SURGE IRRIGATION

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INTRODUCTION

These guidelines are intended to assist SCS field technicians provide technical assistance to farmers in the effective use and management of surge irrigation.

Because surge irrigation is a relatively new practice and research to date is somewhat limited, it is likely that more information and newer engineering techniques to design and manage surge flow irrigation will become available in the future.

The guidelines are primarily concerned with surge flow furrow irrigation, as surge flow with borders has not been studied enough to be included at this time.

Surge flow techniques can increase surface irrigation efficiencies. If irrigation efficiency can be increased, the savings will be twofold. Not only will water be conserved by increased efficiencies, but energy will also be saved because less water will need to be pumped. It should be noted that surge flow is designed primarily for use with gated pipe systems.

Based on field observations of surge irrigation, the efficiency of many surface irrigation systems can be considerably improved. Some researchers believe that the efficiency of irrigation could increase from an average of 50 percent to 70 percent or more. This means that there is a potential water savings of millions of acre-feet per year if surge irrigation is used where it is effective. However, if not properly managed, surge irrigation can seriously underirrigate the field or increase the volume of tailwater as compared to continuous flow irrigation. Skilled labor is needed to manage surge systems effectively.

Although the original concepts and equipment were provided by researchers, the progress made in introducing surge irrigation has been due to the cooperative efforts of Soil Conservation Districts, Irrigation or Water Districts, Surge Equipment Suppliers, Resource Conservation and Development groups, SCS technicians, and farmers willing to try a new practice.

Even though there are many cases of success, there are also cases where surge irrigation has not been effective. Surge irrigation is only another technique in irrigation and is not a cure-all. When working with the farmer, all topics related to irrigation need to be addressed--such as soils, slopes, erosion, crops, flow rates, and plant, soil, and water relationships.

ADVANTAGES-DISADVANTAGES

OF USING SURGE

Advantages

1. Water applied intermittently with surge advances more rapidly to the end of the field for a given application. This reduces the opportunity time (the time that is available for water to infiltrate the soil) at the upper end of the field in relation to the lower end. The result is less deep percolation at the upper end and a more uniform application.

2. Some of the newer surge controllers can be programmed to split the flow between the two sets or use shorter "on-times" for cutback irrigation after the water has reached the end. This is effective in reducing tailwater.

3. Surge allows a lighter application of water with a higher efficiency.

4. Surge irrigation offers the farmer more management opportunities to save water and energy. A lighter irrigation could leave room to store precipitation and reduce irrigation requirements.

5. Properly managed surge flow irrigation will reduce the amount of water pumped and the energy requirements by improving the application efficiency, as compared to the more conventional continuous flow irrigation.

6. Surge flow irrigation is a form of automation which will allow a farmer to practice cut-back furrow irrigation without adjusting gates.

Disadvantages of Using Surge

1. Because less time is needed to get the water to the end of the field, the farmer may under irrigate if he is in the habit of moving to the next set as soon as the furrow is out. As a result the farmer needs to monitor the soil moisture more often than with the continuous methods.

2. The ability to put on lighter applications may under irrigate the crop if the farmer does not adjust his irrigation scheduling accordingly.

3. Surge irrigation requires a higher degree of management which may be a problem when using unskilled labor.

4. The surge equipment must be maintained to operate properly. A malfunctioning valve can cause crop damage. Dirty water can affect the control mechanism of some valves causing them to malfunction.

5. Excessive tailwater may result from improperly set surge flow valves.

6. The farmer may not know where he is in the cycle sequence if the well shuts off during the irrigation.

SURGE IRRIGATION THEORY AND TERMINOLOGY

Continuous Flow Irrigation (Furrow)

In continuous flow (conventional) irrigation, a large furrow stream size is needed to rapidly advance the stream from the head to the tail of the field for a uniform irrigation application and to minimize deep percolation. This larger stream usually will result in excessive runoff because it exceeds what is needed to satisfy infiltration (see figure 1). A smaller stream size will reduce runoff but usually results in excess deep percolation because of the slower advance and longer opportunity time at the head of the field. If a larger initial furrow stream is used for advance and a smaller cutback furrow stream is used after the stream has advanced to the tail of the field, both deep percolation and runoff can be reduced. In continuous flow furrow irrigation, the cutback stream requires the irrigator to come back to the field and reset his stream sizes and then find another use for the water that is not being used due to the cutback.

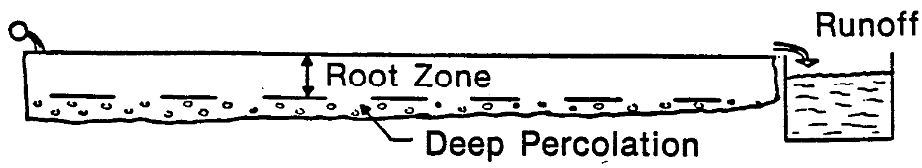
Surge Flow Irrigation (Furrow)

Surge flow irrigation has been defined as "the intermittent application of water to furrows or borders creating a series of on and off periods of constant or variable time spans". Usually the water is alternated (switched) between two irrigation sets (on about one- to two-hour increments) until the irrigation is completed. The switch is accomplished with a surge valve and an automatic controller.

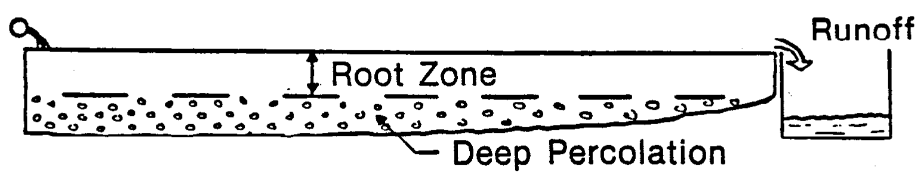
In a typical installation, water is delivered to a surge valve and controller located between two irrigation sets. Gated pipe is used to distribute the irrigation water to each of the two sets from opposite sides of the surge valve. On many soils the experience has been that the same stream size under surge flow irrigation will advance to the end of the field on both sets in nearly the same amount of time it takes the continuous flow method. This would mean that water has advanced to the end of twice as many furrows with about the same amount of water and time (see figure 2). Surge flow greatly reduces the intake at the top end of the field because the opportunity time is much less than under the continuous flow method (see figure 3).

The reasons for the surge effect (reduced water volume for advance) are not fully understood. Several reasons have been suggested. Surging creates a wetting time and a drying (recession) time for each surge; this allows water to soak in and dissolve soil clods, thereby allowing the soil to settle with the water to form a slick, consolidated, sealed surface reducing the intake rate and producing a smoother and hydraulically efficient surface for the next surge. In clay soils, the clay particles continue to progressively swell, even during recession, so that the next surge finds even less infiltration opportunity in the previously wetted

A. Large Furrow Stream - excess runoff and limited deep percolation



B. Small Furrow Stream - excess deep percolation and limited runoff



C. Large Initial Furrow Stream and Small Cutback Furrow Stream limited runoff and limited deep percolation

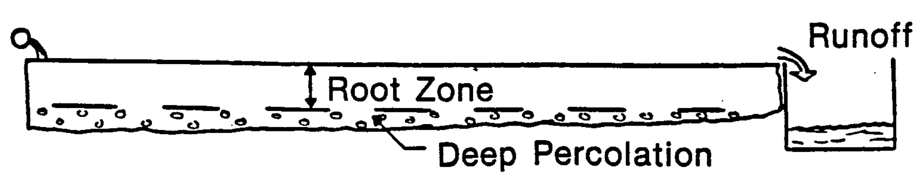


Figure 1. Furrow Irrigation

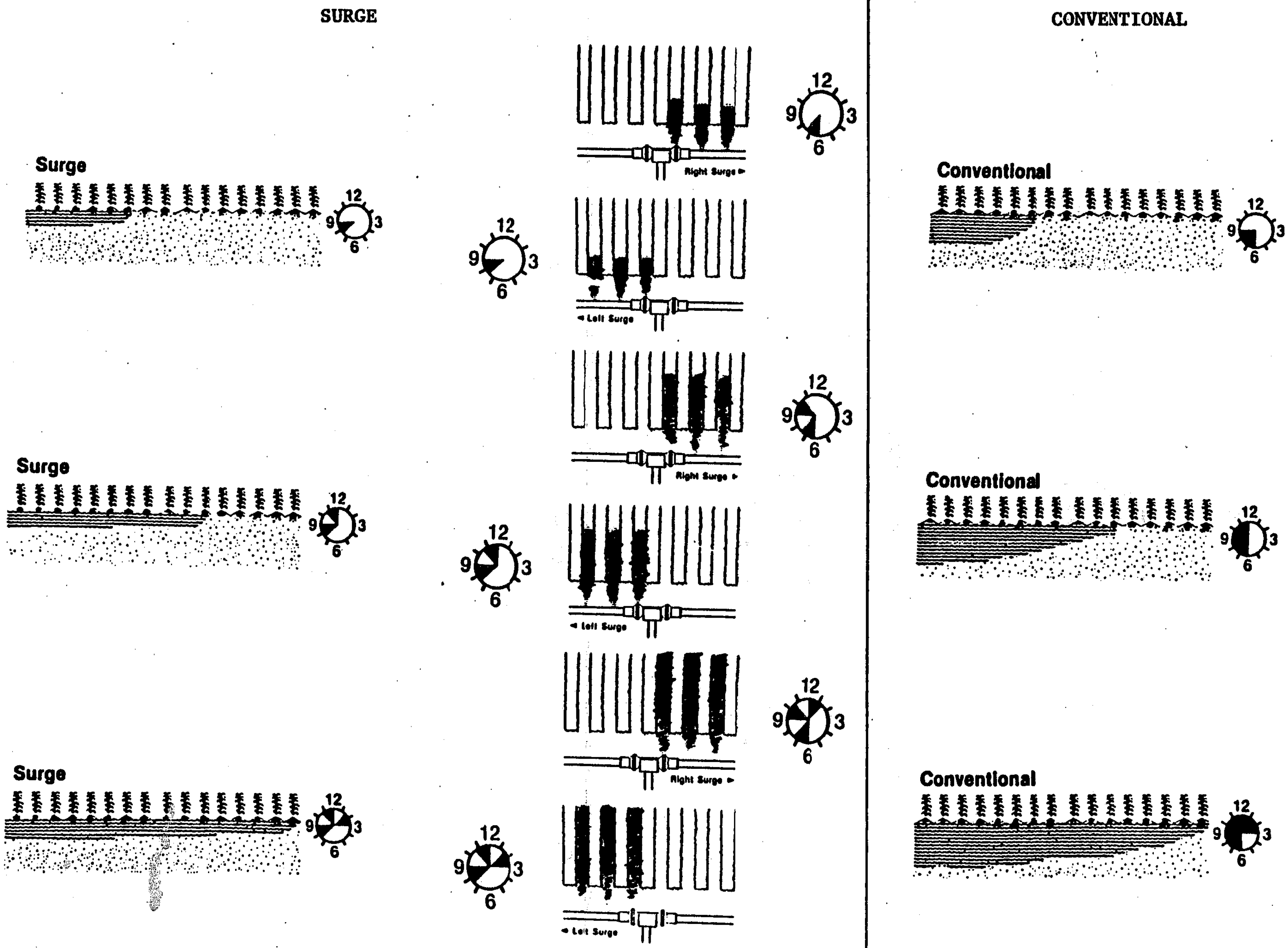


Figure 2. Surge Irrigation vs Conventional

▲ On Time △ Off Time

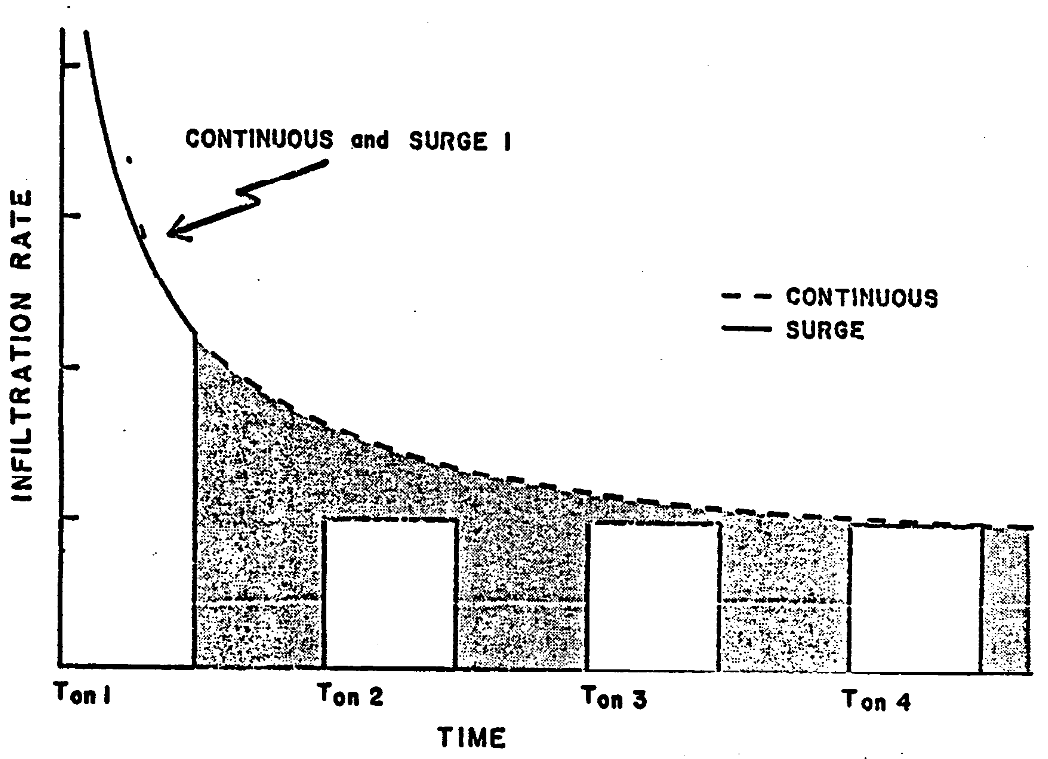


Figure 3. Differences in Infiltrated Volume on an Elapsed Time Basis During Advance Under Surge Irrigation [2]

section. Another explanation suggested is that as each surge flow recedes, the capillary attraction of the soil and water traps air bubbles that block the small pores of the surface soil and slows down infiltration. During each new cycle, the furrow stream retains a higher velocity as it travels over the already wetted and smoothed soil and slows as it reaches the drier soil. Infiltration is a function of wetted perimeter, the second surge would have a smaller wetted perimeter, thus reduced infiltration. Surge flow allows light irrigations to be applied more efficiently, such as an irrigation needed to germinate a crop when the furrows are loose and cloddy. Heavier applications may take longer under surge flow than under continuous flow due to the decreased intake rate and opportunity time. If the on-times are not changed after the furrows have advanced out, the runoff may be much more under surge.

Newer controllers have the capability to reduce the on time to increase opportunity time on both sides. When the on-times are shortened, you can get essentially a cutback furrow stream. 1/ By using the short on times, the furrow does not completely dewater before the next surge is applied; therefore, the advance and recession merges. Another alternative would be to set the surge valve to allow to water both sides at the same time giving a 50% cutback furrow stream. It may be difficult to get a balance on both sides if there is a head difference between the two sets.

If we were able to get an instantaneous furrow stream advance to the end of the field and then select a stream size that would just satisfy the intake requirements of the furrow, we could approach 100% irrigation uniformity and have very little runoff. We cannot obtain 100% efficiency but we can work toward it. Surge flow irrigation, in many situations, can overcome the management problems of using a cutback stream size with continuous flow irrigation.

Advance, Recession and Infiltration

We use advance and recession curves to illustrate the opportunity time available for water to infiltrate into the soil along the length of the furrow. If we know the water infiltration characteristics of the soil and the opportunity time, we can estimate the amount of water infiltrated into the soil at various locations along the length of the furrow.

Figure 4 shows the surface and infiltration profiles in a furrow. The surface profile advances towards the end of the furrow, and the infiltration profile advances downward and toward the end of the furrow. Irrigation efficiencies relate to the shape and magnitude of the infiltration profile.

1/ Attempts to develop automatic cutback irrigation systems determined it was much easier to turn water either on or off rather than to reduce the flow incrementally or continuously. It was simpler to cycle half of the valves on and half off to reduce the average flow rate instead of partially opening or closing valves. This cycling led to the discovery of the surge phenomenon.

