's farm. The evaluation was made on the first set of each irrigation event. Craig manages his system by moving to the next set as soon as most of the rows are through on each set[1]. This is reflected in the infiltration profiles - very little water infiltrated at the lower end. Craig has chosen to accept the risk of some crop water stress at the lower reaches of his field. This strategy results in a high efficiency, since very little runoff occurs and the resultant set times produce little or no deep percolation. While this strategy sets up some risk of crop stress at the downstream end, it does allow more efficient use of rainfall throughout the season. Craig did not get the high efficiency he wanted during the third irrigation where he probably irrigated too soon.

Figure 4 shows the VBMM results at the Neil Grothen farm for the first set of his only irrigation. Neil applied a light application, using his active reuse system to irrigate very efficiently. The light irrigation turned out to be a good strategy, as rains shortly thereafter carried him through the irrigation season.

The Cutoff Ratio

In managing furrow irrigation systems it is important to remember that at any give site the gross irrigation amount (the amount pumped or delivered) is determined by 5 parameters only. Two of these are items that are not likely to be changed within an irrigation system or event: the pump or delivery flow rate and the average furrow length. One item can be changed only to the extent that alternate or other nontraditional row settings are used is the wetted furrow spacing. The last two items are much more flexible and easy to manage even though they contribute equally to the calculation of the gross application: the set time and the number of gates opened per set (set size). One way to think of this is in the form of a question - if I want to apply a certain amount of water and I usually run a certain set time, how many gates should I open? This can be calculated as:

$$N = \frac{Q \times T \times 96.25}{D \times W \times L} \quad (1)$$

where: N = number of gates to open,
Q = pump flow rate (gpm),
T = set time (hrs),
D = desired depth of application (inches),
W = wetted furrow spacing (ft),
L = average furrow length for the set (ft).

This equation can be rearranged to determine the average depth of application based on the set time and number of gates opened:

[1] Craig's row tend to come through fairly uniformly.

$$D = \frac{Q \times D \times 96.25}{N \times W \times L} \tag{2}$$

These two management parameters, the set time and number of gates opened, also determine the distribution of water stored in the profile. Thus, the set time and number of gates opened help determine infiltration distribution, runoff amounts, deep percolation amounts, and ultimately, the irrigation application efficiency. One indicator of furrow irrigation performance that reflects the set time and the number of gates opened is the cutoff ratio, or CR, defined as:

$$CR = \frac{\text{the average advance time (hrs)}}{\text{the set time (hrs)}} \tag{3}$$

The cutoff ratio is an indicator of efficiency, and is described in more detail in Cahoon and Eisenhauer (1993). Achieving the optimum CR will minimize deep percolation and runoff while distributing water as evenly as possible down the length of the furrow. The CR that results in optimum system performance depends on soil and system characteristics. The recommended CR's are shown in Table 3.

When using the CR as a management tool, it is critical that **both** the set time and number of gates are considered. Reducing only the number of gates to reduce the CR will often result in excessive application depths - causing excessive deep percolation, runoff, or both.

One strategy for fine tuning furrow irrigation systems is to choose a combination of set time and number of gates opened that results in both the desired application amount and the desired CR. First, determine the number of gates to open for the desired set time and application depth from Equation 1. Use these settings on the first set. If water does not reach the furrow end, make the necessary adjustments in set time, keeping in mind that the application amount will increase. Then run the CR program, or use the worksheet given in Cahoon and Eisenhauer (1993), to predict the number of gates and set time that will achieve the target CR with the desired gross application. Use these values, or some reasonable compromise, on the next set. If the system performance does not improve satisfactorily, run the CR program using input from the second set and make further modifications on the next set.

One limitation of this procedure occurs with high furrow stream sizes. The average flow rate in each furrow equals the pump flow rate, Q, divided by the number of gates open, N, if pipe leaks are negligible. The maximum desirable furrow flow rate (in gpm) can be estimated by dividing a factor indicating erodibility (12.5 for many Nebraska soils) by the furrow slope, S, in percent (SCS, 1983). Stream sizes greater than this will result in excessive erosion. Another limitation is with respect to channel capacity. Most furrow systems are not capable of transferring water at flow rates greater than 40 gpm without overtopping the furrow. On the other hand, flow rates of less than approximately 7 gpm will often result in inadequate soaking of the furrow width due to the small wetted perimeter.

