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Designing An Automatic Cut-Back Furrow Irrigation System

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CONTENTS

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Agricultural engineers at the Oklahoma Agricultural Experiment Station have designed and constructed an automatic cut-back furrow irrigation system. This system has reduced the labor required for furrow irrigation to one to two percent of that of a conventional system with a man in constant attendance. The automatic system applies water to the field more uniformly than conventional systems because of the cut-back feature designed into it. The automatic system eliminates the factor of expensive and sometimes unavailable labor supply from the decision of whether or not to apply water.

The automatic system can be installed using the manually removed check dams, or it can be adapted to time-clock-controlled automatic gates for complete automation.

Non-automatic cut-back furrow irrigation utilizes a large furrow stream to initially wet the length of the furrows. The flow is then reduced to balance the intake rate of the soil for that length of furrow. This usually results in a more uniform application of water, but the method has not gained wide acceptance because it greatly increases an already high labor requirement and requires greater labor skills. This new automatic cut-back system is engineered to accomplish the cut-back with a small fraction of the total labor and a reduction of the skills level needed.

This publication describes the automatic, cut-back furrow irrigation system and contains information on how to design and build it.

How the System Works

An elevation drawing illustrating the operation of the system is shown in Figure 1. When turned into the ditch, the water rises in the first bay until the initial furrow flow is discharged from each tube. When the furrows irrigated by this bay have watered through the field, the check dam at the end of the first bay is removed, either manual-

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Research reported herein was conducted under Oklahoma Experiment Station Project No. 622.

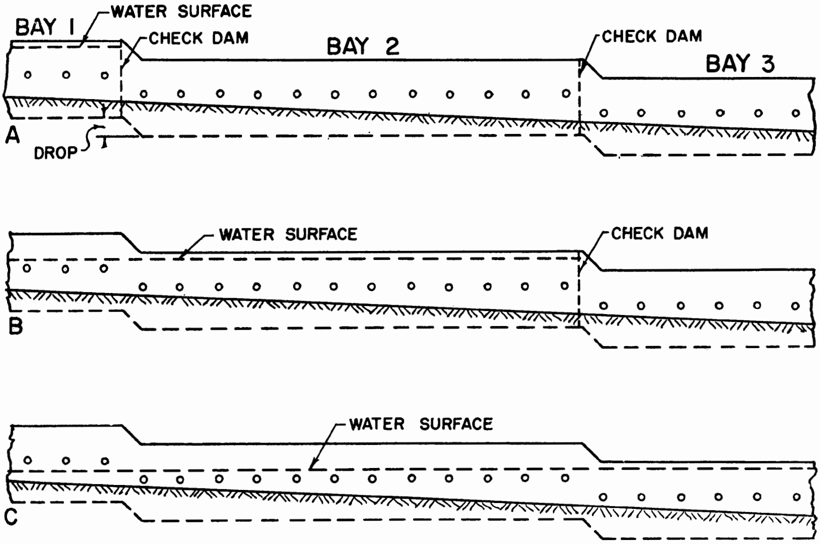

Figure 1. Elevation drawing of cut-back furrow irrigation system using one cut-back. In A, bay 1 is delivering the initial furrow flow. In B, the check dam has been removed from bay 1, bay 2 is delivering the initial furrow flow and bay 1 is delivering the cut-back flow. In C, the check dam has been removed from bay 2, bay 3 is delivering the initial furrow flow, bay 2 is delivering the cut-back furrow flow and bay 1 is shut off.

ly or automatically. Water then rises in the second bay until the tubes in this bay are discharging the initial flow. The tubes in the first bay now have a head equal to the initial head minus the amount of drop between bays, thus establishing the cut-back flow. The number of tubes needed in the second bay depends on the supply flow minus the discharge of the first bay at the cut-back furrow flow. When the furrows irrigated by the second bay have watered through the field, the check dam at the end of this bay is removed. Bay number 3 will now irrigate with the initial flow, bay number 2 will irrigate with the cut-back flow and the tubes in bay number 1 are above the water surface. The number of tubes needed in subsequent bays depends on the supply flow minus the amount discharged by the preceding bay at the cut-back flow.

The labor requirement for a three-inch irrigation on a 15-acre field consists of placing and removing five sheet metal check dams which totals less than 30 minutes. This compares to 22½ hours labor for the siphon tube system with an earthen ditch with one man in constant attendance.