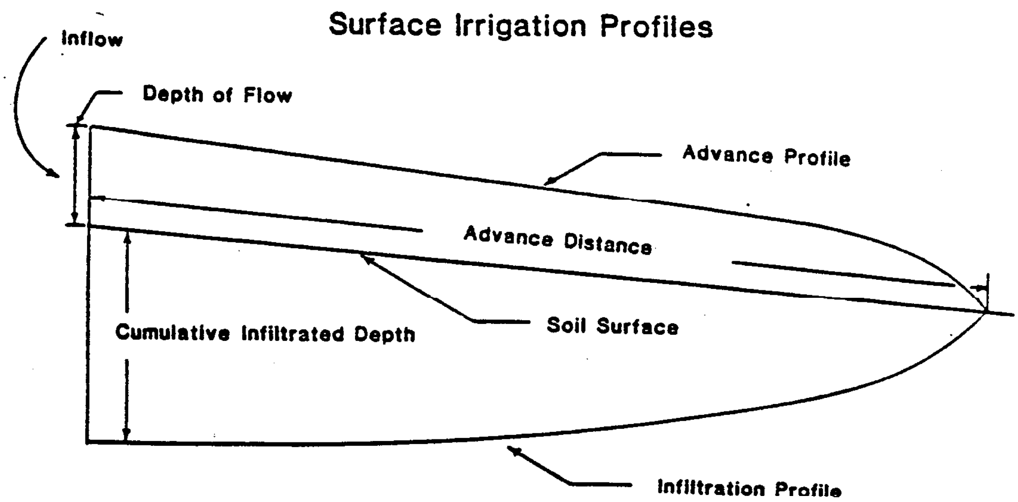


Figure 4. Water Surface and Infiltration Profiles [1]

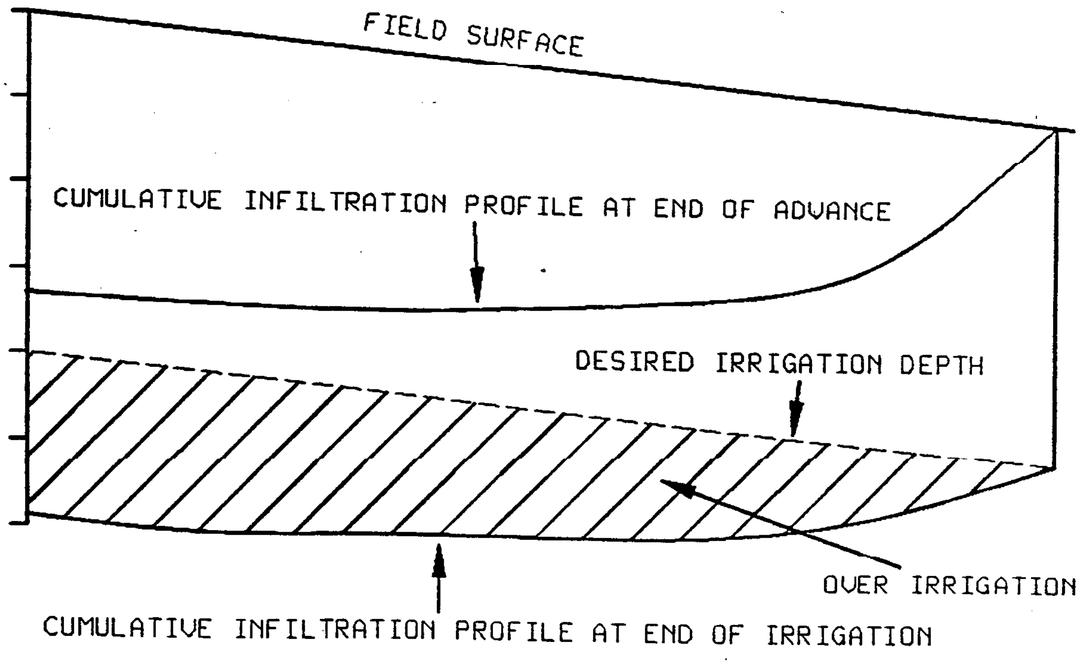


Figure 5. Cumulative Infiltration Profile

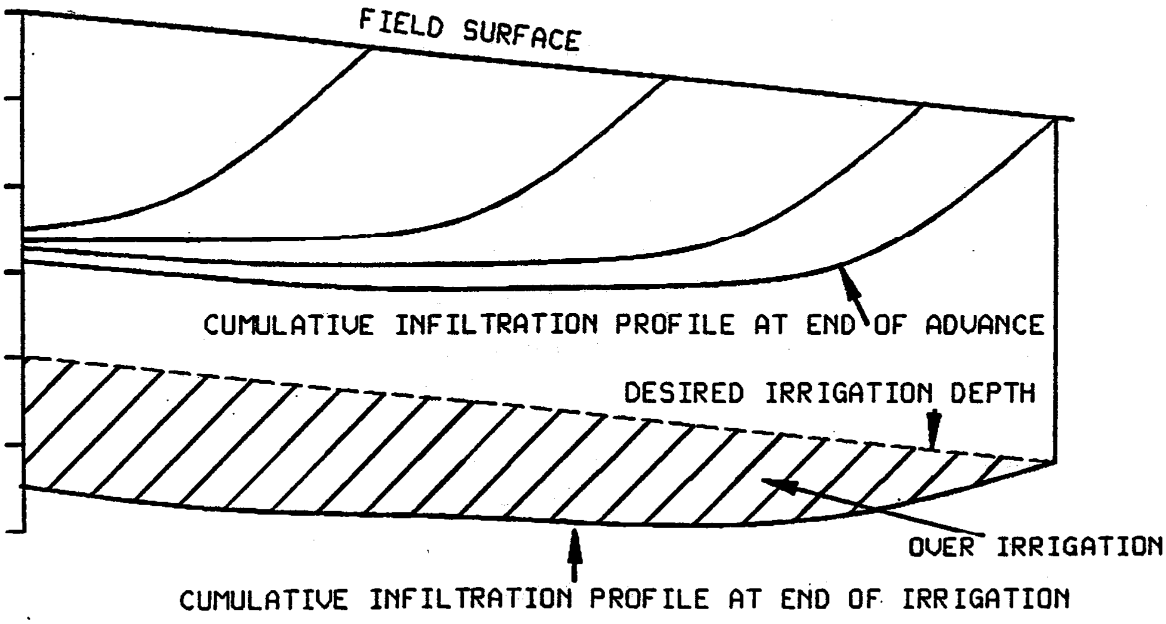


Figure 6. Cumulative Infiltration Profile Using Surge Flow with Uniform On-Times

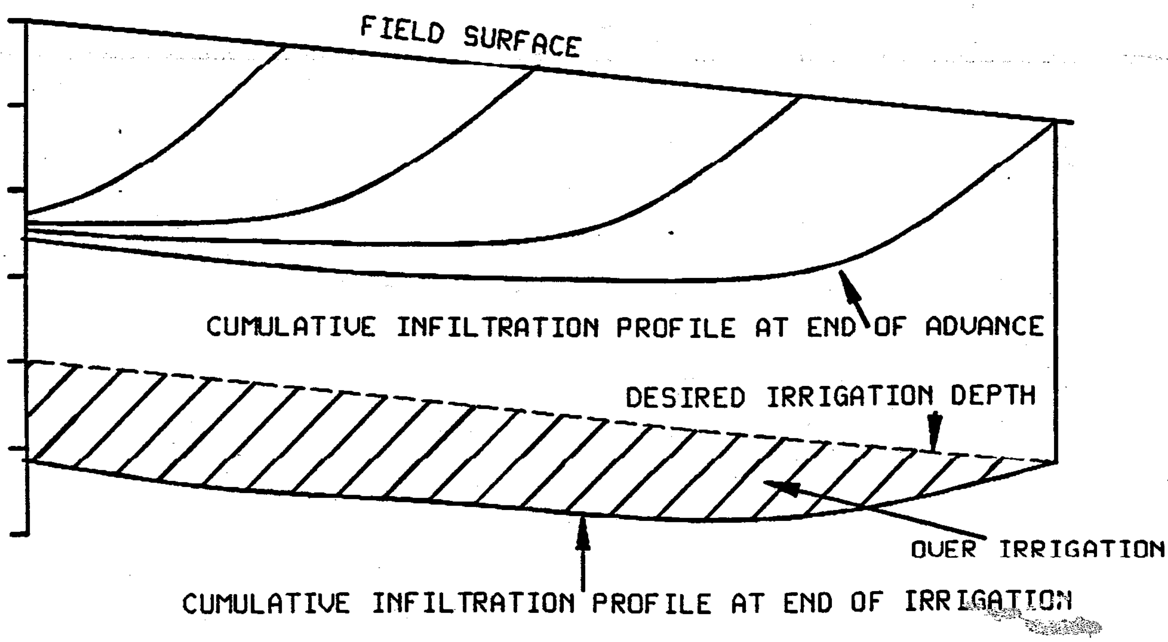


Figure 7. Cumulative Infiltration Profile Using Surge Flow with Increasing On-times

Advance Profile. When water is applied to the furrow, part of the inflow infiltrates, and the rest remains on the surface and advances down the furrow. The advance is affected by many physical processes including furrow slope, roughness, and shape. However, the inflow rate and the infiltration characteristics of the soil primarily determine the surface storage and the rate of advance.

Ideally, the water should advance rapidly so that the tail end of the furrow starts receiving water before over-irrigation occurs at the inlet. Moreover, it would be ideal if the advance rate paralleled the recession rate after the inflow is stopped. Therefore, any method of quickening the wetting front advance by changing the hydrodynamics of the overland flow (through surge flow) or favorably altering infiltration characteristics (possibly achieved through soil surface changes due to surge flow) will improve surface irrigation efficiency.

Figure 5 illustrates the cumulative depth applied profile when the water reaches the end of the furrow and after the root zone is filled at the end of continuous flow irrigation.

Figure 6 illustrates the cumulative depth profiles after several surges of equal on times and at the end of surge flow irrigation.

Figure 7 illustrates the cumulative profiles after several surges of equal advance by increasing on-times and at the end of the irrigation. This may decrease the intake at the head of the field.

Recession. After water application to the furrow is stopped, the surface water remaining in the furrow continues to infiltrate into the soil and flow down the furrow until it is gone. The time of recession is when the water disappears from the furrow surface. This is the end of opportunity time. In graded furrow irrigation, this usually begins at the head and travels to the lower end. Figure 8 is an illustration of advance and recession curves. The advance and recession curves are drawn by plotting lapsed time measured from the time water is turned into the furrow, against the length down the furrow for both advance and recession. The time between the two curves is the opportunity time. If an irrigation curve is drawn parallel to the advance curve at a time interval of needed opportunity time, you can see if the opportunity time is greater than or less than the required time for infiltration.

In surge flow irrigation, the water is applied intermittently, giving a series of advances and recessions. This makes it more difficult to use advance and recession data to determine opportunity time and water infiltrated.

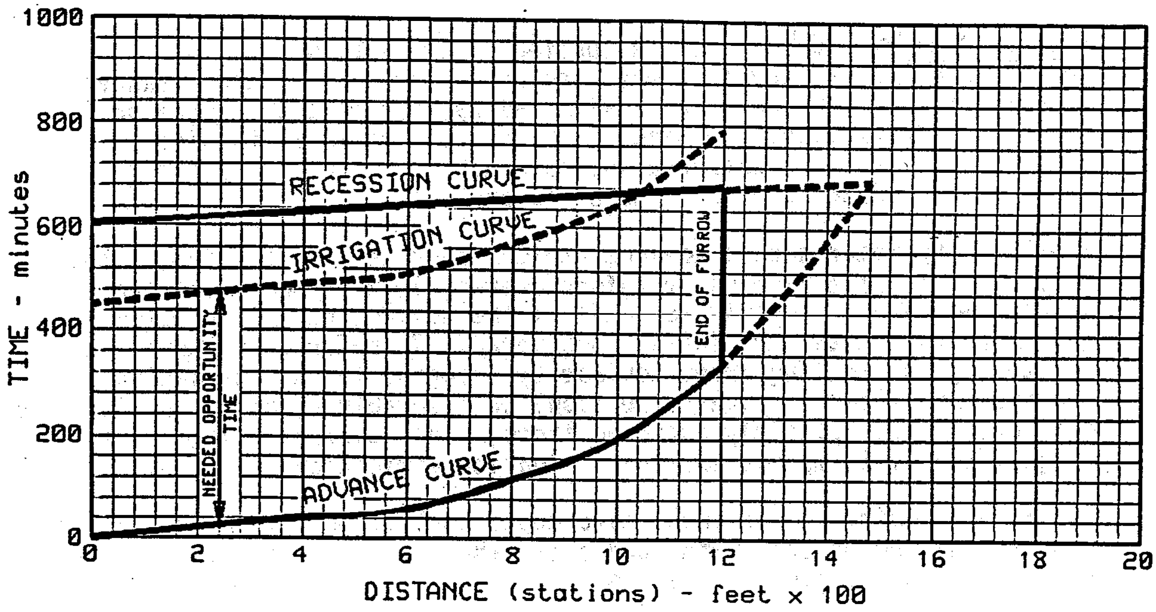


Figure 8. Advance and Recession Curves

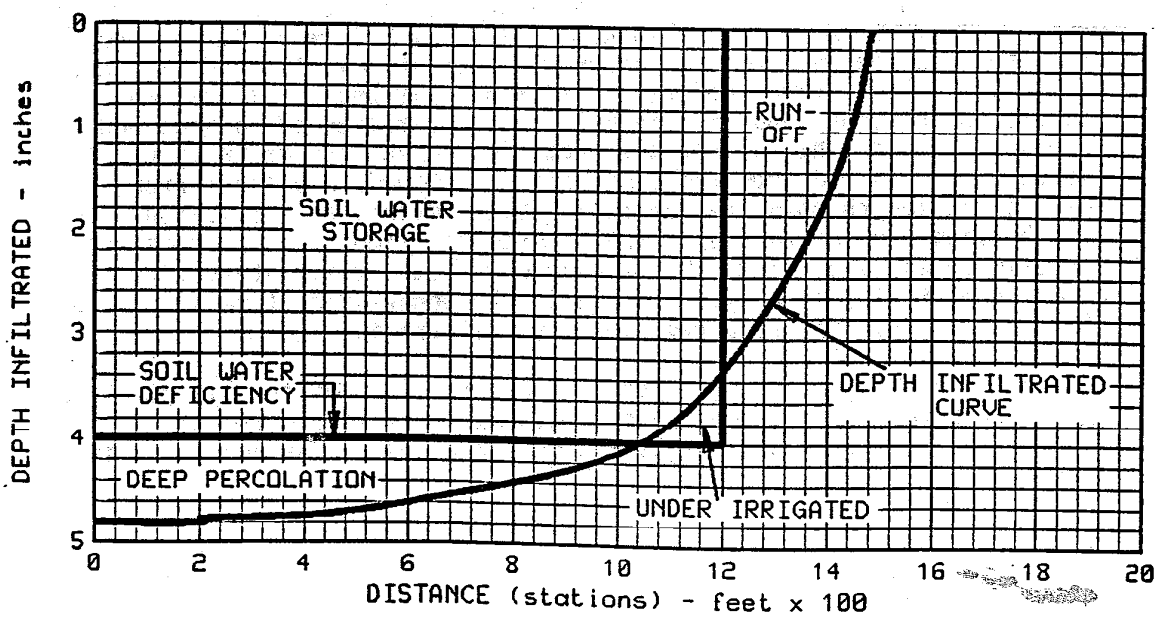


Figure 9. Depth Infiltrated Curve

Infiltration. Infiltration characteristics in a heterogeneous soil vary with space and time. Factors influencing infiltration are soil texture, and structure; type of clays, and cations in the soil. Some factors are relatively static while others change. Seasonal soil changes cause variations in the infiltration characteristics. Reasons for these changes include cultural practices and the related soil compaction, growth or decomposition of vegetation, and biological or microbial activity. Intake or infiltration is a complex physical process which is difficult to describe quantitatively for the conditions found in irrigated fields.

Overall, infiltration characteristics are somewhat transient. Many of these changes are not controllable. However, as suggested earlier, some infiltration change may result from surge flow. The change in furrow intake apparently occurs because of surface layer consolidation following desaturation between surges.

Figure 9 is an illustration of a depth infiltrated curve. Using the opportunity time from figure 8 and the appropriate furrow family intake curve, the depth infiltrated can be determined down the length of the furrow. If the advance and recession curves on figure 8 are extended until they meet, this will represent runoff from the field. On figure 9, the area above the field soil water deficiency (SWD) line and to the left of the end of the furrow line represents the amount of water stored in the soil. The area below the SWD line represents deep percolation. The area to the right of the end of the furrow represents runoff.

Surface storage, recession, and runoff. Surface storage and the recession of water after the inflow is stopped are important to irrigation efficiency. Part of the water in surface storage will infiltrate into the soil and part will runoff. The runoff (or tail-water) is lost unless a return flow system is installed. Furrows may be blocked at the end to pond water, but in many cases much of this water will ultimately be lost to percolation below the root zone.

Furrow shape, slope and roughness. Furrow shape reportedly does not noticeably affect the advance or infiltration characteristics. Furrows are usually parabolic in cross-sectional shape and can be described with a quadratic function. The furrow shape will usually change somewhat with time. This change is related to erosion and sediment transport in the furrow.

Average ranges in magnitude of a uniform furrow run slope do not appreciably affect advance and infiltration characteristics. However, nonuniform slopes can greatly affect advance and therefore irrigation efficiency.

Furrow roughness will affect the advance; but, the effects have not been studied in detail. The roughness will change throughout the season due to irrigation and rainfall.

Wetted Perimeter and Furrow Shape. Infiltration into furrows is a function of intake opportunity time and wetted perimeter of the furrow cross section. During the advance phase of furrow irrigation the wetted perimeter at a given longitudinal location increases with time and then slightly decreases after a static period. The slight decrease may be due to a reduction in furrow roughness with an increased conveyance capacity permitting a reduced flow depth.

Terminology

Cycle Time: The sequencing pattern of surge flow is created by a series of on/off water applications to the furrow. The cycle time is the period of time to complete an on/off cycle: The cycle time may be of any desired duration and can vary from a few minutes to hours.

Cycle Time = Valve on-time plus Valve off-time

On-time (Half-cycle:) The time that water is allowed to flow on one side of the surge controller before it is switched to the other side.

On-time is important as it interacts with the dead storage and infiltration requirements. An on-time that is too short will limit the rate of advance of the furrow stream and it may not reach the end of the furrow. Also if the ontime is too short, the furrow may not be dewatered long enough for the effects of surge to develop. On the other hand, an on-time that is too long will begin to approximate continuous flow, and the irrigation will operate in a continuous flow mode rather than a surge flow mode.

Infiltration characteristics for a given field will largely determine the optimal surge cycle time for the field. Since infiltration changes during the irrigation season, the cycle time may need to be adjusted.

Cycle Ratio: The cycle ratio is the ratio of the time that the valve is open to the cycle time.

$$\text{Cycle Ratio} = \frac{\text{Valve on-time}}{\text{cycle time}}$$

A cycle ratio of 0.5 is prevalent today and indicates that the valve on-time is equal to the valve off-time.

Irrigation Time: The irrigation time is the total time the water is being applied to a set or sets.

Application Time: The time water is actually applied to a furrow. It is usually the same as irrigation time for continuous flow furrow irrigation and a fraction of irrigation time for surge flow irrigation.

Advance Time: The time it takes water to advance from the upper end to a selected station along the furrow, or the lower end frequently called travel time, (minutes or hours).

Infiltration Time: The time required for the desired water application to infiltrate into the soil.

Recession Time: The descending part of a stream flow or the time lapse after water application has stopped until the water recedes or disappears from the surface at selected stations along the furrow (minutes or hours).

Opportunity Time: Opportunity time is the time that water stands on the surface enabling water to penetrate or infiltrate the soil. It is computed for stations by finding the difference between advance time and recession time.

Irrigation Set: A furrow irrigation set is the group of furrows that is being irrigated at the same time. In surge flow irrigation flow it is alternated between two "sets" of furrows.

SOILS AND INFILTRATION

The suitability of an individual soil series for surge flow irrigation is dependent upon its physical properties. Soil behavior is influenced by the inherent morphological properties, as well as, temporal properties associated with cultural practices.

Section 15, Chapter 1, of the National Engineering Handbook defines those properties most important to irrigation. These are applicable to surge irrigation as it is a surface irrigation method. The primary soil properties of interest are texture and structure as they influence intake. These properties are inherent and remain stable over time if the soil is undisturbed. Cropland soils, however, do not remain in an undisturbed condition. Infiltration and permeability are influenced by the physical condition of the tillage zone (tilth). They vary with the cultural practices employed prior to, and during the crop season. For this reason, they are considered temporal soil properties.

Variations in the lower tillage zone density are commonly associated with differences in intake. Plowpans are examples of high in-place densities which restrict hydraulic conductivity and enhance runoff. As the in-place density increases, there is a corresponding decrease in intake rate. This tends to reduce the effectiveness of surge irrigation.

The presence or absence of surface crusting influences infiltration. A crust is a surficial zone, with well expressed mechanical continuity of the soil fabric, resulting from reconstitution. Raindrop impact and freeze-thaw processes are mechanisms of reconstitution. A third kind of crust is formed by and in locally transported sediment such as by a furrow stream. These crusts are referred to as fluventic crusts.

