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OWRR Project A-021-Oklahoma

REUSE OF SURFACE RUNOFF FROM FURROW IRRIGATION

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by
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ABSTRACT

REUSE OF SURFACE RUNOFF FROM FURROW IRRIGATION

Six irrigated fields in the Oklahoma Panhandle were instrumented to determine the amount and time distribution of surface runoff from furrow irrigation. Type H flumes with water level recorders were used to obtain a continuous permanent record of the runoff.

The volume of runoff was calculated as a percentage of the volume of water applied for the individual sets and each series of irrigation sets. The variation in runoff percent of the individual sets was analyzed. The characteristics of the time distribution of the runoff from the irrigation sets were defined and used in the design of reuse systems.

The runoff percentages from the individual irrigation sets were found to be distributed as a log-normal relationship with a different mean and standard deviation for each field.

Reuse systems can be designed with either cycling or continuously operated pumps. Cyclic pumping could be used to accomplish cut-back irrigation. A system with a continuously operated pump requires a smaller pump and pipe size and would have a lower fixed cost.

The total annual cost of installing and operating reuse systems is justified for five of the six fields instrumented.

KEY WORDS: Furrow irrigation/ reuse systems/ runoff/ storage pit/ out-back.

REUSE OF SURFACE RUNOFF FROM FURROW IRRIGATION

Research Project Accomplishments

INTRODUCTION

Reuse of surface runoff from furrow irrigation should be considered in the design of modern irrigation systems. In some areas reuse of runoff from irrigation is mandatory. Even in areas without such laws, the farmer may risk legal action if he allows excessive runoff. Reuse systems are more commonly installed for economic reasons. Often runoff water can be applied to the field at a lower cost than pumped or diverted water; moreover, water application efficiency may be improved if the system is properly designed. Sometimes the reuse of surface runoff from irrigation may be essential to prolong the life of the groundwater supply.

Davis (2) described a reuse system as an integral part of an irrigation system which is designed to achieve an economic balance between water, labor, capital, power, and land resources. He stated that if the cost or availability of labor and capital are greater than the cost of water, a farmer may be forced to sacrifice water as a substitute for labor and equipment. Reuse of irrigation water may be more economical than the use of additional labor or equipment to increase the efficiency of the system.

Whether a reuse system is installed for legal, economic, or conservation reasons, there exists a need for better design procedures.

A major problem in the design of reuse systems is the inability to estimate the amount and time distribution of runoff from furrow irrigation. There is little runoff data on which to base the design of reuse systems. To obtain the most economical reuse system, it is necessary to determine the optimum relationship of storage size and pumping rate based on the expected runoff and existing conditions for a given irrigation system.

Objectives

1. To determine the amount and time distribution of surface runoff from several furrow irrigated fields.

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2. To determine the optimum relationship of storage size and pumping system capacity based on objective number 1.

3. To design systems to recirculate runoff water to the upper end of the field from which it occurs.

4. To determine the economic feasibility of recirculating the runoff water.

Limitations of the Study

The study was limited to furrow irrigation using gated pipe distribution systems with deep wells as the water source. Data were collected from six irrigated fields with crops of corn or grain sorghum. Row lengths of 1/4 and 1/2 mile were studied. Each field was operated by a different farm manager.

Review of Literature

Bondurant (1) classified reuse systems according to the method of handling runoff water as follows: if the water is returned to a field lying at a higher elevation, it is usually referred to as a return-flow system; if the water is applied to a lower lying field, this is termed sequence use. He also classified systems according to storage capacity. Systems which store collected runoff water are referred to as reservoir systems. Systems which immediately return the runoff water require little storage and are termed cycling-sump systems.

Davis (2) states that the size of the sump depends on the value of the land upon which the sump is constructed and on the desired control of water at the point at which the tailwater is returned. He noted that the fluctuating and rather low flow from cycling systems may preclude its efficient use on some fields. For these fields, he recommended the use of a continuous pumping operation.

Fischbach (3) describes an automated surface furrow irrigation system which uses a control circuit to operate a cycling reuse system.

A five year study of three large farm areas in the Rupert, Idaho region showed an average farm runoff of 18.5 percent of the total water delivered to the farm (6). Each of the three areas was newly developed when the study began. Portneuf silt loam soils in the area were deep, fertile and well-drained.

From surveys made in California, Davis (2) reported 10 to 20 percent runoff from farms averaging 160 acres in size.

Shockley (5) reported surface runoff losses of 35 percent from a field with 660 foot rows and 12 hour sets when applying 5.67 inches of water.

Marsh (4) reported an average runoff of 31 percent of the water applied during 32 separate measurements between 1941 and 1953.

Bondurant (1) reported that a southern Idaho farm of 105 irrigable acres produced an average runoff of 11.6 percent of the water applied.