If there is a supply ditch ahead of the first bay, an overfall check dam must be placed ahead of the bay to prevent the water storage from being a factor in the operation of the system. Weed guards ahead of the system also help keep the tubes from clogging.

Designing a System

Cut-back furrow irrigation systems must be specifically designed for each particular area to be irrigated. Accurate information is needed for their design since they are a permanent installation poured in concrete. The operation of the systems cannot depart far from their design values so they must be right the first time. The following general points must be considered in the design of these systems.

Water Supply

The water supply flow for the system must be accurately determined. Once the system is designed for a given flow, it is essential that it be operated very near to this design. Any of the common measuring devices such as weirs, orifices, Parshall flumes, or velocity meters can be used to measure the flow. It is advisable to secure the services of someone experienced in water measurement to insure accurate measurement.

Slope of Land Surface

The slope of land surface in the direction of the ditch must be determined. The total drop in the ditch throughout its length should be about the same as the drop in elevation of the ground surface. In order to insure that the furrow tubes are not below the ground level, the ground surface profile along the ditch must be known. An engineer's level can be used to determine this difference in the elevations.

Length of Ditch

The length of the distribution section of the ditch in which the tubes will be placed should be accurately chained. The ditch must be designed so that no partial bays are left over. This usually involves adjustments in the first trial designs. The size of the furrow streams may have to be varied slightly in order to fit the system to the field. The procedure is described in the example design.

Furrow Stream Size

The desired size of the initial and cut-back furrow flows must be determined. This should be done by field trials. The time required for different sizes of initial furrow streams to advance past measured stations should be determined. This should be done at different locations down the ditch to determine the variation across the field. Since the rate of advance changes as the growing season progresses, the time trials may need to be conducted near the beginning and end of the irrigation season. Some reasonable depth of water application should be selected and the size of initial furrow stream which will apply from two-thirds to three-fourths of this depth by the time it has watered through the furrow should be selected. The furrow stream size should not be so large as to cause significant erosion. This can be determined by observation.

After a size of initial furrow stream has been selected, trials should be run with this size to determine the cut-back furrow stream required. Once the initial stream has watered through the furrow, it should be reduced different amounts to determine the cut-back stream size which will balance the water intake rate of the soil and maintain a wetted furrow throughout.

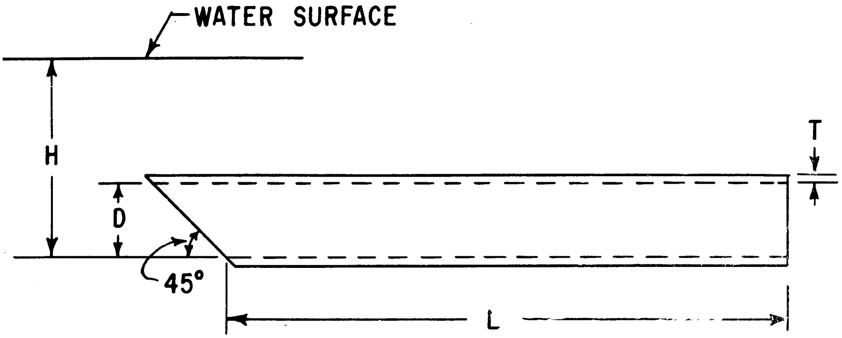

Figure 2. A drawing of the outlet tubes with hooded inlets used in this system.

The information on the sizes of furrow streams needed can best be determined on existing irrigation systems. The operation of the system to be designed will be no more accurate than the information obtained from these determinations.

Selection of Tube Size and Head

A series of tests were run on short, level tubes of standard galvanized pipe with the configuration shown in Figure 2.