This type of crust for the same thickness appears to offer less resistance to seedling emergence and may have higher infiltration rates than reconstituted crusts. They appear, however, to reduce infiltration and thus increases the rate of advance.

The tendency of a soil to crust is related to surface texture. Soils with high contents of silt and very fine sand tend to form a crust readily. These include: silt loam, silty clay loam, clay loam, and loam. Other textures may need field examination to determine suitability.

Because of morphological differences in individual soil series that are related to geographic locale the designation of soils suitable for surge irrigation should be done at the area level. In addition, on site investigations should be made to determine the presence or absence of plowpans on these soil types which are highly susceptible to compaction.

The Soil Properties Record may be used to identify and document those combinations of soil and cultural practices which lead to poor physical conditions. For a more detailed discussion, see Appendix A, Surge Flow Irrigation Infiltration.

SURGE IRRIGATION MANAGEMENT

Surge flow requires a greater level of management (skill), than conventional furrow irrigation, but less labor. Helping the farmers get off to a good start with surge irrigation is the major goal of this guide. We do not have the scientific equations or charts to help us provide advice to farmers on surge irrigation. Researchers are working on this, so eventually we may have this kind of help available. The advice that we can provide is based on the experience of technicians that have been working with farmers applying surge irrigation.

Surge on-time and furrow stream size are the two major variables we can work with in managing surge. Experience has provided some good starting points. Evaluations and studies of the results will help with fine tuning.

Stream Size

Selecting the proper stream size and the time of irrigation are important if surge irrigation is going to prove successful to the farmer. In some situations, this requires the farmer to change the number of rows he has been irrigating as a set to get the proper stream size.

One method of determining the minimum furrow stream size (gpm) is by dividing the length of the field or furrow (in feet) by 100 and multiplying by 2.

$$Q\ (\text{gpm}) = \frac{L\ (\text{feet}) \times 2}{100}$$

This method of determining the minimum stream size should be qualified for a soil type or intake family.

Another method for estimating a proper stream size is based on an estimate on how much water is needed to advance the furrow to the end by using the following equation:

$$Q = \frac{FLW}{1.6041\ TE}$$

Q = Inflow rate or stream size (gpm)
F = depth of water application (inches)
L = Furrow length (feet)
W = Row width or spacing (feet)
T = Time of application (minutes)
E = Application efficiency (%/100)

For the time of application (T), use the total expected time for the water to get to the lower end of the field on one side of the surge valve. (ie 360 minutes per side). The depth of application is the inches of water you want to apply to get water out. It will be less than the total irrigation depth, additional water will be needed for filling the profile. For an initial estimate, use a net D of 3.0 to 6.0 inches for pre-irrigation and right after cultivation and a D of 1.5 to 3.0 inches for all other irrigations, but judgment will be necessary. Refer to your State SCS Irrigation Guide for an estimation of efficiency. Remember that for advance there is no tailwater, the only loss will be deep percolation, so adjust efficiency accordingly. After Q has been determined, check to see how many gates can be opened at one time. Determine the number of sets required for the number gates opened at one time to irrigate the entire field. Next adjust Q, so that the number of sets is an even number.

Example: Q was calculated to be 27.7 gpm/furrow. The flow from the well is 554 gpm. This means 20 gates (554 gpm/27.7 gpm/gate) can be opened at one time. There are 90 gates on each side of the surge valve. It will take (90/20 gates per set) 4.5 sets. If the flow is nonerosive (as determined by State Irrigation Guide) for the soil type, the flow can be increased and 5 sets should be used for design. Ninety gates divided by 5 sets is equal to 18 gates per set. The 554 gpm divided by 18 gates per set is equal to 30.8 gpm. If the flow rate was excessive, then use the same procedure to determine Q for 4 sets. Now determine the net depth of application (D) applied for your design Q, with the other variables remaining the same. Finally, subtract the depth applied so far during the set from the total application depth required. Use this value to determine the additonal time required to provide a complete irrigation on each side using:

$$T = \frac{FLW}{1.6041\ QE}$$

The total set time will be the combined advance and cutback times. This time may change from one irrigation to the next. It is important that the total time to apply the desired volume of water for the desired depth of application be computed in order to prevent under-irrigation, but minimize wasted water caused by over-irrigation.

The furrow stream size determined above should be equal to or greater than the conventional irrigation stream recommended in the irrigation guide. The upper limit of stream size is controlled by erodible stream size and overtopping of furrows. Normal amounts of crop residues do not have a significant effect on water advance. The minimum stream size must also exceed the intake rate of the soil. For uniform efficiency, adjust streams so furrow advance is uniform among all furrows.

A change in stream size will usually require a change in set size (furrows per set) which the farmer may not be able or willing to do. Many times farmers have been able to get out or advance the water to the end of both sets in about the same time as they were able to do on one set using continuous flow furrow irrigation. In other words, advance twice as many furrows with about the same amount of water and time as the continuous flow or about one half of the water per furrow.

Advance Mode On-time

A rule of thumb for the time required for water to advance over previously wetted soil surfaces is 2 to 5 minutes per 100 ft. over bare soil, and 4 to 8 minutes when close growing crops are growing in the furrow. This is important for determining on-time.

If we assume we want to "get out" the furrows in from 4 (under ¼ mile) to 6 (over ¼ mile) cycles and actual application time per furrow is ½ of what conventional takes, the following "rule of thumb" can be used as a start to determine on-time for advance.

furrows ¼ mile long or less

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

furrows over ¼ mile long

$$\frac{\text{continuous flow out time}}{12} = \text{on-time}$$

Indications are that better results are obtained if each subsequent on-time is increased to get about the same advance distance each cycle. Some newer controllers have this capability.

Infiltration Mode On-time (Cutback)

Once the furrow is "out" it is desirable to split the flow between the two sets (cut-back) or shorten the on-time to maintain a wet furrow to increase the opportunity time. This will increase infiltration and reduce runoff. If the same on-time is used for the infiltration mode as for the advance mode, excess runoff may occur and the field may be under irrigated.

A "rule of thumb" may give an idea of what on-times should be. A better way to be certain surge irrigation is operating properly is to observe it. Also, surge may not improve the rate of advance on all soils or late season irrigations. If the rate of advance is too slow for efficient irrigation, you may reduce the number of furrows per set to increase the stream size, if the furrows can handle the larger stream and it is not erosive. Also, check the tailwater. If it is excessive, the "cutback" mode of surge may be effective in reducing tailwater.

Following are three alternative methods to determine proper on-times: The irrigator must be flexible and prepared to make needed adjustments.

ALTERNATIVE #1

VARIABLE TIME-CONSTANT DISTANCE METHOD

This method appears to be the most efficient and effective method of surge irrigation based on area Soil Conservation field experience and research done at Colorado State University. This is especially true on run lengths in excess of ¼ mile. Not all equipment available today has the capability of automatically utilizing several different surge on-times needed for practical use of this method. This method will probably be used more frequently when more surge controllers have been developed with this capability.

1. Set up two irrigation "sets" with a surge controller interconnecting the two "sets". This should be done preferably at the edge of the field to be watered that has the easiest access down the length of the field. Use the same size "sets" you normally use.

2. Measure off and flag points down the length of the set at 100' intervals, beginning at the upstream end of the furrows and ending at the downstream end.

3. Begin surge irrigation.

4. Allow water to advance down furrows on one set until approximately 75% of the furrows have advanced 300', then switch water to the other set and follow the same process. The time that is required to do this will be the initial on-time that will be used on the rest of the field.

5. During the second surge, allow water to advance down the previously wetted furrows and then allow it to wet up an additional 300'-500' of dry portion of furrows. The time that is required to do this will be the second on-time that will be programmed into the controller to be used on the remainder of the field.

6. Continue this process of determining consecutive on-times by wetting up a constant amount (300'-500') of dry furrows with each surge until the water has advanced to the end of the field. (Manual adjusting of various furrow flow rates will usually be needed to keep all rows advancing at the same rate.).

7. After the water has reached the end of the field, a reduced on-time should be programmed into the controller. This on-time will be set such that water will advance down the wetted furrows to a point approximately 3/4 of the distance down the field. At this time, the water should be switched to the other set. This will be the final on-time. Ideally, the remaining water in the furrow after switching will continue to advance to the end of the rows. If it fails to do this, the final on-time should be increased until it does. This final on-time will allow you to add additional layers of water to the furrow at a very even distribution rate while greatly reducing tailwater.

8. Use these established on-times on the remainder of the field if row conditions and lengths are similar.

ALTERNATIVE #2

CONSTANT TIME-VARIABLE DISTANCE METHOD

This method is most efficiently used on lengths of runs no more than ¼ mile and when the surge controller does not have the capability of automatically utilizing several surge times. (There may be problems of adequate stream size to get water out end of field).

1. Set up two irrigation "sets" with a surge controller interconnecting the two "sets". This should be done preferably at the edge of the field to be watered that has the easiest access down the length of the field. Use the same size sets you normally use.

2. Measure off and flag points down the length of the set at 100' intervals, beginning at the upstream end of the furrows and ending at the downstream end.

3. Begin surge irrigation.

4. Allow water to advance down furrows to approximately 35 to 45 percent of the length of the total run length. Use this time for your trial single on-time.

5. Using a single constant on-time will result in a lessening amount of dry furrow being wetted with each surge. The amount of dry furrow wetted up with each surge should be approximately 75% of the amount of dry furrow that was wetted up on the previous surge. Keep up with this and if about 75% of the previous wetting of dry furrow is not accomplished on the current surge, increase the single on-time by ½ hour intervals until this is accomplished.

6. There is one big disadvantage with using a single on-time. Once the rows are out, the single on-time that was required to get the water out will result in excessive amounts of tailwater. Ideally, one should go back after the rows are out and manually reduce the on-time to the time required to travel a distance of approximately 75% of the row length as described in Item #7 of the previous method. The system should then be allowed to surge until the desired amount of water has been supplied.

7. Use the established single on-time and the final on-time on the remainder of the field if row conditions and lengths are similar.

ALTERNATIVE #3

FLOW INCREASE METHOD

This method will utilize a portion of either Alternative #1 or Alternative #2 to accomplish rate of water advance down the rows. The difference in this method is that the number of rows per set will be altered.

1. Set up two irrigation "sets" with a surge controller interconnecting the two. This should be done preferably at the edge of the field to be watered that has the easiest access down the length of the field.

2. The big difference between this method and the first two methods is that the number of rows set on each side will be only ½ to 3/4 the number of rows normally used. The purpose of this is to increase the flow rate of each individual furrow thereby giving an even faster rate of advance. One must be careful, however, to maintain a nonerosive furrow stream. This method, as indicated by field experience, works best on higher intake soils or on extremely long lengths of runs and may not be an asset on normal run lengths for low intake soils.

3. Begin surge irrigation.

4. Follow either Alternative Method #1 or Alternative Method #2 as described previously until the rows are out. Using the increased furrow stream, however, requires a very short on-time on the final surge after the rows are out to prevent excessive tailwater. Normally, the final on-time would be set to switch when the water reached approximately 3/4 of the total row length. An alternative after the initial surges get the row out (when cross slope will allow for uniform furrow streams), would be to open both surge valves and irrigate through both sides of the surge equipment for the remainder of the set.

5. Use this method with established on-times on the remainder of the field.

When using any of these methods, it is <u>extremely important</u> that one realizes that in most cases, the surge sets will need to be allowed to run a longer length of time than what normally has been done with continuous irrigation after the rows reach the end of the field. This is necessary in order to provide the water application that will meet the needs of the crop. This is true unless only a light application is desired. This is especially the case when low intake rate soils are being irrigated. If the proper amount of water is not applied, even though one may have watered to the end of the rows, crop yields will suffer. Irrigators really need a full understanding of their soil moisture needs to effectively use surge irrigation. An excellent and field practical method of monitoring and understanding soil moisture needs and conditions is by using gypsum blocks and/or other soil moisture measurement methods in the water management program.

The Surge-Continuous Flow Furrow Irrigation Monitoring worksheets should be used to record the results. They will provide a record of the results and will be the basis of future management decisions. Also, because furrow conditions change, more than one irrigation should be studied. The first irrigation of the season may act considerably different than later ones. The soil infiltration characteristic and furrow flow hydrodynamics may change sufficiently in most cases to require different on-times and/or flow rates. (see Appendix B)

EVALUATION

Occasionally a surge irrigation set will not perform as expected. When this occurs, a detailed field evaluation may be necessary to determine if system changes would result in increased efficiency, better uniformity or decreased tailwater.

In other cases, a detailed surge evaluation is desired to compare the performance of a continuous flow furrow irrigation system to the results of surge irrigation on the same field. This information is requested by a farmer to assist him in making a decision concerning whether or not to purchase and use surge irrigation equipment. When surge irrigation is to be compared to continuous stream furrow irrigation, it is desirable to conduct a detailed evaluation of the continuous flow system first. The advance and recession data gathered on a continuous flow system evaluation will provide information which is useful in determining the on-times and furrow flow rate to use on a surge evaluation.

Evaluation Procedures

Procedures for doing detailed furrow irrigation evaluations can be found in:

1. Technical Note Engineering NM-E, "Placing Irrigated Soils in Proper Intake Families."
2. Irrigation Water Management Chapter of the SCS Irrigation Guide for New Mexico.

The major objective of evaluating furrow irrigation is to determine the distribution and the amount of water infiltrated or taken into the soil at various location along a furrow.

This is determined by:

1. Using advance and recession time data and curves to determine opportunity time (the time available for water to infiltrate into the soil).

2. Using Soil-Water Intake Curves and the opportunity time to determine the water intake at various locations down the furrow.

Advance and Recession

Under continuous flow furrow irrigation we have only one advance and recession. In surge irrigation we have a number of them, this makes determining the opportunity time for the various stations down the furrow more complicated.

Soil Water Intake Curves

In both continuous flow and surge irrigation the infiltration characteristics of the soil must be determined. There are several alternative procedures for determining soil water intake characteristics, some of which are listed below:

1. We can use the standard Intake Family Curves for Furrow Irrigation. These can be found in the two references listed above or in NEH-15, Chapter 5. These curves are used after determining the average accumulated intake (inches) for the furrow and the average opportunity time (minutes). The proper family curve is found by locating the intersecting point of average accumulated intake (inches) and average opportunity time (minutes). Then the amount of intake for the opportunity time at specific locations or stations can be read from these curves.

2. When furrow inflow-outflow data is available, a field cumulative intake vs. opportunity time curve can be developed. This method is discussed in NEH-15, Chapter 5, Furrow Irrigation under Intake Evaluation. After the curve is developed, it is used like No. 1 above. This should be a better representation of the soil intake characteristics, because it is developed from field data of the evaluation.

3. The third is also a field method for developing a cumulative intake vs. opportunity time curve. Using this procedure application time is recorded when the furrow advance reaches each 100' station. Intake is then calculated for each advance data point using the equation:

$$\text{Intake(in)} = \frac{1.6041 \times \text{furrow stream (gpm)} \quad \times \quad \text{Application Time (min)}}{\text{Advance Length(ft.)} \times \text{Row spacing(ft.)}}$$

Intake is then plotted against advance time on Log-Log paper to yield the desired cumulative intake vs. opportunity time curve. This is a short cut to the method described in Appendix C. This procedure is intended to be used to determine the distribution of the water infiltrated, not to determine the Intake Family.

4. A recirculating furrow infiltrometer can also be used to obtain a cumulative intake vs. opportunity time curve. Detailed construction plans and procedures for assembling and using a flowing infiltrometer can be found in Appendix G.

Evaluation Procedures (surge)

Any of the procedures previously discussed can be used to determine the soil water intake characteristics for evaluating continuous and surge flow irrigation. The accumulated intake from the standard intake family curves is a function of the wetted perimeter, you must multiply this intake by the ratio of the wetted perimeter to the furrow spacing to obtain field application depth.

When both conventional and surge evaluations are being made, the conventional evaluation data can be used to develop a field curve. Surge irrigation will often alter the intake characteristics from the conventional method. An adjusted intake curve for the surge set can be developed by locating the intersecting point of average opportunity time and the total water infiltrated (water applied to furrow minus tailwater) and drawing an adjusted curve through this point parallel to the original intake curve. This procedure can also be used to adjust the curve for continuous flow furrow irrigation.

At the conclusion of a detailed surge evaluation, opportunity times are used with the soil water intake curve to obtain intake at each furrow station. These values can be used to calculate application efficiency and system uniformity. Pumping cost can be examined with this efficiency data to make recommendations for possible system changes. Surge flow irrigation evaluation examples are in appendix D.

SURGE EQUIPMENT

The original prototype of surge equipment by ARS in Kimberly, Idaho consisted of two bladder valves and a single on-time controller. It was the commercial development of the prototype equipment that introduced surge irrigation. Many new valves and improved controllers have been introduced in the three short years since a surge valve was introduced on a commercial basis.

Surge Valves

Presently being marketed are two main alternating flow direction types, the water or air-operated bladder valve and water or electrically operated mechanical valves.

The water-operated bladder valve is operated by the hydraulic pressure from the water supply pipeline. The controller alternates the water pressure to each of the bladders within the valve. When one bladder is subjected to the water pressure, it is inflated and closes off the flow of water to that side. The opposite bladder is opened to the atmosphere and is deflated, allowing the water to flow through that side (see figure 10).

There are various configurations of "butterfly" type mechanical valves. There are single disk valves that divert the flow either right or left and double disk valves that alternately open and close to divert the flow either right or left. These are powered by storage batteries, air pumps or solar cells in with an internal battery pack (see figure 11 and 12). There are also other types of mechanical valves, including water operated types.

Also a single valve has been developed for special use in situations such as operating across a farm road or across turn rows.

Controllers

Most controllers are electronic. The newer ones are programmable so different on-times can be programmed. This is needed to be able to automatically change the on-time for cutback. The minimum capability recommended is a two stage timer.

There are also controllers available that have built in programs to determine the variable on-times. Some are powered by electrical storage batteries and some use solar cells with internal battery pack backup. It is important that controllers ~~be~~ protected (sealed) from dust and moisture. Also, one should check into service time turn-around prior to selecting and purchasing a surge controller.