PROCEDURE

The inflow to each irrigation system was measured with a Sparling propeller type flow meter. Three of the well power plants were governor-controlled and the other three had tachometers which were used to keep the pump speed constant.

H flumes instrumented with Stephens A-35 water level recorders were used to obtain a continuous record of runoff from each field. The H flumes were individually calibrated in the laboratory before being installed. Farms were selected such that the runoff from the field drained to a common point so that it could all be measured.

ANALYSIS OF DATA

The volume, average rate, and time distribution of surface runoff were of specific interest in the analysis of data. The volume of runoff is a function of several variables. The variables measured were the water application rate, row length, furrow spacing and field slope. The application time and number of rows were recorded for each irrigation set.

Other variables which may affect the volume of runoff from furrow irrigation are the variation in soil type, moisture content, climatic factors, and the uniformity of flow to individual rows in an irrigation set. The measurement and exact relationship of all of these variables were not within the scope of the study.

Table I presents the average depth of application per irrigation, depth of runoff, and runoff percent for each station along with other pertinent information about each field. The runoff data from farms with two possible well flow combinations were analyzed separately.

The data presented in Table I for Stations 2, 3, 5, and 6 were plotted on log-log paper in Figure 1. An equation of the form

$$Y = a\ X^{b} \qquad [1]$$

was developed since they had nearly equal slopes and all had 1/2 mile row lengths. A least squares technique was used to fit Equation [2] where Y is the depth of runoff volume in inches and X is the average depth of application, also expressed in inches.

$$Y = 0.0044\ X^{4.027} \qquad [2]$$

Equation [2] can be used to predict the average depth of runoff as a function of the average application depth, within the range of the empirical data, for fields of similar characteristics.

The volume of runoff from the individual sets of each field varied considerably. This variation can be attributed to the set application time or the average flow per row.

Another contributing factor is the uneven flow to the furrows of the same set.

Variation in Individual Furrow Flow Rate

Individual furrow flow rates were measured with a small HS flume. The flume was calibrated in the laboratory and a scale attached to the flume near the outlet.

Table II shows data collected from 18 irrigation sets with from 23 to 85 rows per set. The flow for some rows was over twice that of others in the same set. The variation in individual furrow flow is a factor that causes excessive runoff.

TABLE I

Station No.	Well Yield, gpm	Row Spacing (inches)	Average Slope, (percent)	Amount of Data, (hours)	Average Application Depth (inches)	Average Runoff Depth (inches)	Percent Runoff
1	930	56	.34	278	5.24	1.08	20.7
2-A*	1700	56	.33	405	2.15	0.09	4.2
2-B	960	56	.33	311	2.16	0.10	4.7
3	1075	56	.36	443	3.11	0.43	13.9
4-A*	1750	60	.14	159	3.67	0.96	26.2
4-B	700	60	.14	429	3.09	0.87	28.2
5	1575	56	.33	475	3.28	0.51	15.5
6	725	40	.33	587	3.51	0.69	19.6

* All fields had 1/2 mile rows except No. 1 which had 1/4 mile rows. Stations A and B were the same fields with different well flows only.