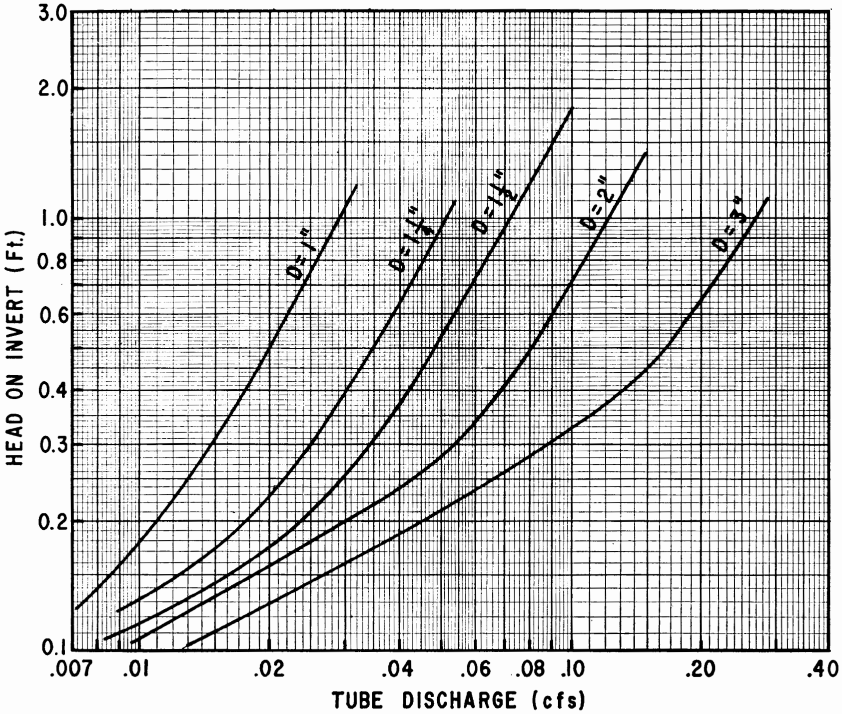

Figure 3. Relationship of head to discharge for galvanized pipes 2.10 feet long with hooded inlets.

Figure 3 shows the relationship of head to discharge for tubes of galvanized pipe 2.1 feet long. This length allows 10 tubes from a standard 21-foot joint of pipe. When the sizes of initial and cut-back streams are decided, the size of tube can be determined from this figure.

In order to arrive at the sizes of initial furrow flow available, Figure 4 can be used. The nomograph is entered on the left hand scale with the value obtained by multiplying the land slope in the direction of the ditch in foot per foot by supply flow to the ditch expressed in cfs. A line is drawn from this value through the furrow spacing to the pivot line. A line is drawn from this intersection on the pivot line through the diameter of tube which gives the nearest value of initial furrow flow to the value desired. This diameter of tube should then be checked in Figure 3 for the heads required at the initial furrow flow and the cut-back furrow flow.

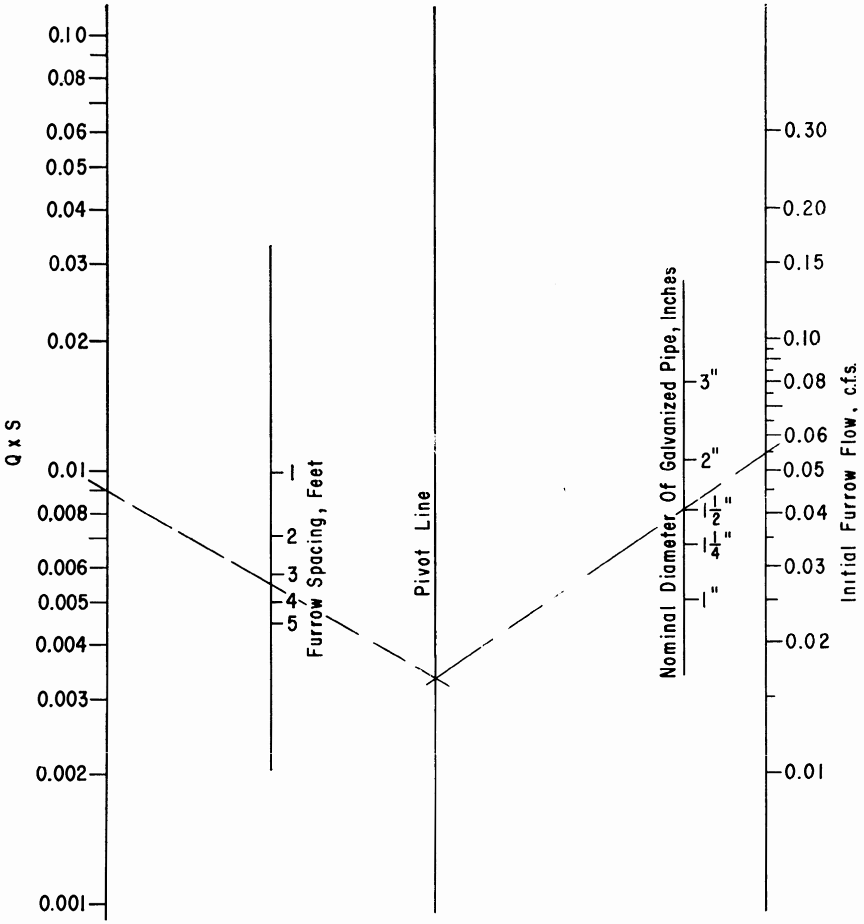

Figure 4. Nomograph for selection of size of discharge tubes needed for various operating conditions. Multiply the supply flow in cubic feet per second by the slope in foot/foot and enter the result on the left hand side of the graph. Draw through the furrow spacing on scale 2 to the pivot line. From this intersection on the pivot line draw through the even pipe size which gives nearest the desired initial furrow flow.