Figures 5-8 show the results of using the CR method to help improve irrigation system performance as measured using the VBMM. In figure 5, Pat Oschner had two problems to overcome: high application amounts and poor distribution down the furrow. Keep in mind that the CR method is a tool for improving distribution uniformity, while equations 1 and 2 and the VBMM program may help change the application amount. The improved performance from the first set to the second at Pat's site is largely because he reduced his set time proportionately more than he reduced his number of gates. This caused the gross application to be more in line with the SMD. The CR for both sets is very near the target value, so changes were not based on the CR program output. Ultimately, Pat may want to irrigate more frequently (the 4 inch SMD encourages long set times) and use the maximum non-erosive flow to achieve a more uniform application.

At Mark Bailey's site (Figure 6), the problem was not low efficiency, but poor uniformity. Management settings used in the first set would require more frequent irrigations because of the relatively small infiltration amounts in the downstream third of the field. The CR program suggested a 4.5 hour set with 23 gates open. This is a little extreme, so Mark compromised and used an 8 hour set with 40 gates open. This improved the uniformity significantly, without changing the gross application. The CR went from 0.75 to 0.5, which is much more in line with the target of 0.35.

Mike Schlick (Figure 7) had a problem similar to Mark Bailey's. Mike reduced his gross application, but the amount infiltrated in the lower third remained about the same. This means that he could get over the field quicker with less water, but his irrigation frequency would not change much. This also opens up a more uniform post-irrigation SMD to store rainfall in.

One component of the CR theory is an empirical relationship between the relative advance time and the relative furrow flow rate (inverse of relative number of gates opened). This relationship is shown in Figure 8 for three different values of the infiltration equation exponent as represented by the three soil textures shown. Plotting the observed values (one point from each Clay County site and several points from Griffith's site) on the same graph shows that the regression analysis is certainly reasonable when compared to field data.

Program Availability

Both the VBMM and CR programs will soon be available in compiled and spreadsheet versions. The compiled versions should run on most IBM compatible computers and the spreadsheet versions will require Lotus 123 or a spreadsheet package that will read Lotus files. The programs will be available from the University of Nebraska Cooperative Extension, and the anticipated cost will be ten to fifteen dollars for the package. The package will also contain a program for calculating infiltration parameters using the two-point method of Smerdon et al. (1988), and a program that determines empirical furrow shape parameters based on field observations. Check any Nebraska county extension office after March 15, 1994 for the programs.

References

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Eisenhauer, D. E., C. D. Yonts, J. E. Cahoon and B. Brown. 1993. Reactive irrigation scheduling for sloping furrow irrigation. Management of Irrigation and Drainage Systems - Integrated Perspectives. ed. R. G. Allen and C. Neale. ASCE.

SCS. 1983. National Engineering Handbook. Section 15 - Irrigation, Chapter 5 - Furrow Irrigation. United States Department of Agriculture, Soil Conservation Service.

Smerdon E. T., A. W. Blair and D. L. Reddell. 1988. Infiltration from irrigation advance data, I:theory. J. Irrig. Drainage Engr. 114(1):4-17.

Table 1. Site characteristics for the 1993 Nebraska field demonstrations.

Cooperator	Soil Texture	Runoff Return?	Slope	Furrow Spacing (in)	Wet Furrow Spacing (in)	Pump Flow Rate (gpm)
Bill Griffith, Cozad	loam	No	0.15%	36	36	(1)
Craig Welty, Cairo	sand	No	0.25%	36	72	(1)
Neil Grothen, Adams Co.	loam	Yes	0.93 %	30	60	12 gpm/furrow
Pat Oschner, Clay Co.	loam	No	0.50 %	36	48	700
Mike Bailey, Clay Co.	loam	Yes	0.30 %	30	30	900
Mike Schlick, Clay Co.	loam	Yes	0.23 %	30	60	1400

(1) Used flow meter totalizer on each set.

Table 2. Management parameters and VBMM output for each event observed.