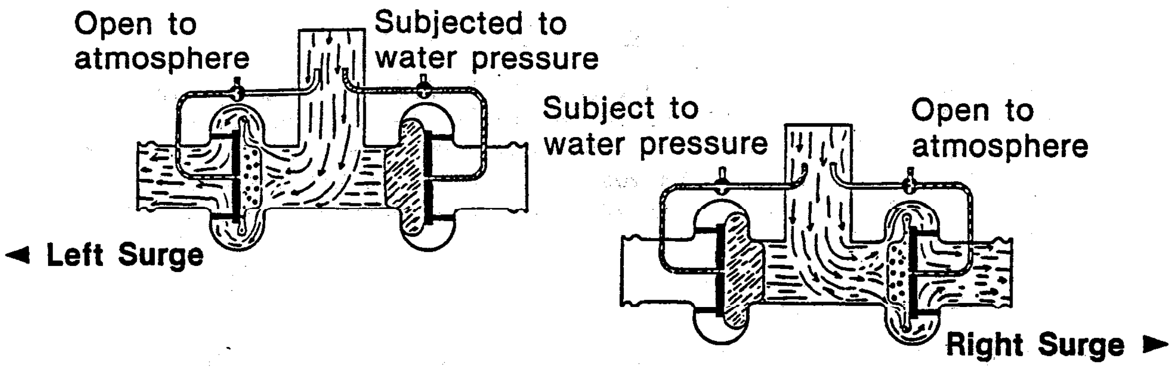


Figure 10. Water Operated Bladder Valve

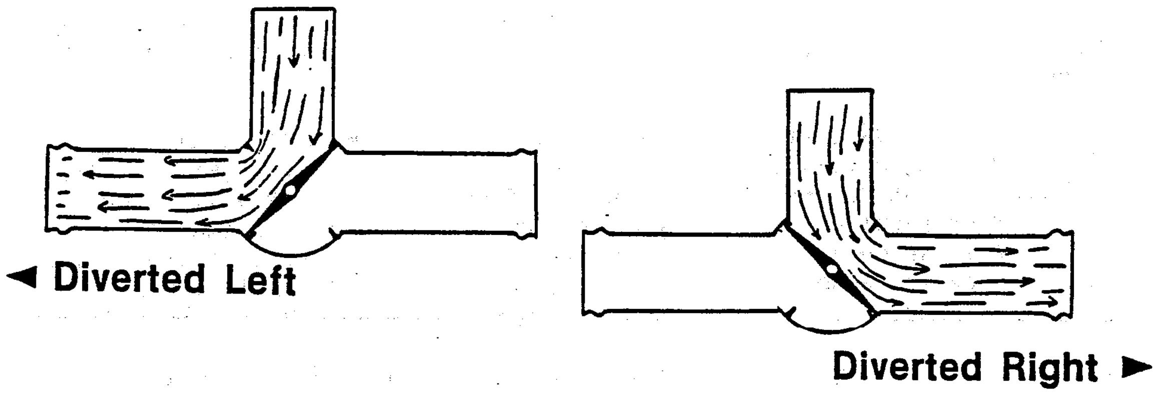


Figure 11. Single "Butterfly" Type Mechanical Valve

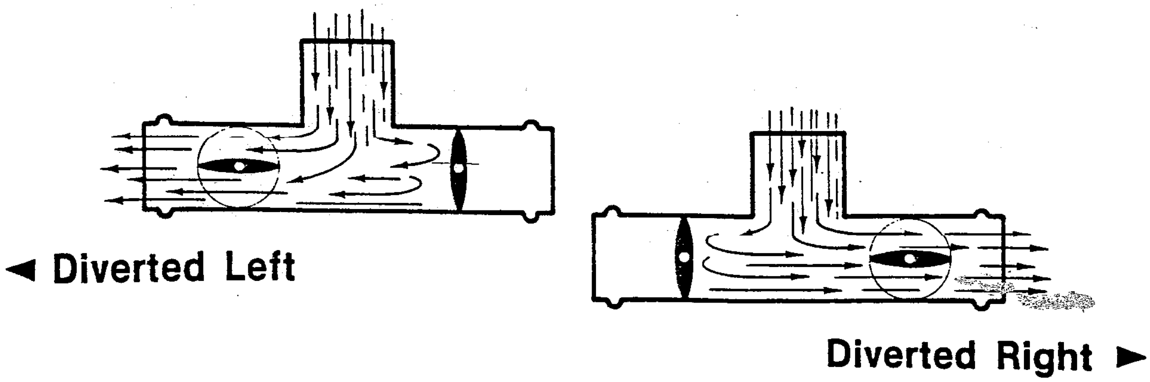


Figure 12. Double "Butterfly" Type Mechanical Valve

Locating Controllers and Valves

The alternating flow direction valves are placed between the two sets of furrows being irrigated. If irrigation water is delivered along the top of the field in buried pipeline, an alfalfa valve would be located between two sets of furrows. The surge valve would be connected to the alfalfa valve outlet by means of a hydrant. The water is distributed to the field from both sides of the valve with gated pipe. If portable pipe is used, the portable pipe would deliver the water to the surge valve between the two sets being irrigated. Sections would be added or removed as the irrigator moves from one set of furrows to another.

If the water delivery point is in the center of the field, the surge valve can be used to divert the water to both sides. One set of furrows would be irrigated to right of the center and one set to the left. The rest of the gates would be closed. Sets are changed by closing and opening the gates on the gated pipe. When starting an irrigation, start at the outermost rows on each side of the valve first. When one irrigation set is completed, move irrigation set progressively toward the valve. This will allow you to inspect the gated pipe for leaking gates at the beginning of the irrigation. The leaking gates can be repaired (such as replacing gaskets) when the valve has switched to the other side. There can be a significant savings in water used and irrigation efficiency will be improved. Also, as the sets more toward the valve, the outer sections of gated pipe can be disconnected and used elsewhere on the farm. Also, damage to aluminum pipe by electrolysis is greatly reduced by separating pipe sections to allow drainage and drying when not in use.

If the gated pipe is placed on sloping ground, the open gates at the lowest point will have the greatest flow. The number of rows irrigated at one time or flow rate from gates (gate opening) may need to be altered to make the application as uniform as possible. This is important when the slope is over 1-1/2 percent.

The following problems may be encountered with water powered bladder type valves:

With small volumes of flow (gpm) and an appreciable length of surface pipe, it takes a longer time to complete a water change operation (switch sides). With cross slope (side cast) of 1% or more, the uphill side may not close off. Also, with low flow volume, it may not be possible to use multiple controllers in the same system. Further, with multiple valves, it is difficult to keep set change operations synchronized. Occasionally the problem may be solved by:

1. increasing the operating pressure head for the controller.

2. providing maintenance i.e., clean out sand sediment in supply line to pitot valve.

3. change out the older pitot valve with a newer type.

If the water is delivered to one side of the field, the "Automatic Single-Pipe Irrigation System" described in appendix F could be used. This system may not be in commercial production.

Valve and Controller Maintenance

The controller is electronic and requires the kind of care all electronic equipment needs. It needs to be protected from the elements and stored in a safe place when not in use. If it is operated by a battery, the battery must be charged for the controller to function. Check occasionally to see that all connections are secure and the electronics are clean and dry. Some valve types can be operated in freezing weather by taking proper precautions i.e., cover valve with tarp, etc.. However, with temperatures below 27°F (-3°C) water freezing in furrows between surges will completely fill furrows with ice. When not being used, valves need to be drained before freezing temperatures occur so the freezing water doesn't damage them.

The water operated bladder valve needs about 3/4 to 5 psi of head to operate the bladder. If the pressure head is not sufficient, a gate or valve can be placed between the pitot tube and the surge valve. The gate or valve can be partially closed to create sufficient head.

A filter should be placed in the line after the pitot tube on the water operated bladder valve. The small inline screen filter used for trickle irrigation can be used. Sediment and trash can plug the switching valve to the bladders if it is not filtered. If the valve is plugged, switching is not accomplished and water continues to flow to the same set.

On occasion, a bladder may fail (leak). Small holes may be repaired with a rubber patch while bad breaks will require bladder replacement.

Safety

Damage to pipelines may occur if proper precautions are not taken to provide vacuum relief. Vacuum (negative pressure) within the pipeline will cause collapse of the line.

Conditions when vacuum collapse may occur include:

1. Large volumes of flow in connection with fast switching "Butterfly" type valves.

2. Long lengths of 8" and large diameter lines with fast switching "Butterfly" type valves.

3. When watering 70 or more rows a distance of 1 or more sets away from the surge valve.

4. Very tight and well sealed pipe joints.

5. Long lengths of gated pipe serving as flow line to an area several hundred feet downslope from the valve.

To prevent possible damage due to vacuum collapse, an air vent must be incorporated into the line to provide suction relief.

This may be accomplished by:

1. An air hole high on the open side of the valve.

2. Slightly loosen and turn gates upward on a couple of joints of pipe on each side of the surge valve.

3. Provide for an open gate on each side of the valve to allow air into the closing line.

4. Install an air vacuum relief valve.

Also, the need for a pressure relief valve should be investigated in pipelines connected to surge valves.

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SURGE FLOW IRRIGATION INFILTRATION

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The potential of surge flow irrigation to achieve higher water use efficiency than continuous flow irrigation primarily results from the reduction in intake rate during surge flow irrigation compared to continuous flow intake rate. This reduction in intake rate occurs during the off-times after the soil is initially wetted. Intake is primarily a soil and water property which can be affected by soil texture, soil structure, soil mineralogy and chemistry, sediment movement, soil moisture, irrigation hydraulics, and irrigation water quality.

Overall, soil properties in agricultural fields tend to be somewhat heterogeneous and often vary with space (anisotropic) and time. Some of the important factors affecting infiltration are relatively static while others change. Seasonal variation in intake is commonly observed and often can be related to cultural practices. Even in a specific field intake characteristics tend to be transient and usually not controllable. Furthermore, research on surge flow intake is relatively new and limited in extent. Thus, it is difficult to quantitize surge flow intake for a specific irrigation in a specific field.

A detailed analysis of the soil physics of intake is beyond the scope of this chapter. However, brief explanations and simplified analyses are included to provide a starting point for understanding surge flow intake phenomena.

1.0 Possible Mechanisms Which Contribute to Surge Flow Intake Rate Reduction Phenomena

Several mechanisms have been suggested by researchers to explain the discontinuous reduction in intake rate which occurs between the end of one surge on-time and the beginning of the next surge. Some of these mechanisms have been observed or are supported by field and laboratory experiments while others remain unproven. Ongoing and future research will likely yield new information concerning the mechanisms of this phenomena. The following sections briefly explain some of the proposed mechanisms. General information about these phenomena can be obtained from texts on soil physics. Finally, the surge flow intake rate reduction phenomena is likely due to a combination of several mechanisms rather than solely an effect of one process.

1.1 Hydration of Clay Particles

It is a commonly known fact that certain types of clay particles swell during the hydration process. Commonly, these clay particles are interspersed between sand and silt particles in the soil. During the surge flow on-time these clay particles are wetted and begin to swell. During the surge flow off-time the hydration process continues and these particles continue to swell and reduce the hydraulic conductivity of the soil. The extent that hydration reduces intake is a function of soil texture, water quality, and types of clay particles in the soil. Although clay hydration is important, it is unlikely that hydration is completely responsible for the surge intake phenomena.

1.2 Reduction in the Hydraulic Gradient During The Surge Flow Off Time

It is not the intent of this section to provide an detailed analysis of hydraulic gradient effects. Rather, a brief discussion of the complex relationships which govern the hydraulic gradient is provided.

A hydraulic gradient exists in all soil profiles and is a function of gravity potentials and soil matrix potentials. The soil matrix potential primarily consists of the capillary potential of the soil. Capillary potential is often several orders of magnitude greater than the gravity potential for a dry soil profile. As the soil is wetted the soil matrix potential of the wetted soil decreases and eventually the gradient promoting intake is largely due to gravity. Thus, initially the hydraulic gradient is primarily a function of matrix potential, and eventually at large intake opportunity time the gradient is primarily a function of gravity potential.

A common and simple equation used to describe flow in a saturated porous media (soil profile) is Darcy's law which is

$$q = K \frac{\Delta H}{\Delta L} \qquad (1)$$

where q is the flow rate of water per unit area, K is the saturated hydraulic conductivity of the media, ΔH is the hydraulic potential, and ΔL is the length of the media through which water is flowing. Figure 1 illustrates an application of Darcy's law for water flowing through a column of soil. The quotient $\Delta H/\Delta L$ is the hydraulic gradient term in Darcy's Law.

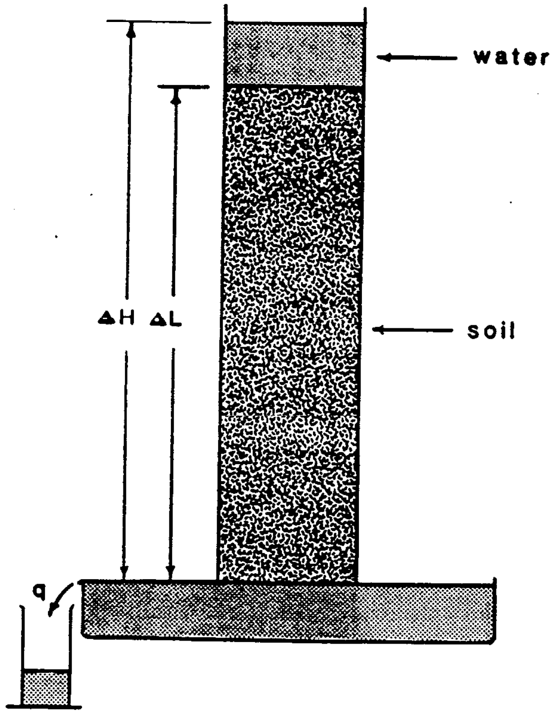


Figure 1 Application of Darcy's Law to a Vertical Soil Column

Equation (1) is used to derive the Green-Ampt intake equation which may be used to determine intake rates for one dimensional flow.

However, equation (1) is not directly applicable for use in determining surge flow intake rates in furrows. Figure 2 illustrates the wetting profiles at several subsequent intake opportunity times ($t_1<t_2<t_3<t_4$) for continuous flow intake. The wetting profile initially is somewhat circular and with time gradually elongates due to the contribution of gravity potential increasing and the soil matrix potential decreasing.

Infiltration in a Furrow

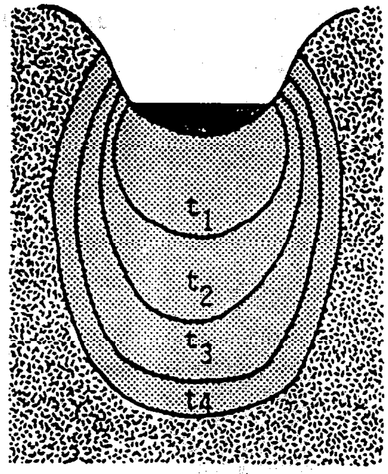


Figure 2 Wetted Profiles in a Furrow

Because of the geometry of a furrow, intake occurs as two dimensional flow and equation (1) is not applicable. Equation (1) also assumes that the wetted portion of the soil is completely saturated. During surge flow intake the wetted soil near the surface of the furrow is saturated with water during the on-time and then desaturates during the off-time. Thus, equation (1) is not directly applicable to surge flow intake. However, Richard's equation, which is based on equation (1), can be used to describe two dimensional unsaturated flow. The solutions to Richard's equation are complicated and the accuracy of these solutions is debatable. No complete mathematical models of surge intake are used in research today. However, some of the relationships used in Richard's equation can be used to provide insight into the surge flow intake problem.

The basic relationship defined by Richard's equation involves three soil characteristic or parameters. These parameters are: 1) ψ, the soil matrix suction (suction is the negative of potential); 2) θ, the volumetric ratio defining the amount of water in the soil; and 3) K, the hydraulic conductivity of the soil. During surge intake ψ, θ, and K all have different values throughout the soil profile, and all change with intake opportunity time. Furthermore, all three of these parameters are interrelated as illustrated by Figure 3. This interrelationship makes it difficult to predict what effect surge flow intake has on the hydraulic gradient.

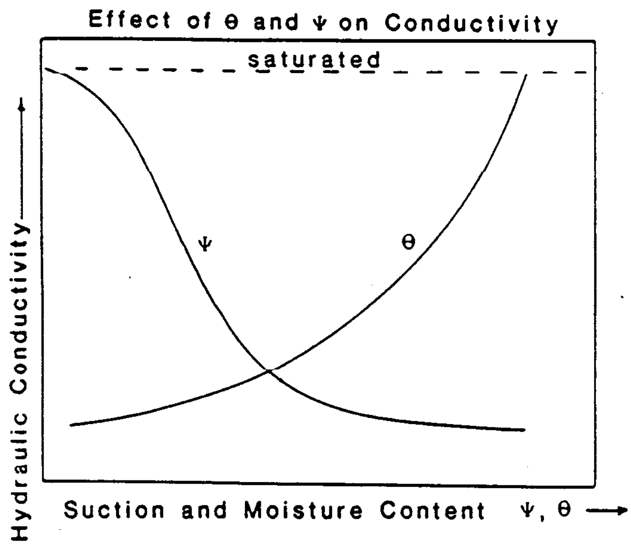


Figure 3 Relationship Between K, ψ, and θ

Figure 4 shows that hysteresis is involved in the relationship between soil matrix suction and water content. This figure shows that suction and water content relationship follows one curve when the soil is being wetted (adsorption) and another curve when the soil is being dried (desorption). Furthermore, during surge flow intake a layer of soil very near the surface of the furrow likely undergoes a scanning loop which ranges between these two curves near the saturated water content value. The water content θ of the soil will vary throughout the wetted section of the furrow and in general θ will be largest near the surface of the furrow.

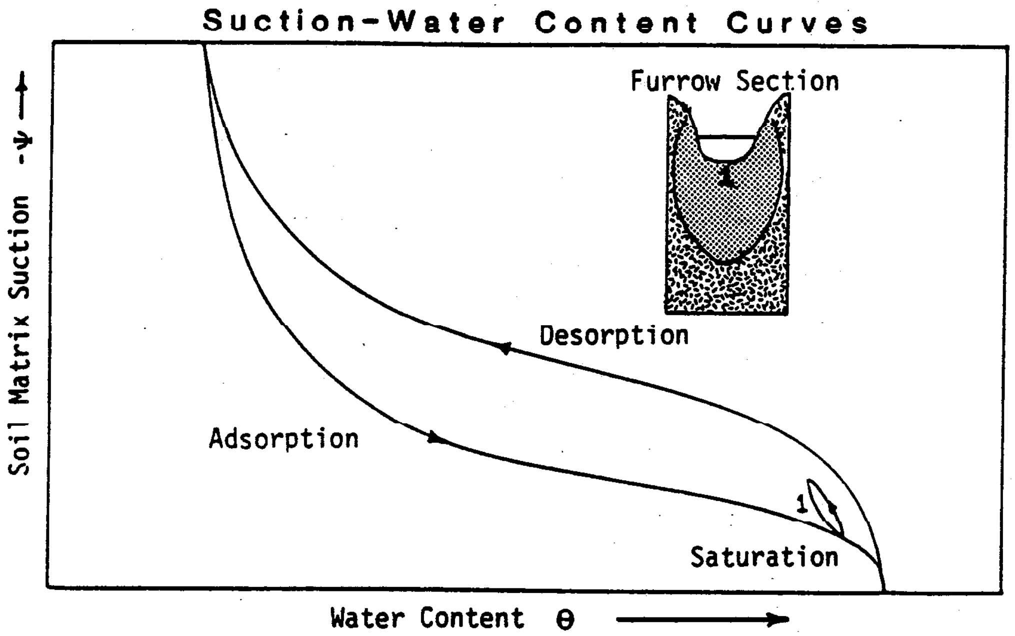


Figure 4 Relationship Between Soil Matrix Suction and Water Content

During the surge flow off-time it is likely that the matrix potential in the soil is redistributed in a manner similar to that illustrated by Figure 5. Note that this figure is for one dimension intake, whereas intake in furrows is two dimensional. Research, to date, has not been done to determine the two dimensional matrix potential redistribution pattern.