Example Design

An example design was developed to illustrate some of the problems encountered in designing a system. The design conditions are intentionally arranged to require successive trials. The conditions for most designs may not be as extreme as this one:

Length of ditch — 1,378 feet
Furrow spacing — 3.33 feet
Water delivery — 3 cubic feet per second
Average land slope in the direction of the ditch—0.0030 foot per foot
Average furrow slope — 0.0025 foot per foot
Desired initial flow — 25 gallons per minute or 0.0557 cubic feet/second
Desired cut-back flow — 11 gpm or 0.0245 cubic feet per second
Length of discharge tubes — 2.1 feet

Developing the Design

The size of discharge tubes needed and their operating head will be determined first, followed by the design of the bays.

The nomograph shown in Figure 4 can be used to select outlet tube size for various design conditions. As can be seen in Figure 4, 1½ inch pipes will be required to obtain a:

Design initial flow = 0.054 cfs — 24.2 gpm
Design cut-back flow — 0.0245 cfs = 11.0 gpm

Figure 3 shows the discharge of various sizes of furrow outlet tubes made of standard galvanized pipe at various operating heads above the pipe invert. The following data are now determined using Figure 3 and design specifications.

Initial head — 0.60′ for 0.054 cfs.

Cut-back head = 0.205′ for 0.0245 cfs;

Drop between bays — 0.60 — 0.205 (initial head — cut-back head) = 0.395′

Number of furrows — 1378/3.33 (ditch length/furrow spacing) = 413 furrows

Fall in land surface = 1378 x .0030 (ditch length x slope) — 4.13′

Fifty-six tubes will be needed to discharge the 3.0 cfs at initial flow. These 56 tubes will require 1.37 cfs at the cut-back flow of 0.0245 cfs. This leaves 1.63 cfs to be carried by the tubes in bay 2 at initial flow. Thirty tubes at 0.0543 cfs will be needed. Table I shows the results of the calculations for each bay.

At this point it can be determined that the system will require either 10 or 11 bays. The two systems will have different average slopes, so the object is to design and choose the best combination of bays which will best fit the field slope.

TABLE I—Preliminary Design of the System for the Example Conditions

Bay No.	Initial flow	Cut-back flow	Number of tubes	Accumulative Number of Tubes	Number of Tubes at Cut-back Flow	Initial Tube Discharge	Cut-back Tube Discharge in Previous Bay
	cfs	cfs				cfs	cfs
1	3.0	0.0	56	56	0	0.0535	0
2	1.63	1.37	30	86	56	0.0543	0.0245
3	2.265	0.735	42	128	30	0.054	0.0245
4	1.97	1.03	36	164	42	0.0547	0.0245
5	2.12	.88	39	203	36	0.0544	0.0245
6	2.045	.955	38	241	39	0.0539	0.0245
7	2.069	.931	38	317	38	0.0545	0.0245
8	2.069	.931	38	317	38	0.0545	0.0245
9	2.069	.931	38	355	38	0.0545	0.0245
10	2.069	.931	38	393	38	0.0545	0.0245
11	2.069	.931	38	431	38	0.0545	0.0245

431 tubes are 18 tubes more than needed. 393 tubes are 20 tubes less than needed. Modifications must be made to fit the system to the field.

11-Bay System

The design shown in Table 1 will not work because it would leave a partial bay. Therefore, in order to fit the bays to the field, the number of tubes per bay will be decreased an average of about two tubes. This will result in 36 tubes per bay for the last six bays (Table II).

Table II shows a modified design using these calculations:

36 x .0245 = .882 cfs at the cut-back flow, water remaining = 2.118 cfs at the initial flow. $\frac{2.118}{36 \text{ tubes}}$ = 0.0588 cfs initial tube discharge.