Cooperator Event.Set	Date	Set Time (hrs)	Advance Time (hrs)	Number of Gates	CR	Gross (in)	Runoff (in)	Deep Perc (in)	Efficiency (%)
Griffith 1.1	7/5	12	7.3	24	0.60	3.9	0.9	1.7	34
1.2	7/6	13	9	48	0.69	2.2	0.4	0.2	70
1.3	7/6	11	8	30	0.73	3.3	0.6	1.1	50
1.4	7/7	12	9	30	0.75	3.4	0.6	1.2	46
1.5	7/7	12	9	30	0.75	3.5	0.6	1.3	45
1.6	7/8	12	9	29	0.75	3.6	0.7	1.6	37
Griffith 2.1	8/12	6	4	24	0.67	1.9	0.4	0	81
2.2	8/12	6	4	24	0.67	2.3	0.4	0	81
2.3	8/13	5	4	24	0.80	1.5	0.2	0	86
2.4	8/17	12.5	5	30	0.40	3.5	1.2	0	66
2.5	8/18	5.5	5	30	0.91	1.5	0.2	0	88
Welty 1.1	8/9	7	7	28	1.00	2.5	0.1	0.2	87
2.1	8/16	11.3	11.3	42	1.00	1.1	0.1	0	95
3.1	8/26	10.5	10.5	45	1.00	1.8	0.1	0.6	61
Grothen 1.1	8/18	12	8	n/a	0.67	1.8	0.5	0.0	83
Oschner 1.1	8/18	24	15	34	0.63	7.5	1.7	1.9	57
1.2	8/19	16.5	10	28	0.61	6.3	1.5	1.0	66
Bailey 1.1	8/11	12	9	60	0.75	3.2	0.6	0.1	87
1.2	8/12	8	4	40	0.50	3.2	0.9	0.0	84
Schlick 1.1	8/10	12	6.5	75	0.54	2.6	0.7	0.0	85
1.2	8/11	7	3.5	50	0.50	2.3	0.6	0.0	84

Table 3. Recommended cutoff ratios.

System Type	Recommended Cutoff Ratio		
	Sandy Soils	Loamy Soils	Clayey Soils
No Re-Use	0.45	0.60	0.70
With Re-Use	0.25	0.35	0.45
Blocked Ends	0.69	0.85	0.90

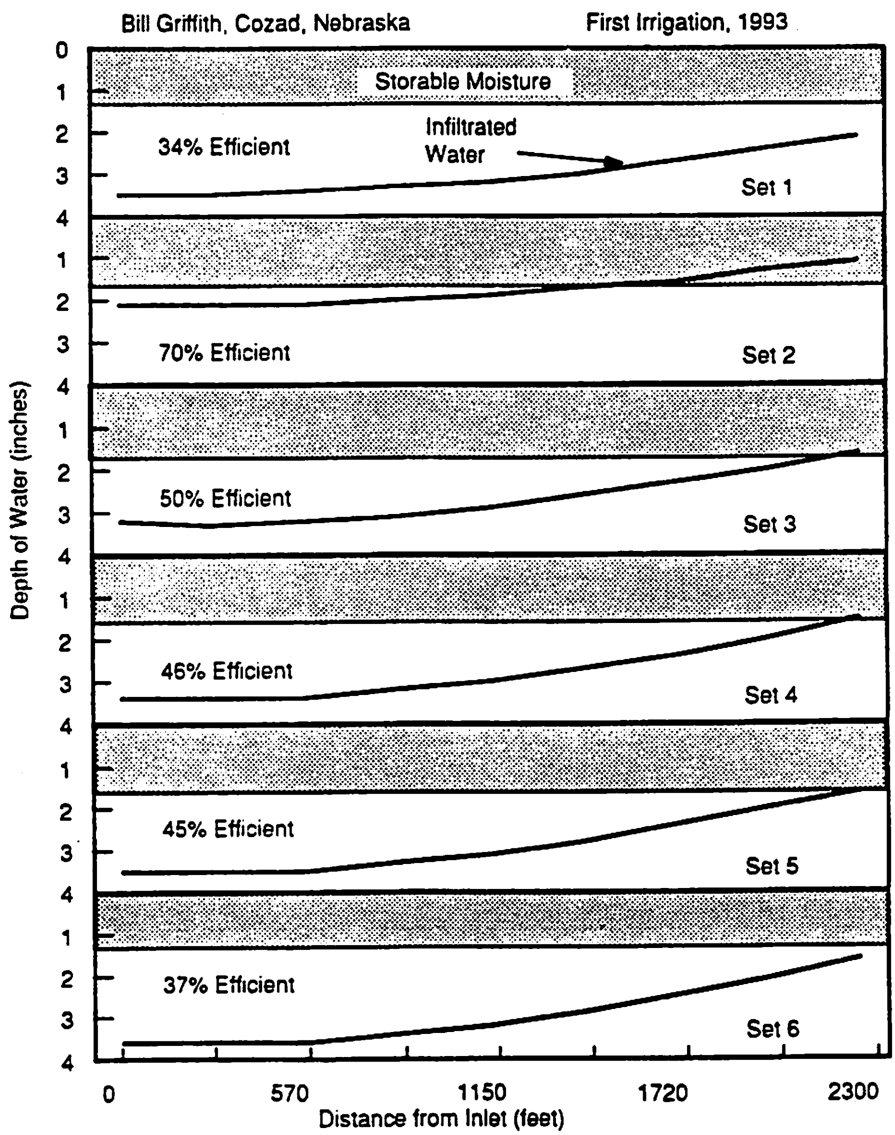


Figure 1. VBMM results for Bill Griffith's first irrigation.