Figure 5 indicates that at an intake opportunity time equal to the surge flow on-time ($t_1 = t_{on}$) the matrix suction is near zero at the surface where the soil is saturated with water. The suction increases with soil depth and at the wet-dry soil interface (wetting front) the matrix potential increases rapidly. At times greater than t_{on} and prior to the next application of water, the matrix suction increases in the layer of soil near the surface and the wetting front moves deeper in the soil profile. The redistribution of the matrix potential may induce a structural change (consolidation) in the top layer of the soil profile. Consolidation is discussed in section 1.3.

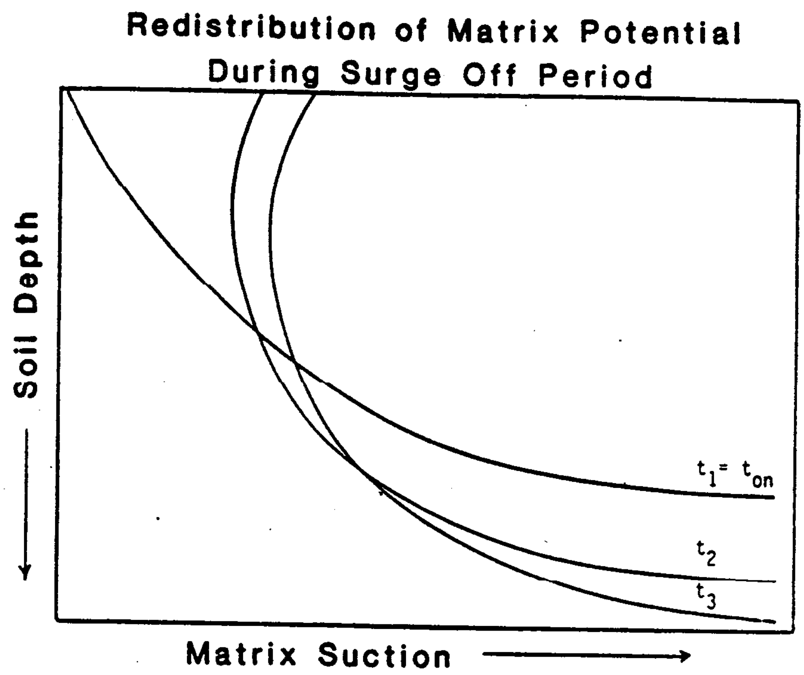


Figure 5 Redistribution of Soil Matrix Potential During Surge Off-Time

Several conclusions can be made concerning how the hydraulic gradient affects surge flow intake. First, the physics of the surge flow intake are significantly more complicated than the physics of continuous flow intake. Secondly, it is difficult to measure and quantify the soil intake characteristics necessary to analyze the physics of surge flow intake. And finally, the evidence remains inadequate to determine the extent to which the hydraulic gradient in a two dimensional furrow shaped soil profile decreases during the surge flow off-time. Ongoing and future research will attempt to conclusively define the effects of the hydraulic gradient on surge flow intake.

1.3 Consolidation in Top Soil Layer During Surge Flow Off-Time

The top, very thin, layer of the soil may undergo consolidation during the surge flow off-time. This consolidation may occur primarily because of the combination of two soil conditions. First, the matrix potential of the top soil layer decreases during the surge flow off-time. Secondly, the aggregate stability was decreased by wetting the soil during the prior surge flow on-time. This combination of effects consolidates the soil. As a result, the bulk density likely increases and the hydraulic conductivity decreases.

It is possible that this consolidation is limited to approximately the top 1 cm of soil or less. However, to date, sufficient research has not been performed to predict the effect of consolidation, nor to define the region of consolidation. Figure 6 illustrates consolidation in a soil profile. Note that the figure is not drawn to scale. In reality the consolidated layer is likely much thinner in relationship to the wetted layer.

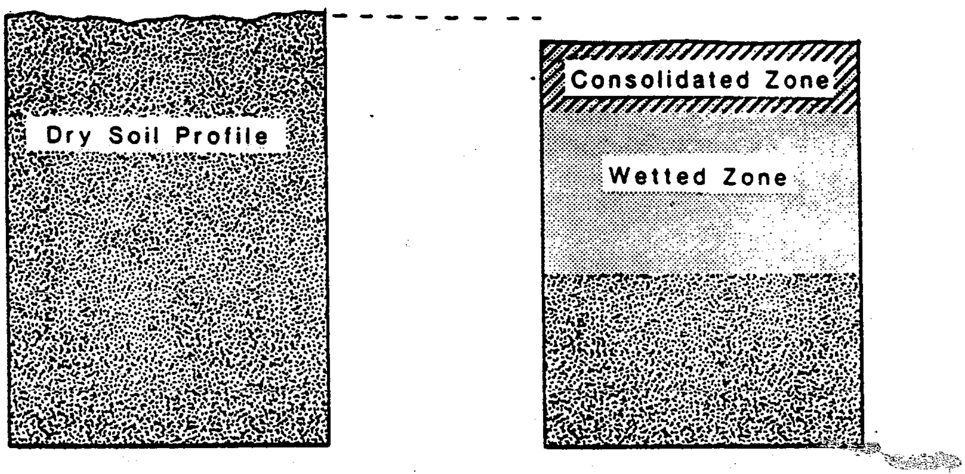


Figure 6 Consolidation of Top Soil Layer During Surge Flow Off-Time

1.4 Deposition and Migration of Soil Particles

Surface sealing by sediment has been suggested by several researchers as the probable explanation of the surge flow intake rate reduction phenomena. Future research will investigate surface sealing and sediment effects on surge flow intake. Currently, there exists conflicting evidence concerning the effect of surface sealing. Because of the limited amount of data, and the difficulty measuring the effect of sediment on intake, some discrepancies are to be expected.

Surface sealing is one effect caused by two sediment related intake phenomena which may occur during surge flow intake. First, deposition of any suspended sediment on the surface of the soil occurs simultaneously with intake. Second, it is possible for soil particles to migrate into soil pore spaces in the surface layer of the soil. The migration of particles tends to seal the surface of the soil and reduce the hydraulic conductivity of the soil.

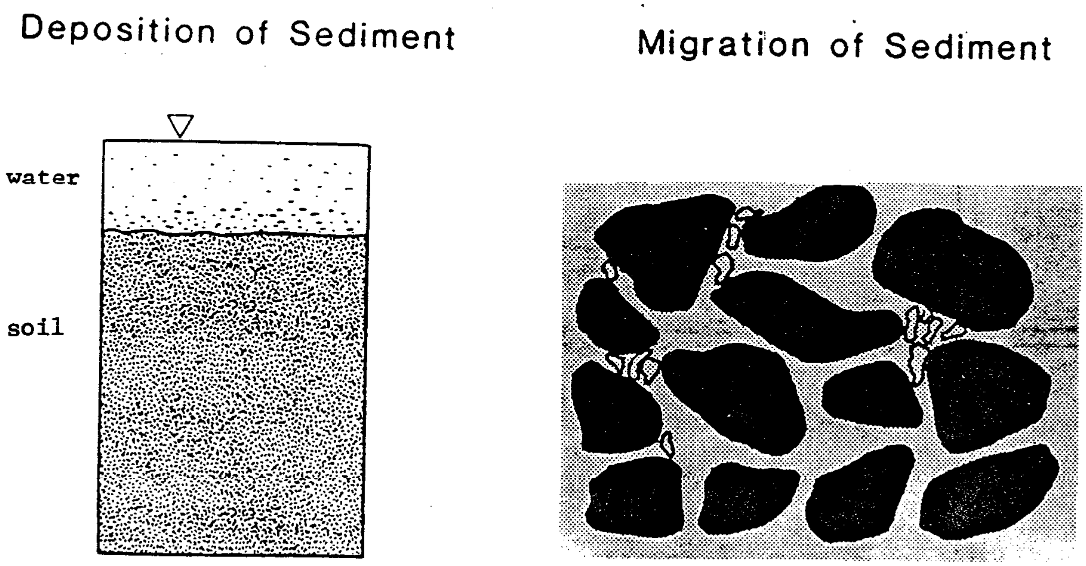


Figure 7 Deposition and Migration of Sediment on Soil Surface

The process of deposition and migration are illustrated in Figure 7. Note that, the right side of Figure 7 is a cross-section of the surface soil layer. And, although this figure indicates that the large solid black soil particles are not in contact with other large particles, in reality, these particles have points of contact with other particles at locations not shown in this figure.

1.5 Entrapment of Air Beneath the Surface Soil

Assuming that during the surge flow off-time the moisture content of the top layer of soil in the furrow decreases, then it is possible for air to enter this layer. Because the soil beneath the top layer was wetted during the surge on-time, the air which entered during the surge off-time might be trapped during the next surge flow on-time. Air trapped in the soil has the effect of reducing the hydraulic conductivity of the soil and thus the intake rate. However, at present no research has established that air entrapment plays a significant role in the surge intake rate reduction phenomena. Figure 8 illustrates a possible air entrapped layer beneath the soil surface. Note that this figure is not drawn to scale. In reality the zone with entrapped air is likely much smaller and closer to the soil surface in relationship to the depth of the wetting front.

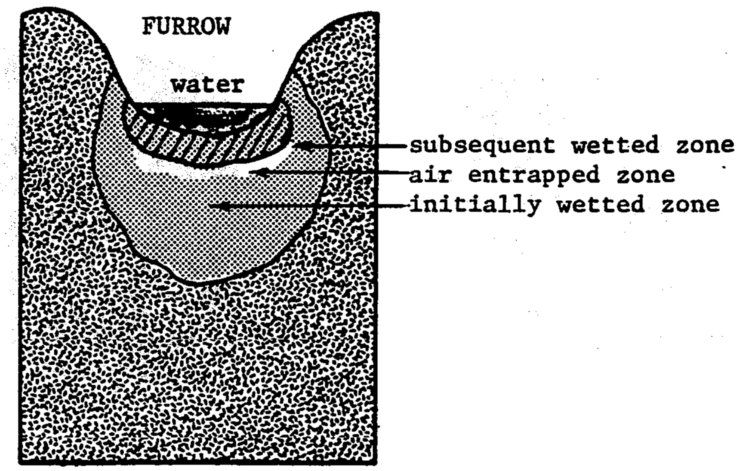


Figure 8 Entrapment of Air During Subsequent Surge Flow On-Times

APPENDIX B. SURGE-CONTINUOUS FLOW FURROW IRRIGATION COMPARISON

A record of our findings, detailed or not, is valuable and desirable as we study and learn how to better manage furrow irrigation. The comparison worksheet can be used to record findings so surge and continuous furrow irrigation can be compared on the same field. As technicians gain experience and build their confidence they may be able to make a lot of determinations without making a detailed evaluation, especially when comparing surge and continuous irrigation. It can also be used (with experience) to determine if a detailed evaluation is necessary.

A lot of time and manpower is needed to do detailed evaluations. Therefore usually only a limited number can be made. Monitoring an irrigation requires much less time and manpower, but will provide a lot of information to help an irrigator make management decisions. The irrigator should always be present when monitoring an irrigation. He will learn what he needs to observe to manage his irrigation properly. Monitoring will provide good information as well as being helpful for the irrigator. The following worksheet can be used to observe and record additional irrigations on the same field during the same season, especially if the irrigator is willing to cooperate.

Data Sheet for Comparing Surge and Continuous Flow

Furrow Irrigation

John Smith	Anywhere	Anytime
Farmer	Location	Date
Bob Jones	Anyone	1A
Techician	Field Office	Field

Basic Data

Crop: Cotton — Daily Comsumptive Use: 0.3

Soil Type: Olton Loam — Crop Root Depth: 60"

Percent Slope: 0.2 — Length of Run: 1300

Furrow Spacing: 40" — Irrigation Pattern: Every other row

Water Holding Capacity of Root Zone at Field Capacity (In.): 19.2

Soil Water Deficiency at Time of Irrigation (in.): 2.0

Desired Application this Irrigation (in.): 1.5

Irrigation Data	Surge Flow	Continuous Flow	
Total Number of Rows in set	12	12	
Number of watered furrows	6	6	
Gallons per minute pumped	140	140	
Gallons per minute per row	23	23	
Application Time (hrs.)	5	8	
Time for water to reach end of furrows (hrs.)	3	4	
Acres per set	1.2	1.2	
Water applied (in.)	1.3	2.1	
Surge on-time	60 min	N/A	
Number of surges per side	5	N/A	
Percent of water which ran off as tailwater	0	0	Blocked end
Cost per acre-inch (dollars)	3.89	3.89	
Cost per acre (dollars)	5.24	8.4[illegible]	
Visible furrow erosion	None	None	

Appendix C. - Job Instruction for Evaluation of Irrigation Systems

JOB INSTRUCTIONS

For
EVALUATION OF IRRIGATION SYSTEMS

General

Evaluation of an irrigation system is simply a determination of how much water is being applied, and where it is going. It is only by making these determinations, that intelligent guidance can be given a landowner in improving the use of his irrigation systems.

Sprinkler Systems

For Sprinkler Irrigation Systems, the evaluation criteria as outlined in USDA Agriculture Handbook No. 82, "Methods for Evaluating Irrigation Systems", will be used.

Surface Flow Methods

For surface flow methods of irrigation in common use, the evaluation steps as listed herein may be used.

Furrow Systems.

1. Run profile of furrows and record row spacing.
2. Set stakes at 100' station.
3. Set measuring devices.
4. Determine approximate amount of water to apply.
5. Using design criteria - est. approx. furrow stream to use and length of time to make application.
6. Start water and record time.
7. Start measuring furrow stream - record time and amount. (Furrow stream fluctuations are undesirable.)
8. Record rate of advance at each station.
9. Using measured stream adjust time to make application.
10. Stop water - record time.
11. Record time water disappears (recession) by stations.

12. Compute intake rate in GPM per 100 feet for each station by dividing Q in GPM by stations. Plot I_a curve - gpm/100' against travel time in minutes (2x3 or 3x3 cycle log paper). The best fit of the points plotted should be used. A curve plotted on log paper will be a straight line. If cut-back stream is used, the initial furrow stream should be used for plotting.

    a. For large furrow streams use stations far enough from ditch to eliminate effect of fast flow, and back the curve in for the close stations (straight line).

    b. Compute "n" (slope of line, measured vertical distance divided by measured horizontal distance) for formula $I_a = aT^n$ gpm/100'.

    c. Convert I_a curve to inches/hr and plot. $I_a = \frac{\text{gpm/100} \times 11.55}{\text{row spacing in in.}}$

    The curve will be parallel to the I_a curve originally plotted.

    d. Obtain "a" (coef. of intake) point where I_a line intercepts, when time is unity.

13. Plot F curve. $F = aT^b$, where $b = n + 1$; Use "a" from inches/hr line. F curve crosses I_a line (in/hr) at 1 hr time. This plus slope of F line (b) can be used to draw line, or use point on I_a line at 1 hr. and point on 1 minute line (1/60 of amount of I_a at 1 minute time) to draw line. The F curve gives the total furrow intake in inches. For extremely large furrow streams some adjustment in the F curve may be necessary. For method of adjusting see Example - Level Furrow System.

14. Using F curve and opportunity time by stations, determine application (inches) by station and plot. (Opportunity time - is difference in time recorded by stations between rate of advance and recession.)

15. Analyze data and recommend adjustment.

Example - furrow system.

This is a graded furrow system with 0.2' per 100 feet grade. The soil is a Pullman, Soil Unit 2, which ordinarily does not require a cut back furrow stream. It is estimated that a net application of 2.5" is needed, or a gross application of 3.0". Two 40" furrows were checked, data recorded and plotted as follows:

Station	Furrow #1 - Q = 11.8 gpm Travel Time (Minutes)	Recession Time (Minutes)	Opportunity (Min.)	GPM/100'	Furrow #2 - Q = 10.5 gpm Travel Time (Minutes)	Recession Time (Minutes)	Opportunity (Min.)	GPM/100'
0+00	---	713	713	---	---	716	716	---
1+00	23	718	695	11.8	26	721	695	10.5
2.50	89	723	634	4.7	96	726	630	4.2
3+00	109	728	619	3.9	124	731	607	3.5
4+00	150	733	583	3.0	163	736	573	2.6
5+00	206	738	532	2.4	216	741	525	2.1
6+00	261	743	482	2.0	272	746	474	1.8
7+00	320	748	428	1.7	331	751	420	1.5
8+00	381	753	372	1.5	406	756	350	1.3
9+00	431	758	327	1.3	481	761	280	1.2
10+00	512	763	251	1.2	556	766	210	1.1
11+00	581	768	187	1.1	616	771	155	1.0
12+00	656	773	117	1.0	691	776	85	0.9
12+32	676	776	100	1.0	716	780	64	0.9
Water off at - 713				Water off at	716			

An analysis of the plotted data Figure B-14 reveals that the lower half of the run was under-irrigated, since less than the needed 3 was applied. Indications are that a cutback stream will be necessary to properly apply the required irrigation. The needed initial and cutback furrow streams can be determined from the plotted data (Figure B-13) as follows:

1. The F curve shows that 500 minutes will be required to apply 3".

2. The initial furrow stream should be applied in time $\frac{T}{4}$ or $\frac{500}{4}$ = 125 minutes.

   At 125 minutes on I_a curve find the required furrow stream of 3.4 gpm/100'. Multiply this amount by the number of stations; 3.4 x 12.3 = <u>41.8 gpm</u>.

3. At the end of 500 minutes, I_a is 1.2 gpm/100'. Multiply this figure by the number of stations to give the cutback furrow stream; 1.2 x 12.3 = <u>14.8 gpm</u>.

4. It may be of interest to check the furrow streams obtained in steps 2 and 3 against the furrow design criteria in Chapter 5, $Q_1 = \frac{IL}{10}$.