10-Bay System

The results of designing a 10-bay system will now be presented. (See Table I).

Increased tubes needed = 20 or, 20/10 bays = 2 per bay.

40 x 0.0245 = 0.98 cfs at cut-back flow. Amount remaining at initial flow = 2.02

2.02/40 = 0.0505 cfs at initial flow.

Table III shows there are 413 tubes in the 10-Bay System also, the required number to fit the system to the field.

The fall in the land surface in the direction of the ditch is 4.13 feet. The first ditch would require the upper end of the ditch to be elevated 0.52 foot. The second ditch would require the lower end of the ditch to be elevated 1.16 foot. The lowest tube should have free discharge at the outlet (not submerged). The length of ditch was intentionally selected so that the initial design resulted in a ditch which was mismatched to the field by about one-half bay. The usual design would match the field slope more closely.

The 11-bay design will be selected over the 10-bay system but modified to better match the field slope.

The individual bays will need to have 0.05 ft. less drop between bays to fit the field slope. The following heads will be used to produce the discharges in Table V.

Table II—A Modified Design to fit the System to the Field Dimensions
(11-Bay System)

Bay No.	Initial flow	Cut-back flow	Number of-tubes	Accumulative Number of Tubes	Number of Tubes at Cut-back Flow	Initial Tube Discharge	Cut-back Tube Discharge in Previous Bay
	——————cfs——————					———————cfs———————	
1	3.0	0.0	51	51	0	0.0588	0.0
2	1.75	1.25	30	81	51	0.0583	0.0245
3	2.265	0.735	38	119	30	0.0581	0.0245
4	2.07	0.93	35	154	38	0.0592	0.0245
5	2.142	0.858	37	191	35	0.0580	0.0245
6	2.094	0.906	36	227	37	0.0581	0.0245
7	2.118	0.882	36	263	36	0.0588	0.0245
8	2.118	0.882	36	299	36	0.0588	0.0245
9	2.118	0.882	36	335	36	0.0588	0.0245
10	2.118	0.882	36	371	36	0.0588	0.0245
11	2.118	0.882	36	407	36	0.0588	0.0245

TABLE II, Modified

407 tubes are 6 less than needed, add one tube to each of the last six bays

6	2.094	0.906	37	228	37	0.0566	0.0245
7	2.094	0.906	37	265	37	0.0566	0.0245
8	2.094	0.906	37	302	37	0.0566	0.0245
9	2.094	0.906	37	339	37	0.0566	0.0245
10	2.094	0.906	37	376	37	0.0566	0.0245
11	2.094	0.906	37	413	37	0.0566	0.0245

Average initial tube discharge — 0.0574

413 tubes are required to fit the system to the field.

TABLE III—An Alternate Design Which Fits the System to the Field Dimensions (10-Bay System)

Bay No.	Initial flow	Cut-back flow	Number of-tubes	Accumulative Number of Tubes	Number of Tubes at Cut-back Flow	Initial Tube Discharge	Cut-back Tube Discharge in Previous Bay
	———cfs———					————cfs————	
1	3.00	0.00	59	59	0	0.0509	0.0
2	1.55	1.45	30	89	59	0.0516	0.0245
3	2.265	0.735	44	133	30	0.0515	0.0245
4	1.92	1.08	38	171	44	0.0505	0.0245
5	2.07	0.93	41	212	38	0.0505	0.0245
6	1.995	1.005	40	252	41	0.0499	0.0245
7	2.02	0.98	40	292	40	0.0505	0.0245
8	2.02	0.98	40	332	40	0.0505	0.0245
9	2.02	0.98	40	372	40	0.0505	0.0245
10	2.02	0.98	40	412	40	0.0505	0.0245
This is one tube fewer than needed, so add one tube to the last bay, giving							
10	2.02	0.98	41	413	40	0.0493	0.0245
					average initial tube discharge	0.0506	

A comparison of the designs is listed below:

TABLE IV—A Comparison of the Results of the Two Designs

Design	Average Initial Tube Discharge	Cut-back Tube Discharge	Head at Average Initial Flow	Head at Cut-back Flow	Drop Between Bays	Number of Drops	Total Drop (Ft.)
	————cfs————		Feet	Feet	Feet		
11-Bay	0.0574	0.0245	0.67	0.205	0.465	10	4.65
10-Bay	0.0506	0.0245	0.535	0.205	0.330	9	2.97

The adjustment in heads and discharges caused by changing the drop between bays shown in Table V causes some variation in cut-back flows and allows the system to be fitted to the field slope within 0.02 foot difference in elevation.