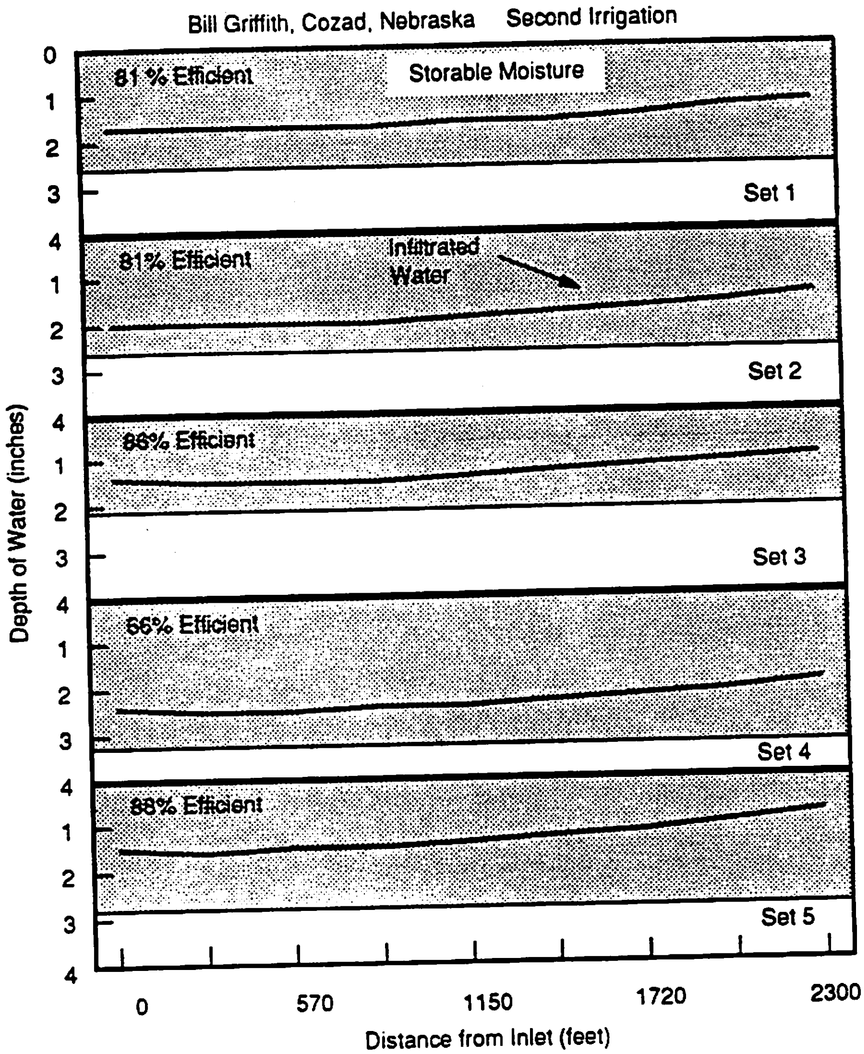


Figure 2. VBMM results for Bill Griffith's second irrigation.