   At the end of 500 minutes, I_a is .34 inches per hour. Therefore $Q_1 = \frac{.34 \times 1232}{10}$ = 41.8 gpm (Initial furrow stream)

   A 'rule of thumb' is that the cutback furrow stream is $\frac{Q_1}{3}$ = 14.0 gpm

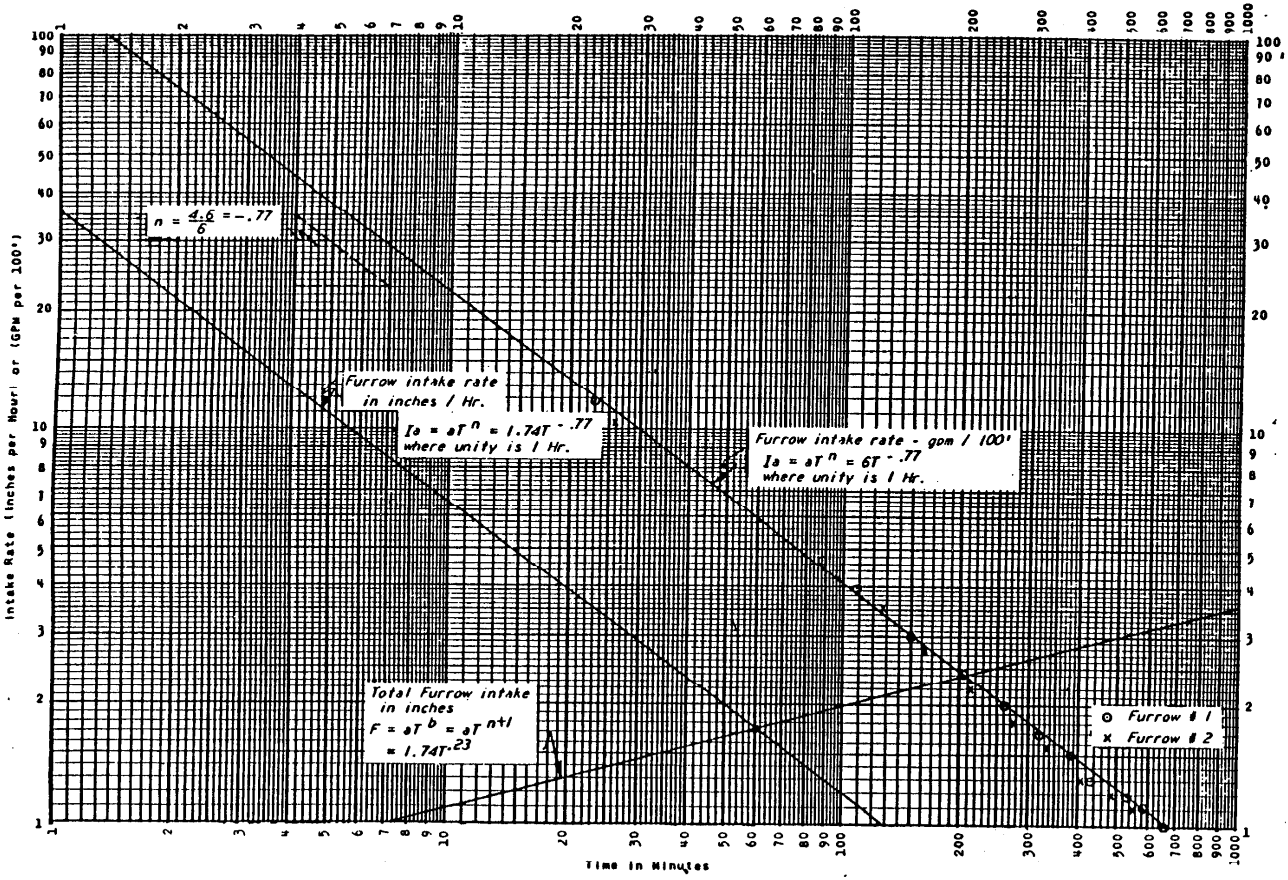


Figure B-13

INTAKE CURVE FOR FURROW SYSTEM

U. S. DEPARTMENT OF AGRICULTURE, SOIL CONSERVATION SERVICE   11-25-58   4-L-12819

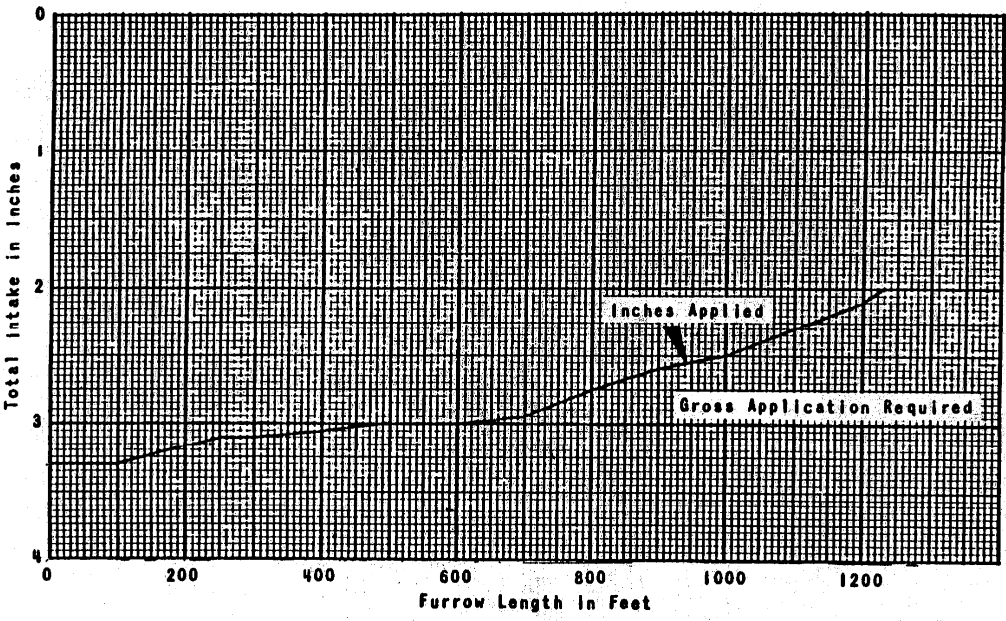


Figure B-14
MOISTURE DISTRIBUTION PATTERN FOR FURROW SYSTEM

G6

Appendix D. - Example Furrow Irrigation Evaluations

Example 1:

In this example, both a continuous and a surge furrow evaluation was performed. The continuous evaluation was used to develop a cumulative intake vs. opportunity time curve. The third method described on page 3 was used.

The farmers goal for this irrigation was to wet the surface soil for the germination of cotton by applying only 1.5 inches of water.

The farmer discontinued the irrigation as soon as he felt the beds were sufficiently wet.

It took a 2.1 inch application to accomplish his goal with continuous furrow flow and only 1.3 inches with surge flow. Surge used less than his goal of 1.5 inches.

The application efficiency and distribution uniformity were very good for both evaluations. The surge left .7 inches of available soil moisture storage available for rainfall.

Note:

The advance and recession curves for continuous flow were plotted using time as lapse time from the start of the irrigation.

The advance curve for surge flow is plotted using application time for advance (lapse time from the start of the irrigation to advance time minus any off time):

sta. 9+75 lapse time = (12:00-9:06) = 174 min.
off time = (1 x 60) = 60 min.
Application time = 114 min.

The time for the recession curve for surge flow is computed by adding application time for advance to total opportunity time:

sta. 9+75 application time for advance = 114 min.
total opportunity time = 256 min
Time= 370 min.

SURGE-CONVENTIONAL FURROW IRRIGATION EVALUATION WORKSHEET

Irrigator John Smith Location Anywhere

Field Office Anyone Date Anytime

Crop Cotton Crop Stage germination Root depth —

Furrow Spacing 3.33 ft., Length 1300 ft., Slope 0.2 %

Soil description Olton Loam

Irrigation No. 5.0 Furrow Condition smooth, loose, few small clods

Desired Application this irrigation 1.5 inches

Surge Data

Cycle No.	1	2	3	4	5					
On time (min.)	60	60	60	60	60					
Advance Dist. (ft.)	750	1050	1300	1300	1300					

Item	Surge	Continuous
1. Water supply to field 1/ (gpm)	140	140
2. No. of furrows per set	12	12
3. No. of furrows watered per set	6	6
4. Furrow Stream (gpm)	23	23
5. Clock Time water turned on	9:06	14:00
6. Clock Time water turned off	19:06	22:00
7. Irrigation time (hrs.) 2/	10	8

Item	Surge	Continuous
8. Application time (hrs.) 3/	5	8
9. Opportunity time 4/		

a. Continuous Flow

	Sta.	Advance (clock time)	Recession (clock time)	Opportunity (minutes)
Head	0+00	14:00	22:05	485
¼	3+25	14:18	22:27	489
½	6+50	15:06	22:35	449
3/4	9+75	16:20	22:35	389
End	13+00	17:55	1:30	445

2257 / 5 = 451

b. Surge Flow

Cycle No. Total (Clock Time)		1	2	3	4	5	6	7	8	9	10	
	Adv.	9:06	11:06	13:06	15:06	17:06						
Head	Rec.	10:14	12:09	14:09	16:06	18:06						
0+00	Opp.	68	63	62	60	60						313
	Adv.	9:33	11:19	13:19	15:17	17:17						
¼	Rec.	10:39	12:30	14:31	16:33	18:32						
3+25	Opp.	69	71	72	76	75						363
	Adv.	10:02	11:31	13:31	15:28	17:28						
½	Rec.	10:38	12:38	14:39	16:45	18:43						
6+50	Opp.	36	67	68	77	75						323
	Adv.		12:00	13:46	15:42	17:42						
3/4	Rec.		12:47	14:48	16:56	18:55						
9+75	Opp.		47	62	74	73						256
	Adv.			13:58	(15:06)	(17:06)						
End	Rec.			(15:06)	(17:06)	20:30						
13+00	Opp.			68	120	204						392

1647 / 5 = 329

	Surge	Continuous
c. Average Opportunity time (hrs)	329	451

Item	Sta.	Surge depth (ft.)	Surge water (in.)	Continuous depth (ft.)	Continuous water (in.)
10. Water applied Penetration 5/					
Head	0+00	____	1.3	____	2.2
¼	3+25	____	1.3	____	2.2
½	6+50	____	1.3	____	2.1
3/4	9+75	____	1.2	____	1.9
End	13+00	____	1.4	____	2.1

Item	Surge	Continuous
11. Gross Water applied per set (inches) 6/	1.3	2.1
12. Runoff, (%/inches) 7/	____/ 0	____/ 0 (Blocked ends)
13. Water Infiltrated (Average inches) 8/	1.3	2.1
14. AWC of Root Zone (inches)	19.2	19.2
15. Soil Water Deficiency (inches)	2.0	2.0
16. Water stored in 9/ root zone, (ave.inches)	1.3	2.0
17. Deep Percolation, 10/ (%/ave. inches)	____/ 0.0	____/ 0.1
18. Application Efficiency 11/	100	95
19. Distribution, (%) 12/(%) or (good, fair or poor)	96	95
20. Cost per Acre-Inch (dollars) 13/	3.87	3.87
21. Cost per Acre (dollars) 14/	5.03	8.13
22. Visible Furrow Erosion (None, slight, moderate, excessive)	None	None

23. Comments Both surge and continuous had very good application efficiency and distribution uniformity, the blocked ends worked well. Surge wetted the beds with 0.8" less water and $3.10 per acre

1/Total of water supply being delivered to field.

2/Total time to irrigate a set, (time turned on-time turned off)

3/Actual time water is applied to furrow. Usually ½ of irrigation time, for surge, same as irrigation time on conventional.

4/Record the clock time that water is turned on to the furrow at the head and the time it advances to each station. After water is turned off, record the recession time that the water disappears from the furrow at each station. At each station, the opportunity time is the difference between recession time and advance time. Average the opportunity time for both surged continuous.

5/When advance and recession curves and accumulated intake curves are used, record the inches of moisture applied at each station. If not an auger or soil probe can be used to determine the depth the water has penetrated after the irrigation is completed. This will give an indication of the water infiltration distribution. An estimate can be made of the inches of water applied at each sta.

6/Gross water applied =

$$\frac{1.6041 \times \text{application time (min)} \times \text{furrow stream (gpm)}}{\text{furrow spacing (ft.)} \times \text{furrow length (ft.)}}$$

7/If you cannot measure runoff, make your best estimate, express in % of water applied to field and inches. (average % of furrow stream x % of application time runoff occurred)

8/Average Water Infiltrated = Gross Water applied (in.) - Runoff (in.) Check to see if this agrees with item 10, water applied or pentration.

9/Average the inches of water stored (infiltrated) in the root zone, water infiltrated or soil moisture deficiency, whichever is less at each ¼ point.

10/Record the average inches of water infiltrated beyond the root zone. If the infiltration is estimated (Amount infiltrated - Amount stored in root zone)

11/ $$\frac{\text{Average Water stored on root zone}}{\text{Gross Water applied to field}} \times 100$$

12/ $$\% = \frac{\text{(average water applied in root zone to low } \tfrac{1}{4} \text{ area (inches)} \times 100}{\text{Average water applied to root zone}}$$

or rank it good, fair or poor

13/ $$\text{Cost per acre - Inch} = \frac{\text{Fuel cost per Hour} \times 450}{\text{Water supply (gpm)}}$$

14/Cost per Acre = (Cost per Acre-Inch) x (Gross Water Applied, Inches)

COMPUTATION SHEET
SCS-ENG-522 REV. 3-69

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

STATE TX	PROJECT Furrow Irr. Evaluation		
BY XYZ	DATE Anytime	CHECKED BY	DATE	JOB NO.
SUBJECT Advance- Recession Field Data (continuous)			SHEET ___ OF ___

	Sta.	Advance time (clock)	Recess. time (clock)	Opportun. time (min.) 1/	Applic. time (min.)	Ave. Cum. intake (in.) 2/
	0+00	2:00	10:05	485	0	
	0+40	:02			2	.3
	1+40	:06			6	.2
	2+40	:16			16	.4
1/4	3+25	:18	10:27	489	18	.3
	3+40	:26			26	.4
	4+40	:37			37	.5
	5+40	:48			48	.5
	6+40	3:03			63	.5
1/2	6+50	:06	10:35	449	66	.6
	7+40	:20			80	.6
	8+40	:38			98	.6
	9+40	4:04			124	.7
3/4	9+75	4:20	10:49	389	140	.8
	10+40	:34			154	.8
	11+40	5:05			185	.9
	12+40	:40			220	1.0
	13+00	:55	13:30	445	235	1.0

1/ lapse time from begining

2/ Average Cumulative Intake

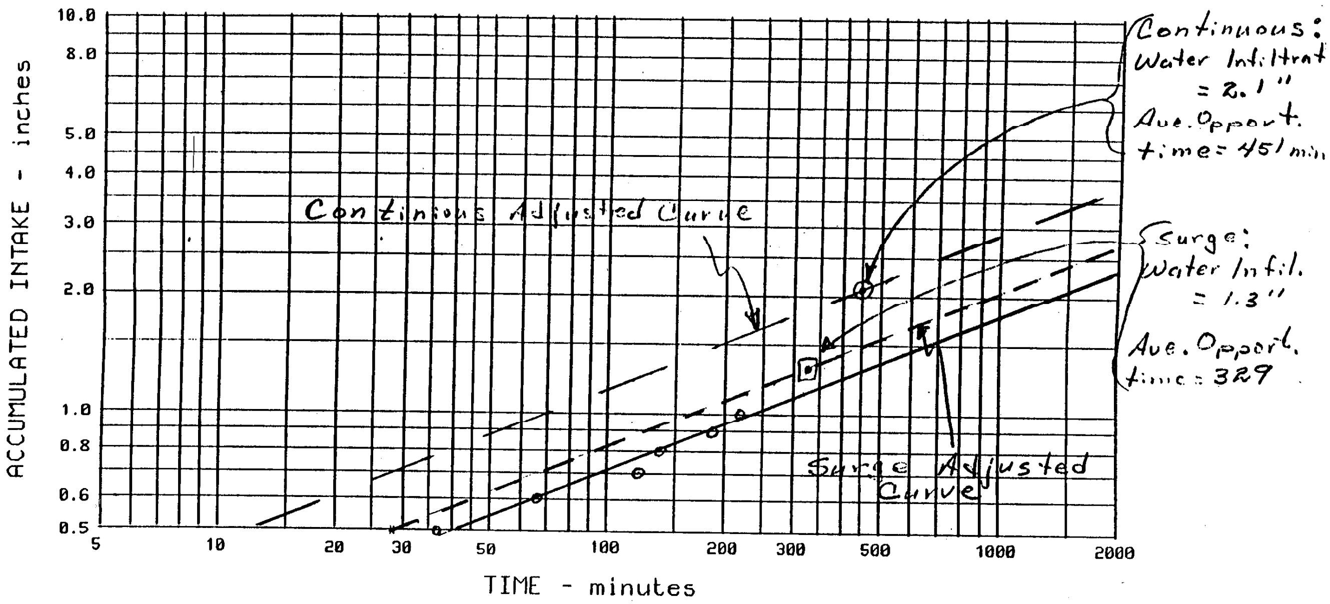
$$= \frac{1.6041 \times \text{furrow stream} \times \text{Applic. time}}{\text{advance length} \times \text{furrow spacing}}$$

$$= \frac{1.6041 \times 23 \times T}{(2 \times 3.33) \times L} = 5.54 \frac{T}{L}$$

↑ alternate furrows irrigated.