TABLE V—Calculations to find the Total Drop in the Ditch

Bay No.	Initial Tube Discharge cfs	Cut-back Tube Discharge in Previous Bay cfs	Initial Head ft	Cut-back Head in Previous Bay ft	Drop Between Bays
1	0.0588	0.0	0.69		
2	0.0565	0.0265	0.63	0.215	.415
3	0.0571	0.0275	0.63	0.215	.415
4	0.0565	0.0265	0.63	0.215	.415
5	0.0565	0.0265	0.63	0.215	.415
6	0.056	0.0255	0.63	0.215	.415
7	0.056	0.0255	0.63	0.215	.415
8	0.056	0.0255	0.63	0.215	.415
9	0.056	0.0255	0.63	0.215	.415
10	0.056	0.0255	0.63	0.215	.415
11	0.056	0.0255	0.63	0.215	.415
				Total Drop	4.150

Non-Erosive Initial Flow

The maximum non-erosive furrow stream for an average loam soil is approximately

$$\text{gpm} = \frac{10}{\%\ \text{slope}}$$

For this example, $\text{gpm} = \frac{10}{0.25} = 40\ \text{gpm} = 0.089\ \text{cfs}.$

The design average initial furrow stream of 0.0574 cfs would be expected to be non-erosive. This can be confirmed from the field tests to determine the size of initial furrow stream.

Determination of Depth of Flow

The allowable difference in elevation of the water surface at the upper and lower end of bay one when it is the cut-off bay is

$$H_f = Z_1 + Z_2 - H_1 - W$$

H_1 is the initial head in bay 3

Z_1 is the drop between bay 1 and bay 2

Z_2 is the drop between bay 2 and bay 3

W is the distance the inverts of the tubes must be set above the normal water surface at the upper end of the bay to prevent discharge due to wave action by the wind.

For this example, assuming $W = 0.04$ foot

$H_f = 0.415 + 0.415 - 0.68 - 0.04$

$H_f = 0.11$ ft., the allowable fall in water surface in the cut-off bay.

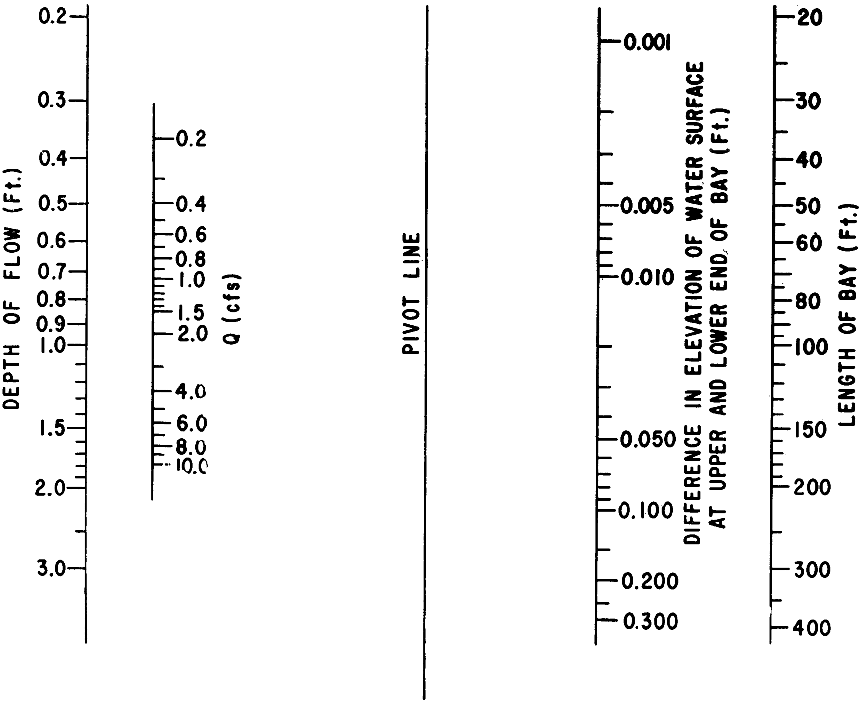

Figure 5. Nomograph showing the hydraulic relationships for the cut-off bay.

The length of bay 1 is 51 x 3.33 = 170 feet

From Figure 5 for a supply flow of 3 cfs, an average depth in bay 1 of 0.85 foot is required.