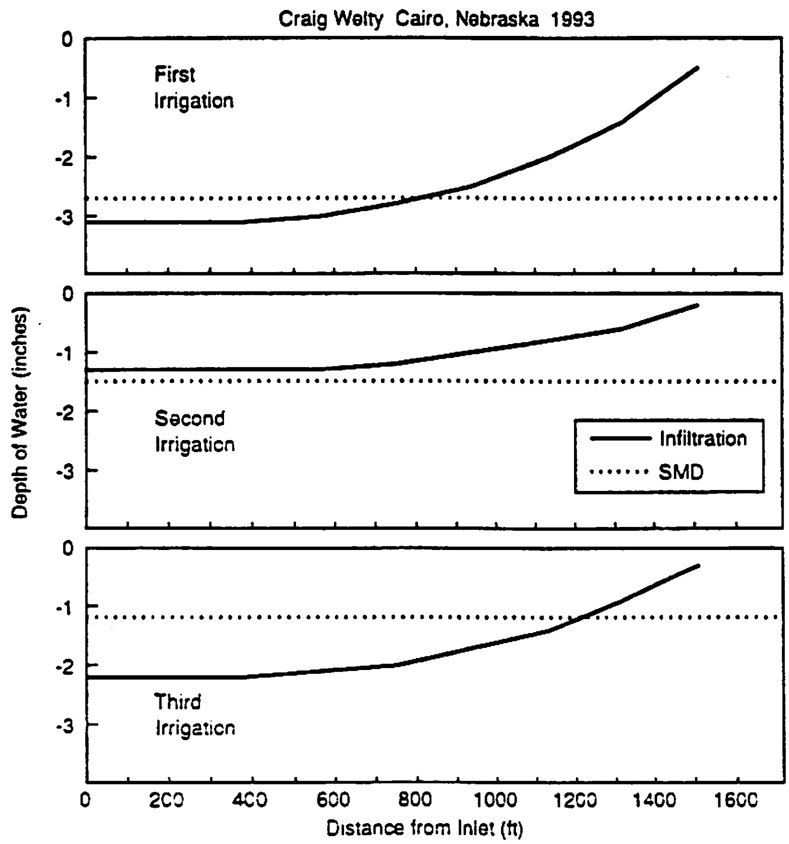


Figure 3. VBMM results for Craig Welty's site for the first set in