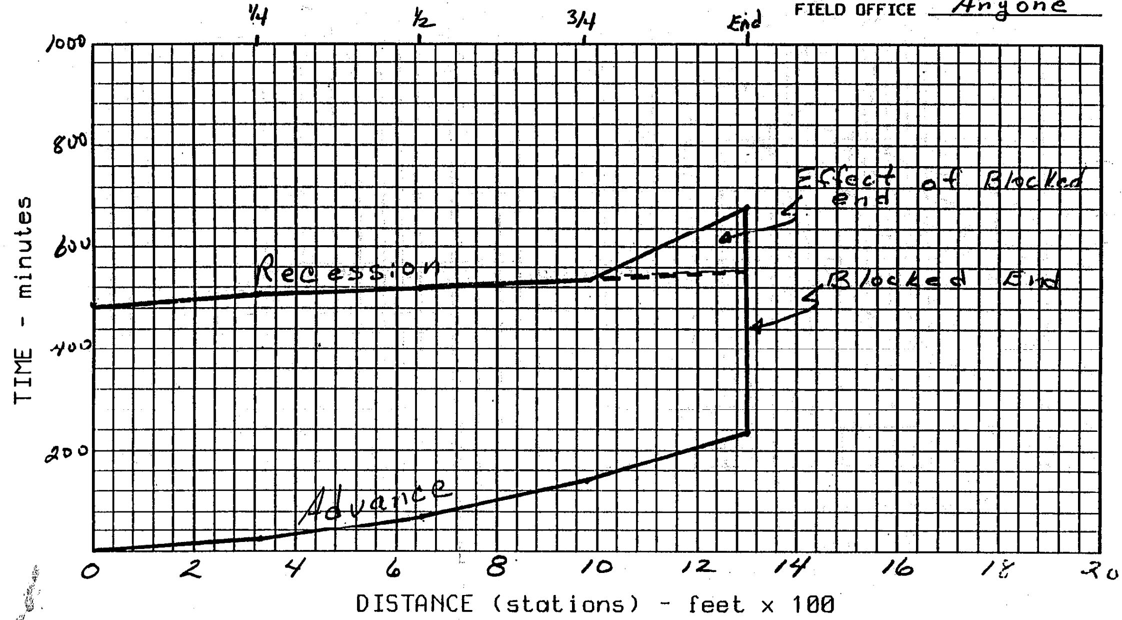
SOIL WATER INTAKE CURVE

LANDUSER John Smith
DATE Anytime
FIELD OFFICE Anyone



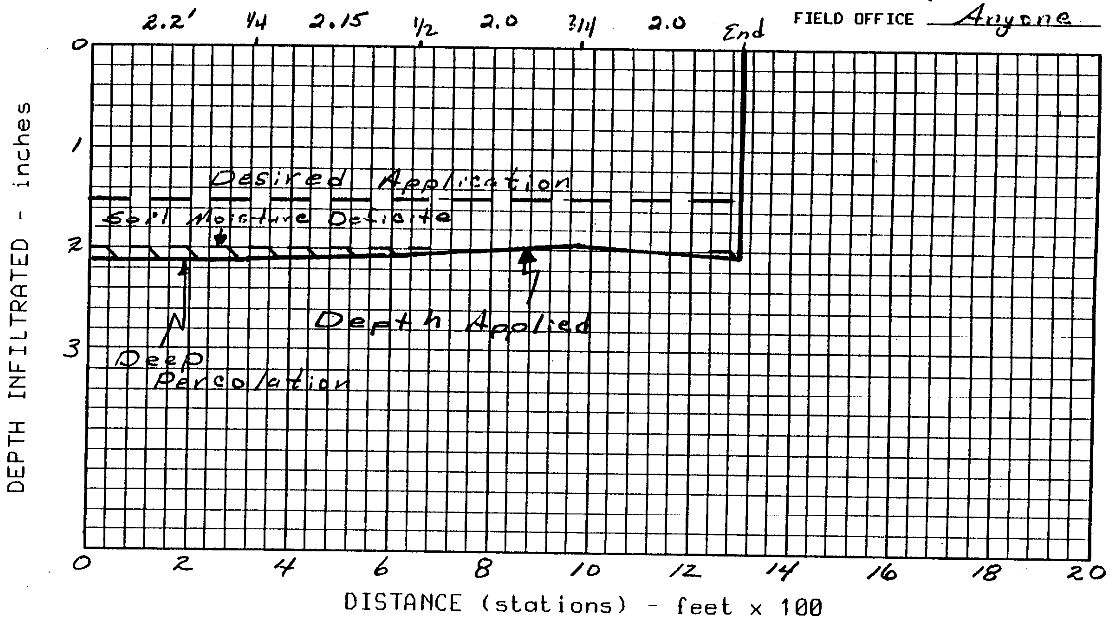
ADVANCE AND RECESSION CURVES

LANDUSER John Smith (continuous)
DATE Anytime
FIELD OFFICE Anyone



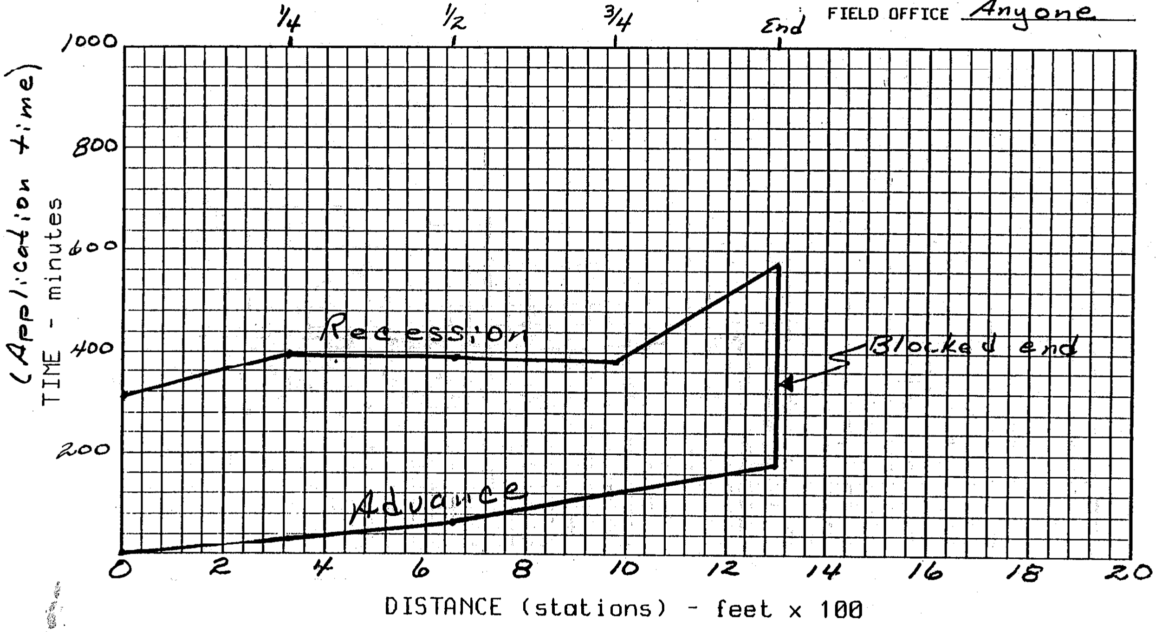
DEPTH INFILTRATED CURVE

LANDUSER John Smith(continuous)
DATE Anytime
FIELD OFFICE Anyone



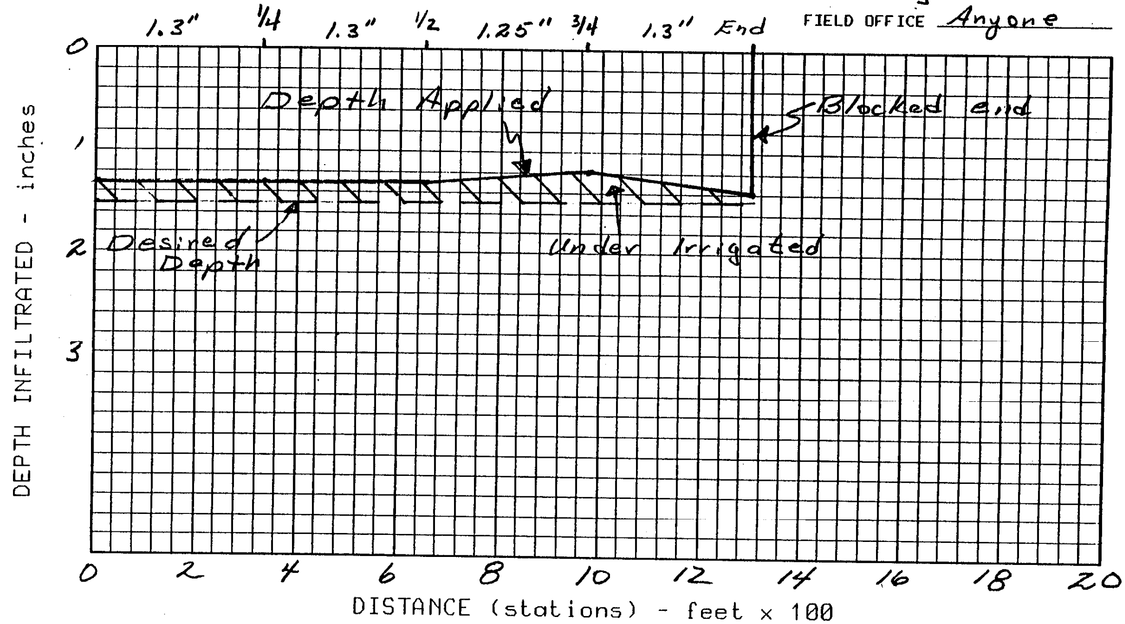
ADVANCE AND RECESSION CURVES

LANDUSER John Smith (surge)
DATE Anytime
FIELD OFFICE Anyone



DEPTH INFILTRATED CURVE

LANDUSER John Smith (surge)
DATE Anytime
FIELD OFFICE Anyone



D11

Example 2:

In this example, only a surge flow evaluation was performed. The cumulative intake vs. opportunity time curve was developed using the third method described on page 3. With surge flow, any off time must be subtracted from the lapse time (from the start of the irrigation to the initial advance time):

```
sta.  11+40, lapse time = (17:40 to 8:00) = 580 min.
             off time   = (3 x 90)        = 270 min.
              Application time            = 310 min.
```

The advance curve for surge flow is plotted using application time for advance (lapse time from the start of the irrigation to advance time minus any off time), same as the above example.

The time for the recession curve for surge flow is found by adding application time for advance to total opportunity time:

```
sta.  11+40 application time for advance = 310 min.
            total opportunity time       = 551 min.
                                  Time   = 861 min.
```

SURGE-CONVENTIONAL FURROW IRRIGATION EVALUATION WORKSHEET

Irrigator Gary Location Dumas

Field Office Dumas Date 7-16-85

Crop Corn Crop Stage reproductive Root depth 5.0

Furrow Spacing 3.33 ft., Length 1520 ft., Slope .2 -.1 %

Soil description Silty Clay

Irrigation No. 2 Furrow Condition loose

Desired Application this irrigation 6.0 inches

Surge Data

Cycle No.	1	2	3	4	5	6	7			
On time(min.)	90	90	90	90	90	90	90			
Advance Dist.(ft.)	515	830	1050	1325	1520	—	—			

Item	Surge	Continuous
1. Water supply to field 1/ (gpm)	690	
2. No. of furrows per set	23	
3. No. of furrows watered per set	23	
4. Furrow Stream (gpm)	30	
5. Clock Time water turned on	8:00	
6. Clock Time water turned off	5:00	
7. Irrigation time (hrs.) 2/	21.0	

Item	Surge	Continuous
8. Application time (hrs.) 3/	10.5	
9. Opportunity time 4/		

a. Continuous Flow

	Sta.	Advance (clock time)	Recession (clock time)	Opportunity (minutes)
Head				
¼				
½				
3/4				
End				

b. Surge Flow

Cycle No. (Clock Time)		1	2	3	4	5	6	7	8	9	10	Total
	Adv.	8:00	11:00	14:00	17:00	20:00	23:00	2:00				
Head	Rec.	9:40	12:40	15:40	18:40	21:40	24:40	3:40				
0+00	Opp.	100	100	100	100	100	100	100				700
	Adv.	8:44	11:10	14:10	17:10	20:10	23:10	2:10				
¼	Rec.	9:49	12:49	15:49	18:49	21:49	24:49	3:49				
3+80	Opp.	65	99	99	99	99	99	99				659
	Adv.		12:16	14:23	17:22	20:22	23:22	2:22				
½	Rec.		13:07	16:09	19:08	22:08	1:08	4:08				
7+60	Opp.		51	106	106	106	106	106				581
	Adv.				17:40	20:33	23:33	2:33				
3/4	Rec.				19:27	23:01	2:01	5:01				
11+40	Opp.				107	148	148	148				551
	Adv.					21:30	23.47	(2:00)	(no recession)			
End	Rec.					23:40	(2:00)	6:02				
15+20	Opp.					130	133	242				[illegible]

$\frac{2996}{5} = 599$

c. Average Opportunity time (hrs) — Surge: 600 — Continuous:

Item

10. Water applied Penetration 5/

	Sta.	Surge depth (ft.)	Surge water (in.)	Continuous depth (ft.)	Continuous water (in.)
Head	0+00	6.5			
¼	3+80	6.3			
½	2+60	5.9			
3/4	1+40	5.8			
End	15+20	5.5			

Item	Surge	Continuous
11. Gross Water applied per set (inches) 6/	6.0	
12. Runoff, (%/inches) 7/	/ 0.0 (blocked ends)	/
13. Water Infiltrated (Average inches) 8/	6.0	
14. AWC of Root Zone (inches)	10.0	
15. Soil Water Deficiency (inches)	6.0	
16. Water stored in root zone, (ave. inches) 9/	5.9	
17. Deep Percolation, (%/ave. inches) 10/	/ 0.1	/
18. Application Efficiency 11/	98	
19. Distribution, (%) 12/(%) or (good, fair or poor)	96	
20. Cost per Acre-Inch (dollars) 13/	2.37	
21. Cost per Acre (dollars) 14/	14.22	
22. Visible Furrow Erosion (None, slight, moderate, excessive)	slight	

23. Comments Both the application efficiency and distribution uniformity were very good. The blocked ends and flatter bottom slope helped distribution uniformity.

1/Total of water supply being delivered to field.

2/Total time to irrigate a set, (time turned on-time turned off)

3/Actual time water is applied to furrow. Usually ½ of irrigation time, for surge, same as irrigation time on conventional.

4/Record the clock time that water is turned on to the furrow at the head and the time it advances to each station. After water is turned off, record the recession time that the water disappears from the furrow at each station. At each station, the opportunity time is the difference between recession time and advance time. Average the opportunity time for both surged continuous.

5/When advance and recession curves and accumulated intake curves are used, record the inches of moisture applied at each station. If not an auger or soil probe can be used to determine the depth the water has penetrated after the irrigation is completed. This will give an indication of the water infiltration distribution. An estimate can be made of the inches of water applied at each sta.

6/Gross water applied =

$$\frac{1.6041 \times \text{application time (min)} \times \text{furrow stream (gpm)}}{\text{furrow spacing (ft.)} \times \text{furrow length (ft.)}}$$

7/If you cannot measure runoff, make your best estimate, express in % of water applied to field and inches. (average % of furrow stream x % of application time runoff occurred)

8/Average Water Infiltrated = Gross Water applied (in.) - Runoff (in.) Check to see if this agrees with item 10, water applied or pentration.

9/Average the inches of water stored (infiltrated) in the root zone, water infiltrated or soil moisture deficiency, whichever is less at each ¼ point.

10/Record the average inches of water infiltrated beyond the root zone. If the infiltration is estimated (Amount infiltrated - Amount stored in root zone)

11/

$$\frac{\text{Average Water stored on root zone}}{\text{Gross Water applied to field}} \times 100$$

12/

$$\% = \frac{\text{(average water applied in root zone to low ¼ area (inches)} \times 100}{\text{Average water applied to root zone}}$$

or rank it good, fair or poor

13/

$$\text{Cost per acre - Inch} = \frac{\text{Fuel cost per Hour} \times 450}{\text{Water supply (gpm)}}$$

14/Cost per Acre = (Cost per Acre-Inch) x (Gross Water Applied, Inches)

COMPUTATION SHEET
SCS-ENG-522 REV. 3-69

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

D17

STATE TX
PROJECT Surge Irr. Evaluation
BY ABC DATE 7-16-85 CHECKED BY DATE JOB NO.
SUBJECT Field Advance Data
SHEET 1 OF 2

App. time = total time water has been applied to the furrow

	Surge	1				2				3				4			
	Sta.	Adv. time	App. time	Rec. time	Opp. time	Adv. time	App. time	Rec. time	Opp time	Adv. time	App. time	Rec. time	Opp. time	Adv. time	App. time	Rec. time	Opp. time
	0+00	8:00	0	9:40	100	11:00	90	12:40	100	14:00	180	15:40	100	17:00	270	18:40	100
	1+00	:02	2														
	2+00	:07	7														
	3+00	.22	22														
1/4	3+80	:44	44	9:49	65	11:10		12:49	99	14:10		15:49	99	17:10		18:49	99
	4+00	:49	49			11:11											
	5+00	9:25	85			11:16	106										
	6+00	(5+15	End)			11:31	121										
	7+00					11:58	148										
1/2	7+60					12:16	167	13:07	51	14:23		16:09	106	17:22		19:08	106
	8+00					12:30	180			14:25							
	9+00					(8+30	end)			14:40	220						
	10+00									15:07	247			17:29			
	11+00									(10+50	End)			17:34	304		
3/4	11+40													17:40	310	19:27	107
	12+00													17:49	319		
	13+00													18:16	346		
	14+00													(13+25	End)		
	15+00																
	15+20																

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

COMPUTATION SHEET
SCS-ENG-522 REV. 3-69

D18

STATE | PROJECT
BY | DATE | CHECKED BY | DATE | JOB NO.
SUBJECT | SHEET 2 OF 2

Surge	5				6				7							
Sta.	Adv. time	App. time	Rec. time	Opp. time	Adv. time	App. time	Rec. time	Opp time	Adv. time	App. time	Rec. time	Opp. time	Adv. time	App. time	Rec. time	Opp. time
0+00	20:00	360	21:40	100	23:00	450	24:40	100	2:00	540	3:40	100				
1+00																
2+00																
3+00																
1/4 3+80	20:10		21:49	99	23:10		24:49	99	2:10		3:49	99				
4+00																
5+00																
6+00																
7+00																
1/2 7+60	20:22		22:08	106	23:22		1:08	106	2:22		4:08	106				
8+00																
9+00																
10+00																
11+00																
3/4 11+40	20:33		23:01	148	23:33		2:01	148	2:33		5:01	148				
12+00																
13+00	20:40															
14+00	20:55	415														
15+00	21:22	442														
15+20	21:30	4:50	23:40	130	23:47		(2:00)	133	(2:00)		6:02	242				

No Recession

COMPUTATION SHEET
SCS-ENG-522 REV. 3-69

D19
U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

STATE TX	PROJECT Surge Irr. Evaluation		
BY ABC / DATE 7-16-85	CHECKED BY	DATE	JOB NO.
SUBJECT Intake Curve			SHEET ___ OF ___

Surge/off time	Sta.	Advance time (clock)	Applica. time (min) 1/	Ave. Cum Intake (in.) 2/
1/0	0+00	8:00	0	
	1+00	:02	2	.3
	2+00	:07	7	.5
	3+00	:22	22	1.1
	3+80	:44	44	1.7
	4+00	:49	49	1.8
2/1	5+00	9:25	85	2.5
	6+00	:31	121	2.9
	7+00	:58	148	3.1
	7+60	12:16	167	3.2
	8+00	:30	180	3.3
3/2	9+00	14:40	220	3.5
	10+00	15:07	247	3.6
4/3	11+00	17:34	304	4.0
	11+40	:40	310	3.9
	12+00	:49	319	3.8
	13+00	18:16	346	3.8
5/4	14+00	20:55	415	4.3
	15+00	21:22	442	4.3
	15+20	:30	450	4.3

1/ Application time = (Adv. time - Start time) - (off time)
Example sta 11+00
(17:34 - 8:00) - (3 × 90)
(9 hr. 34 min) - (270) = 574 - 270 = 304 min

2/ Average Cumulative Intake

$$= \frac{1.6041 \times \text{furrow stream} \times \text{Application time}}{\text{Advance length} \times \text{furrow spacing}}$$