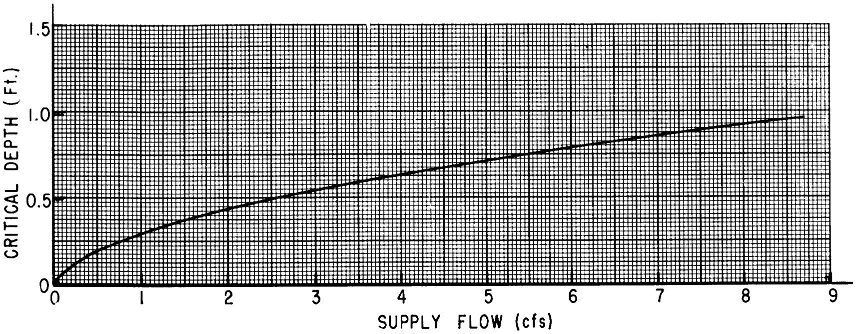

Figure 6. Relation of critical depth to supply flow.

Find the critical depth from Figure 6. For 3 cfs the value is 0.58 ft. This is the minimum depth which can occur in the channel at the drop at the downstream end of the bay. Add $\frac{1}{2}$ x H_f to the critical depth and compare with the average depth previously obtained. Use the larger of the two values as the average depth in the bay. In this example, $0.58 + \frac{1}{2}(0.11) = 0.635$ ft. The average depth of 0.85 foot as determined by the nomograph will be used because it is the larger number.

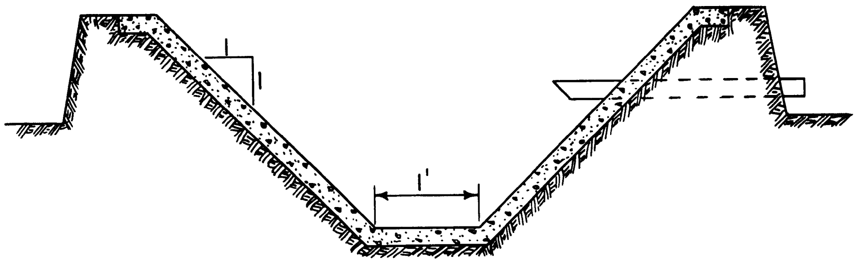

Figure 7. Cross section drawing of concrete ditch with outlet tubes installed.

Figure 7 shows a cross section of the concrete ditch with outlet tubes.

The minimum height, x, of the tube invert from the bottom of the ditch is:

$x =$ average depth $+ \frac{1}{2}(H_f) + W$ In this example $x = 0.85 + \frac{1}{2}(0.11) + 0.04 = 0.95$ ft.

The depth of flow in bay 3 operating at the initial head of 0.63 foot is $0.63 + 0.95 = 1.58$ ft. With a freeboard allowance of 0.20 foot, a depth of ditch of 1.78 feet or 21⅜ inches is required. Depths for the slip-form ditch vary by even two-inch increments, so a 22-inch ditch would be needed. The tube inverts in each bay would be about 0.83 feet vertically from the top of the ditch and the drop between the bays would be as shown in Table V.

Construction of the System

These systems will require more than average construction skills. They will probably be built mostly by experienced contractors. It is expected that slip form equipment will normally be used; however, the ditch could be hand formed.

The tubes must be set to the same elevation in a given bay. They should be accurately leveled end to end and should have an invert projection inside the ditch of at least one tube diameter. One suggested way of accomplishing this is to "score" a slot in the lining as it is poured at the tube spacing and slightly below the level of the bottom of the pipe. While the lining is still "green" dig out the slot and a trench slightly below the bottom of the tube. Set grade stakes accurately in the bottom of each trench. Put enough concrete in the trench to come up to the expected centerline of the tube. Using a machinist's level, position the tubes in the ditch so they are cradled in the concrete and resting on the grade stakes and are level end to end. Care should be taken to see that the hooded projection of the pipe is vertically above the invert. When the concrete has set around the tubes, finish filling the trench with concrete and smooth around the tube.

Economic Considerations

The future of automation is dependent upon the economic considerations. The approach used here will be to compare the annual costs of depreciation, interest, and labor for an automated and a conventional system. The information needed is:

The expected life of the system, the compound interest which could be expected from an investment of like risk, the labor saved per acre per irrigation, the hourly rate for labor, and the number of irrigations in an average year.