each irrigation event.

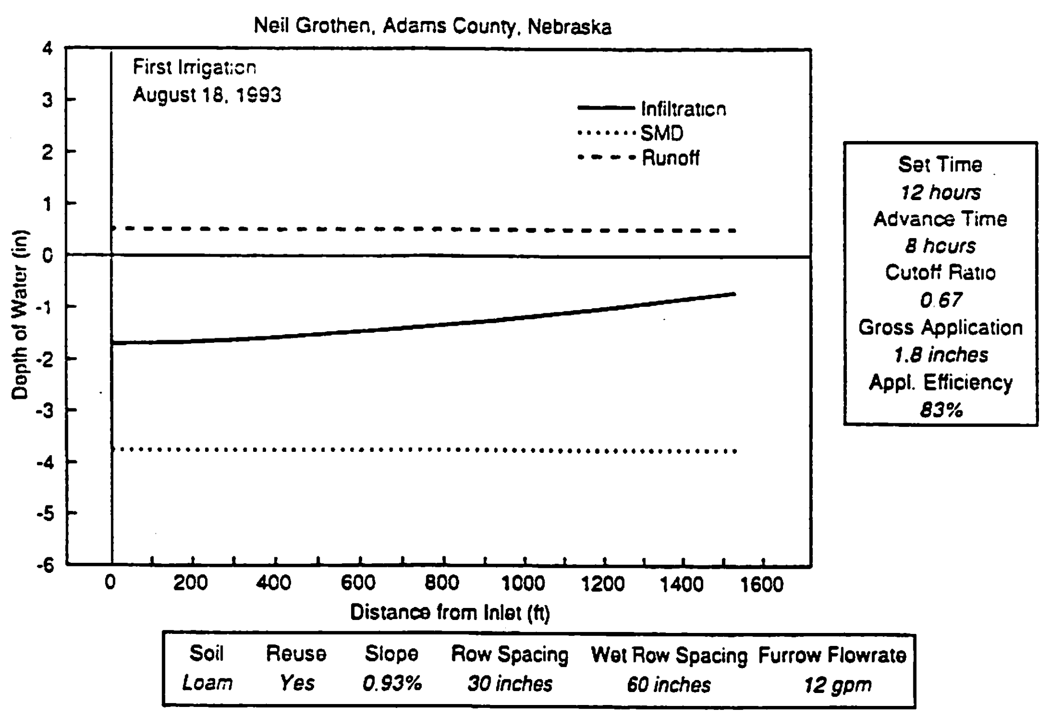
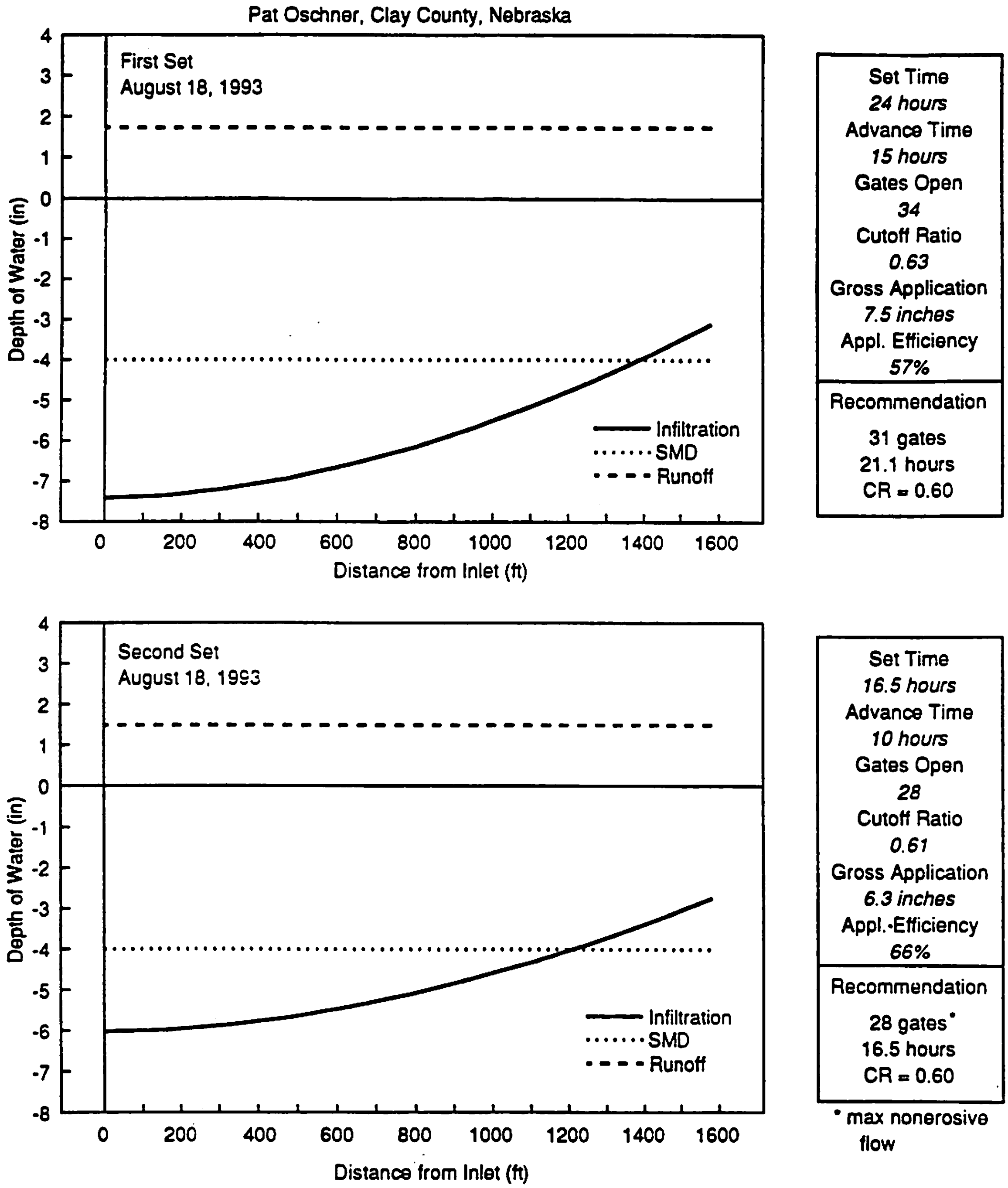