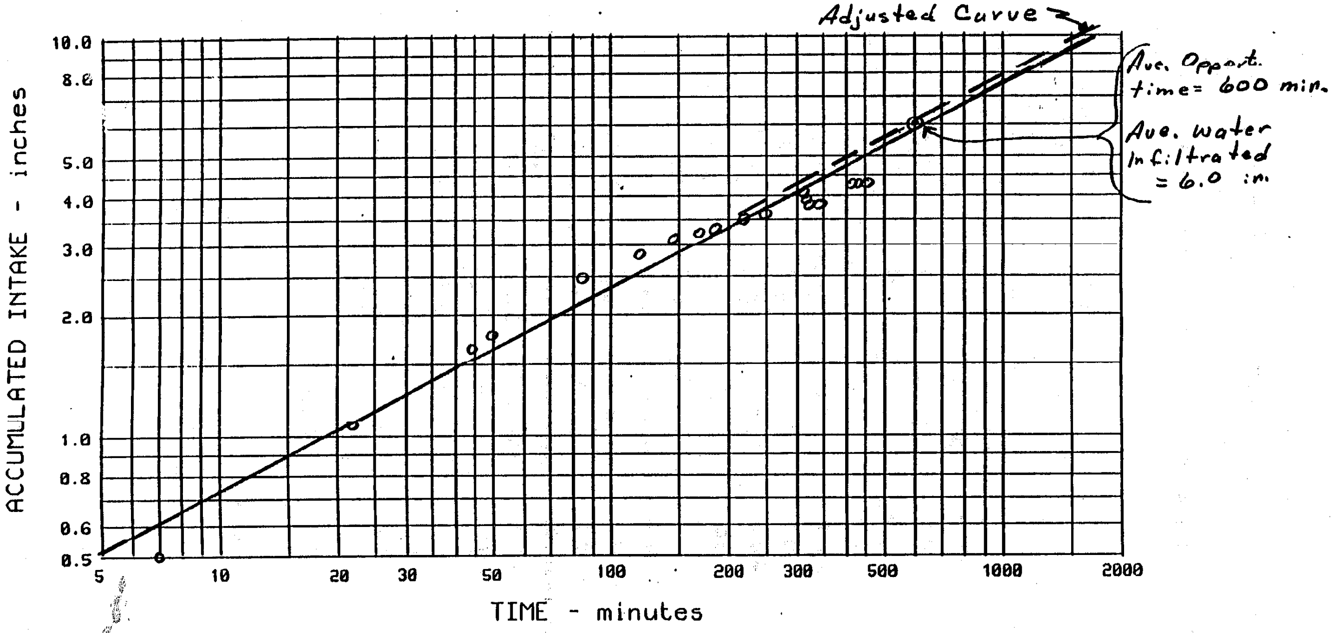
$$= \frac{1.6041 \times 30 \times T}{L \times 3.33} = 14.45 \frac{T}{L}$$

SOIL WATER INTAKE CURVE

LANDUSER Gary

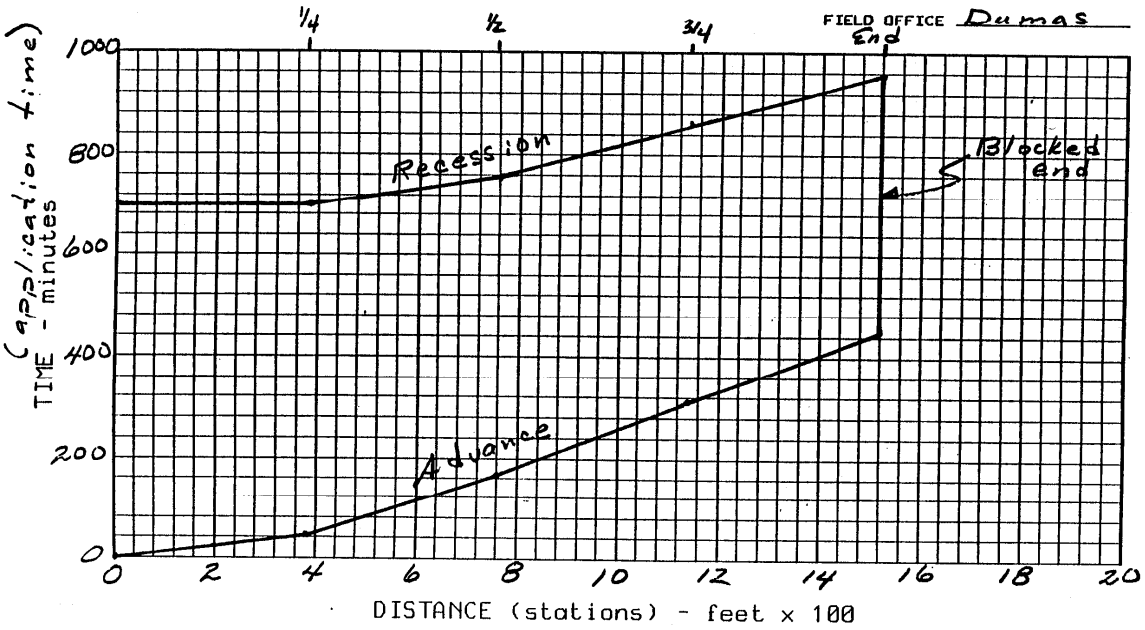
DATE 7-16-85

FIELD OFFICE Dumas



ADVANCE AND RECESSION CURVES

LANDUSER Gary
DATE 7-16-85
FIELD OFFICE Dumas

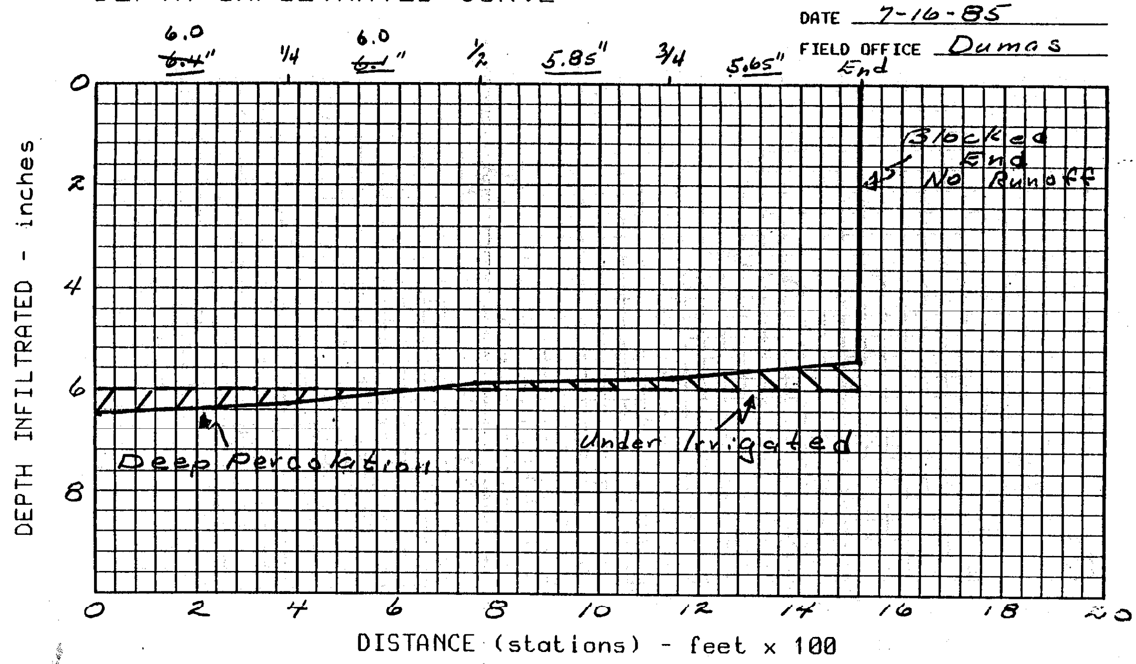


DEPTH INFILTRATED CURVE

LANDUSER Gary

DATE 7-16-85

FIELD OFFICE Dumas



Appendix E. - Evaluation Worksheets

Data Sheet for Comparing Surge and Continuous Flow Furrow Irrigation

______________	______________	______________
Farmer	Location	Date
______________	______________	______________
Techician	Field Office	Field

Basic Data

Crop______________ Daily Comsumptive Use______________

Soil Type______________ Crop Root Depth______________

Percent Slope______________ Length of Run______________

Furrow Spacing______________ Irrigation Pattern______________

Water Holding Capacity of Root Zone at Field Capacity (In.)______________

Soil Water Deficiency at Time of Irrigation (in.)______________

Desired Application this Irrigation (in.)______________

Irrigation Data

Irrigation Data	Surge Flow	Continuous Flow
Total Number of Rows in set	______	______
Number of watered furrows	______	______
Gallons per minute pumped	______	______
Gallons per minute per row	______	______
Application Time (hrs.)	______	______
Time for water to reach end of furrows (hrs.)	______	______
Acres per set	______	______
Water applied (in.)	______	______
Surge on-time	______	______
Number of surges per side	______	______
Percent of water which ran off as tailwater	______	______
Cost per acre-inch (dollars)	______	______
Cost per acre (dollars)	______	______
Visible furrow erosion	______	______

SURGE-CONVENTIONAL FURROW IRRIGATION EVALUATION WORKSHEET

Irrigator____________________ Location________________

Field Office____________________ Date________________

Crop______________ Crop Stage____________ Root depth______

Furrow Spacing______ft., Length_______ft., Slope_______%

Soil description________________________________

Irrigation No.____ Furrow Condition______________________

Desired Application this irrigation______inches

Surge Data

Cycle No.										
On time(min.)										
Advance Dist.(ft.)										

Item	Surge	Continuous
1. Water supply to field 1/ (gpm)		
2. No. of furrows per set		
3. No. of furrows watered per set		
4. Furrow Stream (gpm)		
5. Clock Time water turned on		
6. Clock Time water turned off		
7. Irrigation time (hrs.) 2/		

Item	Surge	Continuous
8. Application time (hrs.) 3/	____	____
9. Opportunity time 4/		

a. Continuous Flow

	Sta.	Advance (clock time)	Recession (clock time)	Opportunity (minutes)
Head	____	____	____	____
¼	____	____	____	____
½	____	____	____	____
3/4	____	____	____	____
End	____	____	____	____

b. Surge Flow

Cycle No. Total (Clock Time)		1	2	3	4	5	6	7	8	9	10	
	Adv.	__	__	__	__	__	__	__	__	__	__	
Head	Rec.	__	__	__	__	__	__	__	__	__	__	
	Opp.	__	__	__	__	__	__	__	__	__	__	__
	Adv.	__	__	__	__	__	__	__	__	__	__	
¼	Rec.	__	__	__	__	__	__	__	__	__	__	
	Opp.	__	__	__	__	__	__	__	__	__	__	__
	Adv.	__	__	__	__	__	__	__	__	__	__	
½	Rec.	__	__	__	__	__	__	__	__	__	__	
	Opp.	__	__	__	__	__	__	__	__	__	__	__
	Adv.	__	__	__	__	__	__	__	__	__	__	
3/4	Rec.	__	__	__	__	__	__	__	__	__	__	
	Opp.	__	__	__	__	__	__	__	__	__	__	__
	Adv.	__	__	__	__	__	__	__	__	__	__	
End	Rec.	__	__	__	__	__	__	__	__	__	__	
	Opp.	__	__	__	__	__	__	__	__	__	__	__

c. Average Opportunity time (hrs) ____ ____

Item			Surge		Continuous	
10. Water applied Penetration 5/		Sta.	depth (ft.)	water (in.)	depth (ft.)	water (in.)
	Head	___	___	___	___	___
	¼	___	___	___	___	___
	½	___	___	___	___	___
	3/4	___	___	___	___	___
	End	___	___	___	___	___

Item	Surge	Continuous
11. Gross Water applied per set (inches) 6/	___	___
12. Runoff, (%/inches) 7/	___/___	___/___
13. Water Infiltrated (Average inches) 8/	___	___
14. AWC of Root Zone (inches)	___	___
15. Soil Water Deficiency (inches)	___	___
16. Water stored in 9/ root zone, (ave.inches)	___	___
17. Deep Percolation, 10/ (%/ave. inches)	___/___	___/___
18. Application Efficiency 11/	___	___
19. Distribution, (%) 12/(%) or (good, fair or poor)	___	___
20. Cost per Acre-Inch (dollars) 13/	___	___
21. Cost per Acre (dollars) 14/	___	___
22. Visible Furrow Erosion (None, slight, moderate, excessive)	___	___

23. Comments ____

____

____

____

1/ Total of water supply being delivered to field.

2/ Total time to irrigate a set, (time turned on-time turned off)

3/ Actual time water is applied to furrow. Usually ½ of irrigation time, for surge, same as irrigation time on conventional.

4/ Record the clock time that water is turned on to the furrow at the head and the time it advances to each station. After water is turned off, record the recession time that the water disappears from the furrow at each station. At each station, the opportunity time is the difference between recession time and advance time. Average the opportunity time for both surged continuous.

5/ When advance and recession curves and accumulated intake curves are used, record the inches of moisture applied at each station. If not an auger or soil probe can be used to determine the depth the water has penetrated after the irrigation is completed. This will give an indication of the water infiltration distribution. An estimate can be made of the inches of water applied at each sta.

6/ Gross water applied =

$$\frac{1.6041 \times \text{application time (min)} \times \text{furrow stream (gpm)}}{\text{furrow spacing (ft.)} \times \text{furrow length (ft.)}}$$

7/ If you cannot measure runoff, make your best estimate, express in % of water applied to field and inches. (average % of furrow stream x % of application time runoff occurred)

8/ Average Water Infiltrated = Gross Water applied (in.) - Runoff (in.) Check to see if this agrees with item 10, water applied or pentration.

9/ Average the inches of water stored (infiltrated) in the root zone, water infiltrated or soil moisture deficiency, whichever is less at each ¼ point.

10/ Record the average inches of water infiltrated beyond the root zone. If the infiltration is estimated (Amount infiltrated - Amount stored in root zone)

11/ $$\frac{\text{Average Water stored on root zone}}{\text{Gross Water applied to field}} \times 100$$

12/ $$\% = \frac{\text{(average water applied in root zone to low ¼ area (inches)} \times 100}{\text{Average water applied to root zone}}$$

or rank it good, fair or poor

13/ $$\text{Cost per acre - Inch} = \frac{\text{Fuel cost per Hour} \times 450}{\text{Water supply (gpm)}}$$

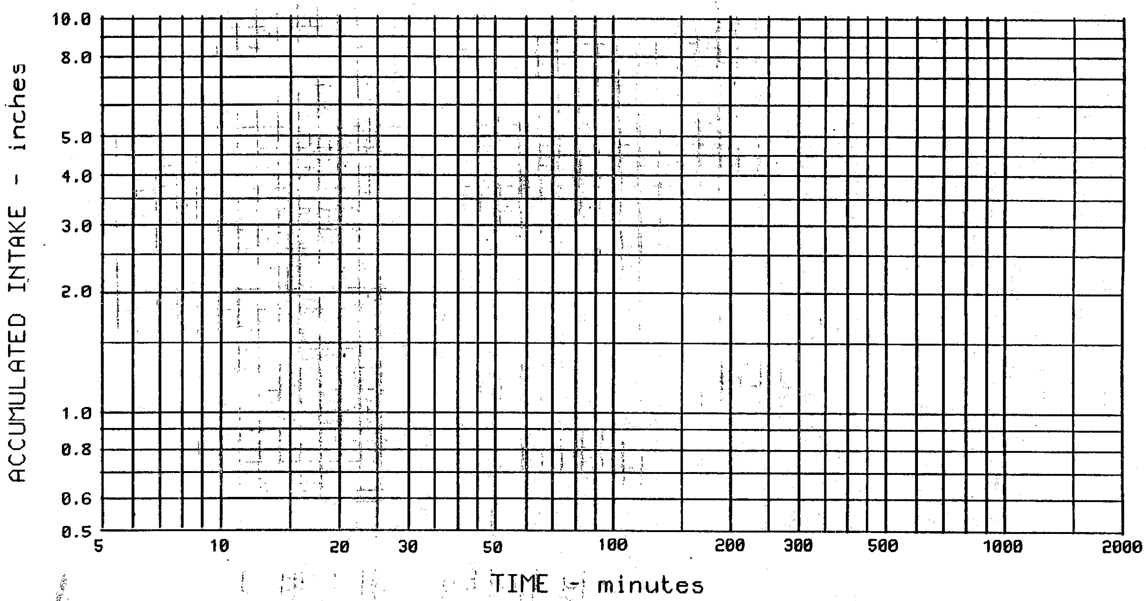
14/ Cost per Acre = (Cost per Acre-Inch) x (Gross Water Applied, Inches)

SOIL WATER INTAKE CURVE

LANDUSER ______________________

DATE ______________________

FIELD OFFICE ______________________

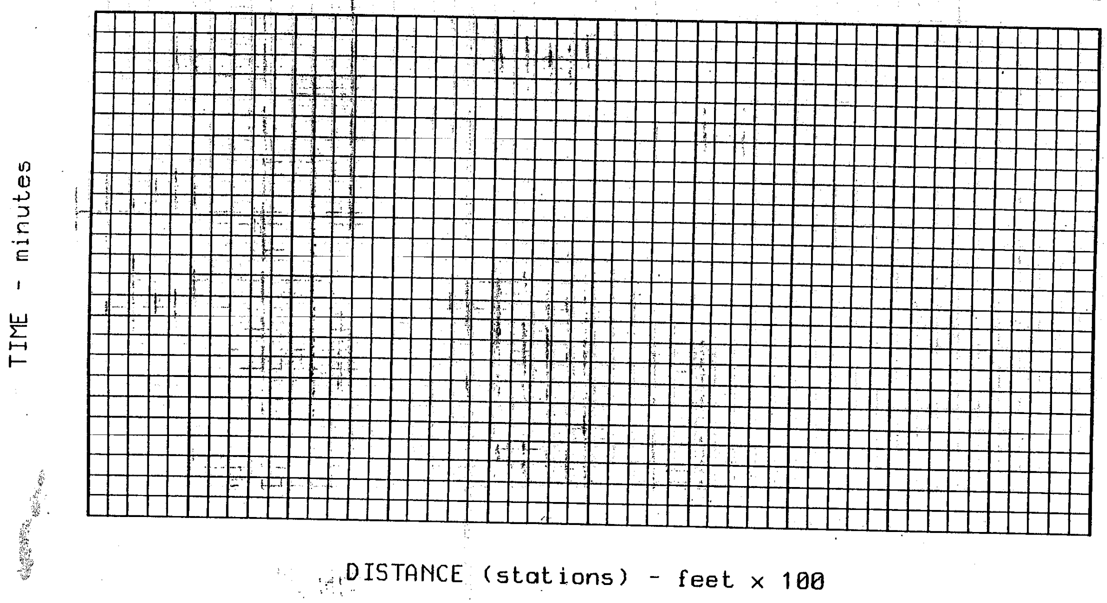


ADVANCE AND RECESSION CURVES

LANDUSER ____________________

DATE ____________________

FIELD OFFICE ____________________



DEPTH INFILTRATED CURVE

LANDUSER ______________________

DATE ______________________

FIELD OFFICE ______________