An analysis comparing an automated system with a typical earthen ditch with a man in constant attendance follows. Assume:
Labor saved per acre = 2 hours per irrigation
Labor costs $1.25 per hour

Five irrigations per year
15-year life and 6% interest; capital recovery factor = 0.103
The cost of an automated system = $80/Acre.

Assuming no cost for annual construction of an earthen ditch and no cost for siphon tubes, the annual depreciation and interest for an automated system would be $80 x .103 or $8.24 more than for an earthen ditch. The labor saving would be (2 x 5 x $1.25) or $12.50 per year, leaving a net saving of $4.26 per acre.

This simplified analysis makes no allowance for system maintenance either for automated or conventional systems or for annual construction costs or siphon tube costs for an earthen ditch. This analysis assumes that labor capable of doing a good job of irrigating is available when needed. It further assumes that equal yields will be obtained from each method of irrigating. At present, insufficient data is available to assign a value to this factor. Any advantages due to decreased ditch losses also are not considered.

The system of automated furrow irrigation with manually operated check dams at The Irrigation Research Station, Altus, Oklahoma, required an estimated $75 per acre investment (Figure 8). This system appears to be justified. Whether additional automation such as automated gates and controls would be justified might depend upon the

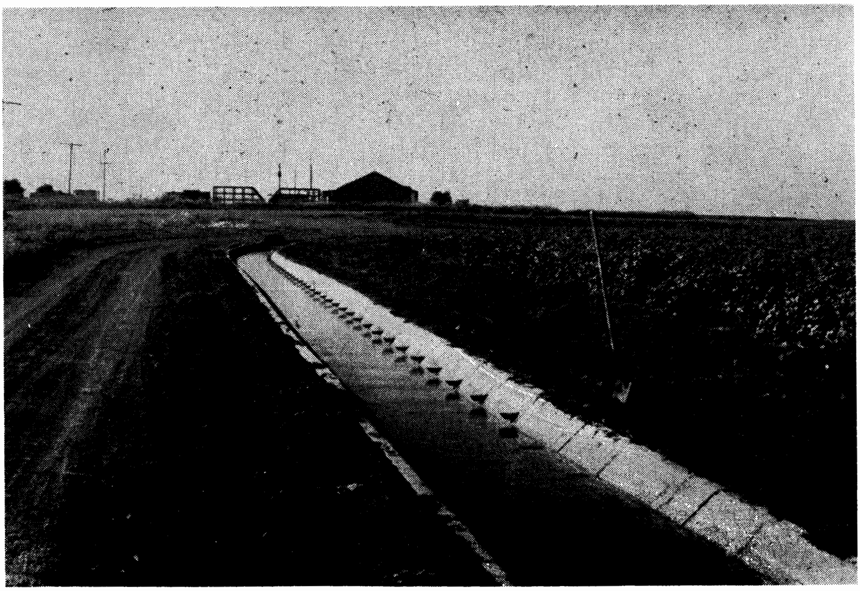

Figure 8. The tubes in the foreground are operating at the cut-back flow, and the flow in the tubes in the upstream bay has been cut off.

value placed on convenience. If one were working in a distant location or if he placed a high value on an undisturbed night's sleep, these considerations might override the purely economic considerations.

This analysis illustrates that there are different degrees of automation and that partial automation might be more economical than complete automation for a particular situation.

Summary

By means of an example problem this publication presents the method and design aids necessary to design an automatic cut-back furrow irrigation system. There may be some design conditions for which it is not possible to design such a system, but an automated cut-back furrow irrigation system can be designed for most conditions.

The design conditions should be accurately determined.

These systems will irrigate through the field for one time period with a large initial furrow stream and then continue watering with a cut-back furrow stream for one time period. They will then shut off the flow to the furrow. This is accomplished by the removal of check dams. They offer the possibility of improving the uniformity of water application with furrow irrigation. Probably the biggest advantage is the elimination of most of the labor required for applying the water. Another advantage is that the decision to irrigate for optimum soil moisture condition can be made practically independent of the labor supply.

The labor saved, when compared with an earthen ditch with a man in constant attendance, is expected to pay for the system in less than its useful life.

A time-clock-controlled cut-back furrow irrigation system has been designed and constructed. Whether it is justified compared to manually removed check dams depends on the value placed on convenience.

These systems could also be designed as primary flow systems without the cut-back feature.

10-66/2.85M