Figure 4. VBMM results for the first set of Neil Grothen's only irrigation.



Soil	Reuse	Slope	Row Spacing	Wet Row Spacing	Pump Flowrate
Loam	*No*	*0.5%*	*36 inches*	*48 inches*	*700 gpm*

Figure 5. VBMM and CR results for Pat Oschner's site.

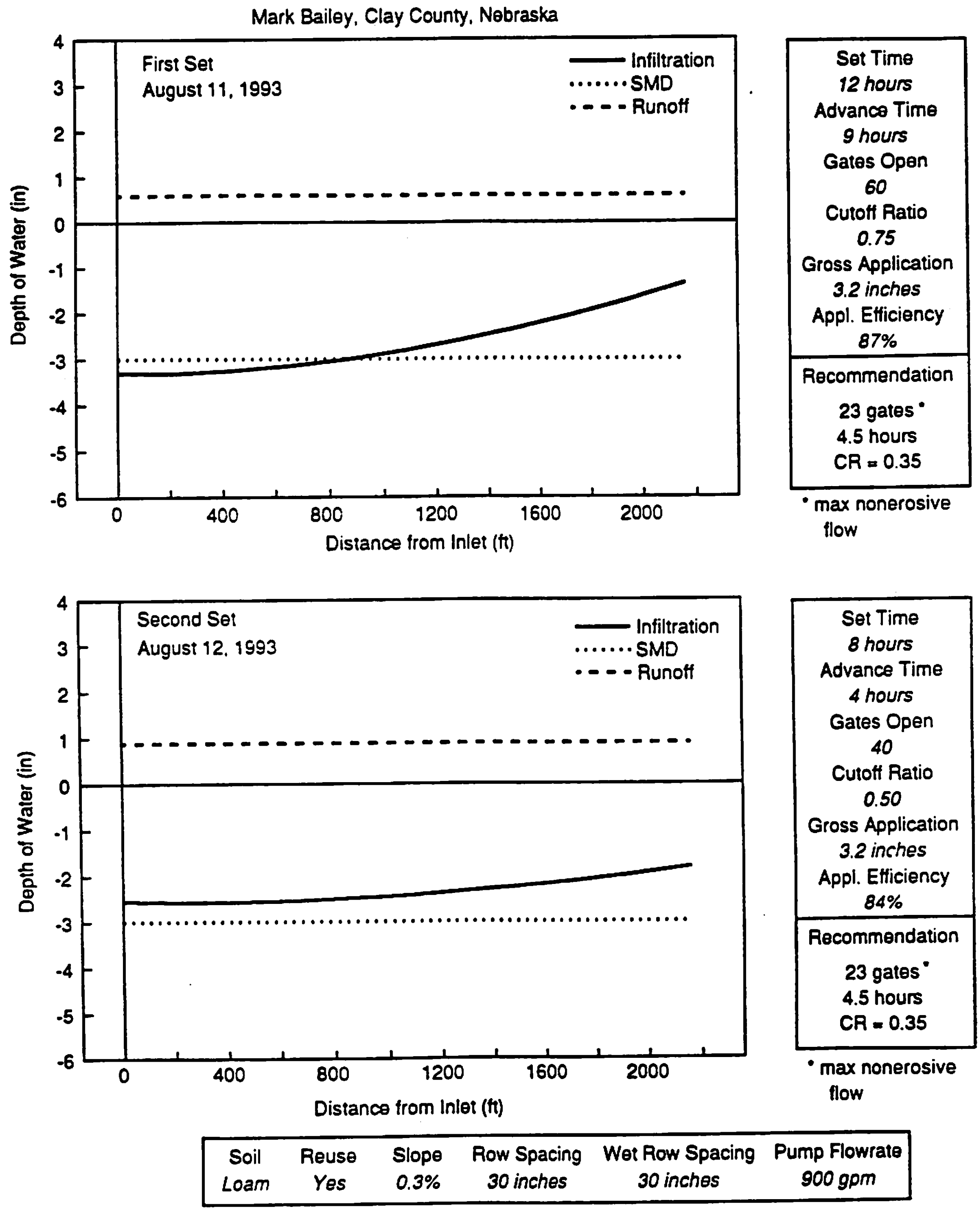
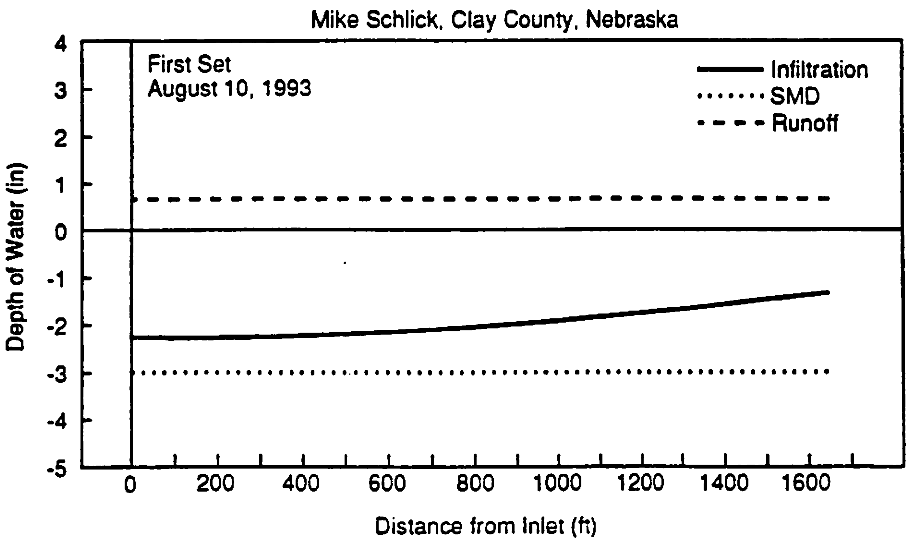


Figure 6. VBMM and CR results for Mark Bailey's site.

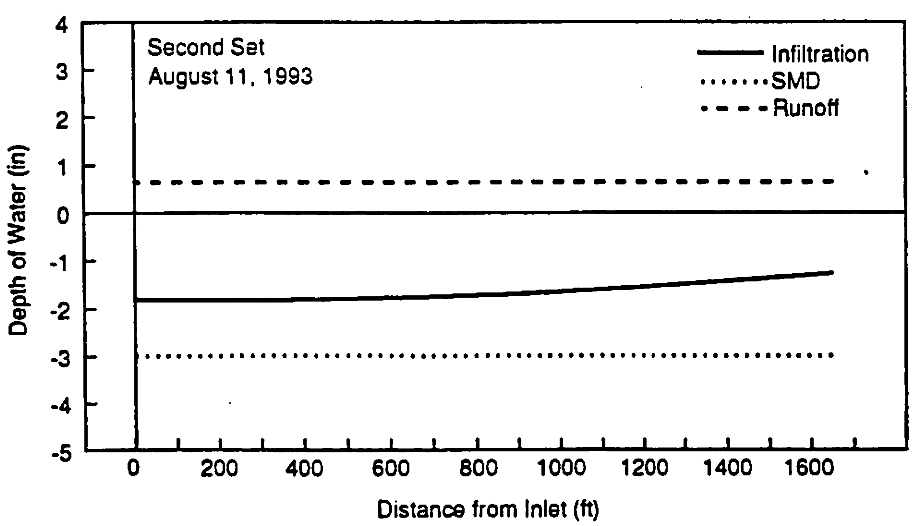


Set Time
12 hours
Advance Time
6.5 hours
Gates Open
75
Cutoff Ratio
0.54
Gross Application
2.6 inches
Appl. Efficiency
85%

Recommendation

35 gates *
5.6 hours
CR = 0.35

* max channel capacity



Set Time
7 hours
Advance Time
3.5 hours
Gates Open
50
Cutoff Ratio
0.50
Gross Application
2.3 inches
Appl. Efficiency
84%

Recommendation

35 gates *
4.9 hours
CR = 0.35

* max channel capacity

Soil	Reuse	Slope	Row Spacing	Wet Row Spacing	Pump Flowrate
Loam	*Yes*	*0.23%*	*30 inches*	*60 inches*	*1400 gpm*

Figure 7. VBMM and CR results for Mike Schlick's site.

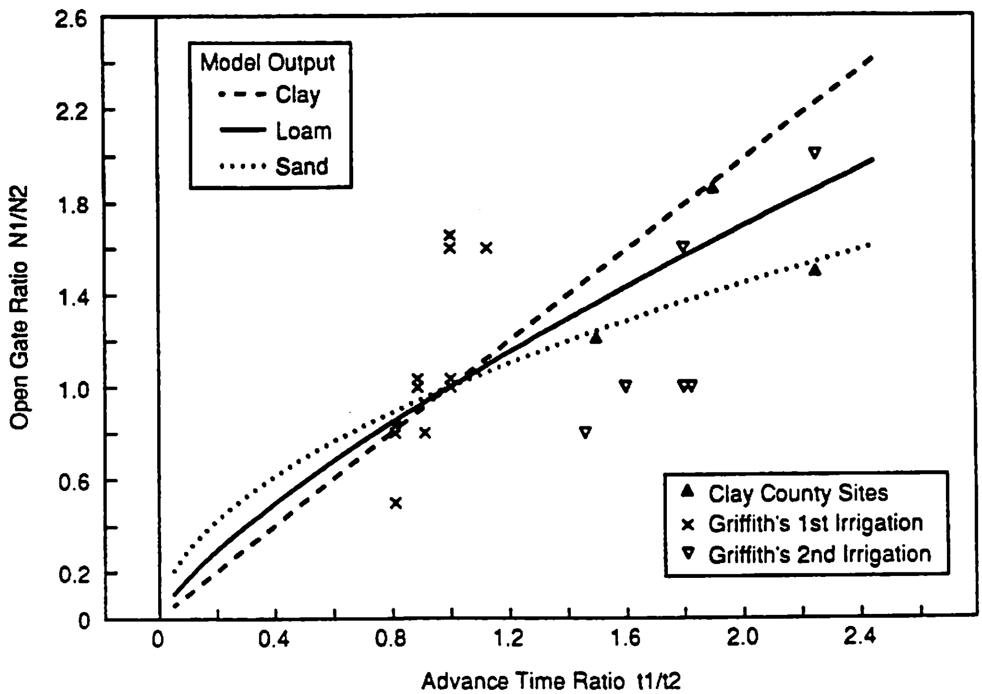


Figure 8. Observed values of relative advance time and open gates compared to the model results for the three sites in Clay County, 1993.