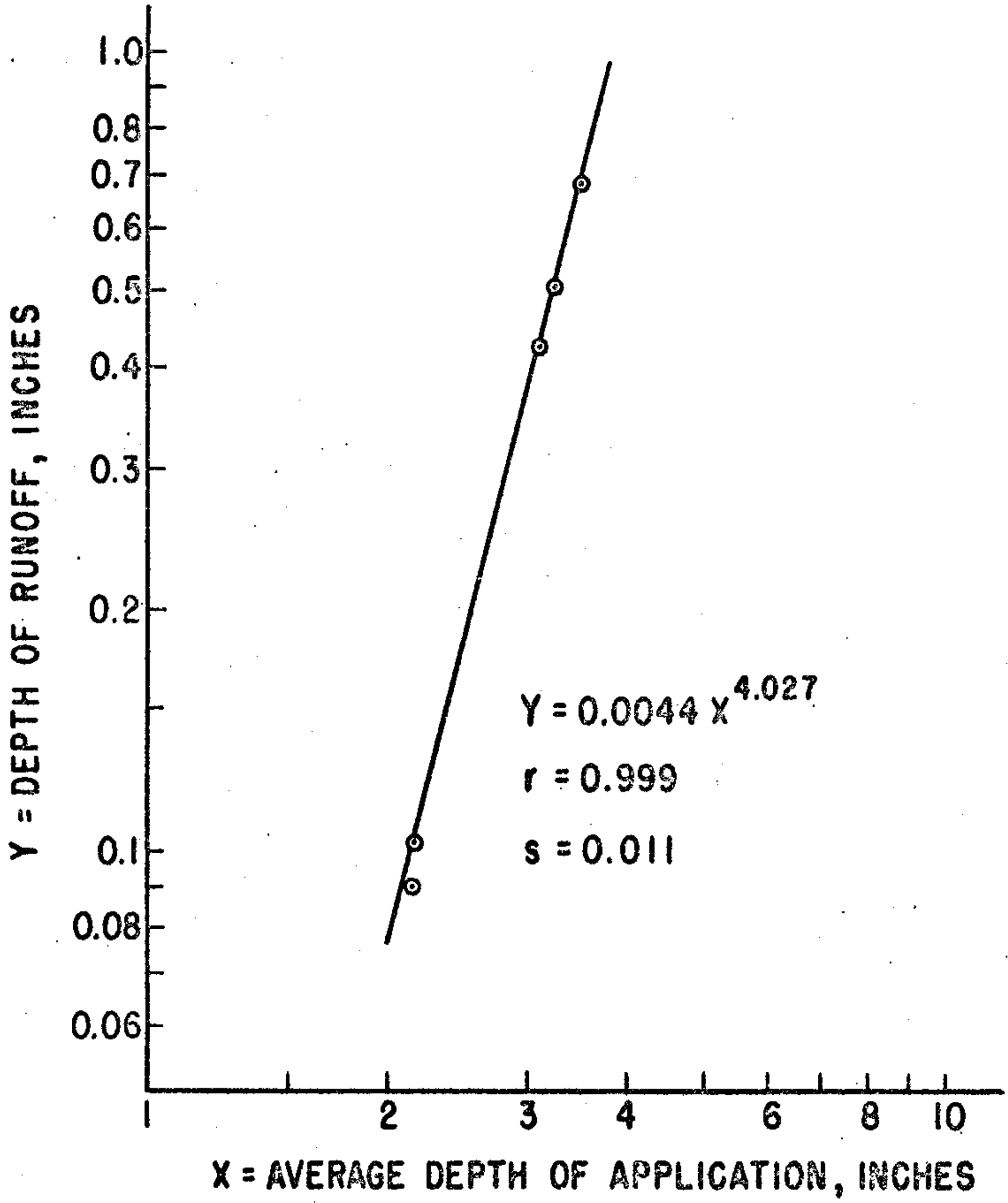

Figure 1. Relationship to Predict the Depth of Runoff for Fields with 1/2 Mile Row Lengths and Slopes Between 0.33 and 0.365 Percent

Table II. Individual Furrow Flow Analysis

Irrigation Set	Number of Rows in Set	Sum of Furrow Flows (gpm)	Avg. Furrow Flow (gpm)	Std. Dev. (gpm)	Std. Dev. Per gpm
1	25	332	13.28	3.18	.24
2	24	619	25.79	4.11	.16
3	25	563	22.52	4.32	.19
4	70	755	10.79	2.33	.22
5	61	751	12.51	2.28	.18
6	50	746	14.30	1.81	.13
7	85	601	7.07	1.74	.25
8	80	631	8.34	1.82	.22
9	80	653	8.16	1.87	.23
10	55	594	9.29	1.97	.21
11	53	577	10.89	3.85	.35
12	52	490	9.42	1.86	.20
13	60	569	9.48	2.28	.24
14	43	499	8.05	1.65	.20
15	59	508	8.95	2.25	.25
16	30	355	11.83	2.15	.18
17	46	436	11.50	1.95	.17
18	23	357	15.61	3.00	.19

Variation in Runoff for Individual Sets

The volume of runoff for each set was calculated as a percentage of the volume of water applied for that set. The runoff percentages were plotted on log-probability paper and were found to approximate a straight line for each station. The probability was figured as

$$P = \frac{1}{t_p} \times 100 \qquad [3]$$

where

$$t_p = \frac{1+N}{m}$$

and P is the probability of the runoff percent from a set being equaled or exceeded during any one set, t_p is the recurrence interval in number of sets, and m is the m^{th} largest runoff percent in the period of record, N sets.

Figure 2 shows the log-probability graph for Station 5. Using the graph, 90 percent of the sets from Station 5 would have less than 23.5 percent runoff. The runoff percent for any other desired probability can be obtained in a similar manner.

Table III shows the runoff percent expected at common probability levels for each station. Since variation in runoff for different sets does occur, these relationships are important in the design of reuse systems.

A reuse system designed to handle the water from the average set would frequently overflow. A system designed to handle 90 or 95 percent of the total runoff would be more acceptable to the farmer. If a reservoir was constructed capable of storing the larger runoff volumes, the additional water could be used later when less than average runoff occurs.

Time Distribution of Runoff

The rate of runoff which occurred with respect to time during an irrigation set is of importance in the design of recirculation systems.

The pin trace on the strip charts of the water level recorders formed a continuous record of time versus head in the H flume measuring devices. Head readings were converted to flow rates using the calibration curves to obtain a

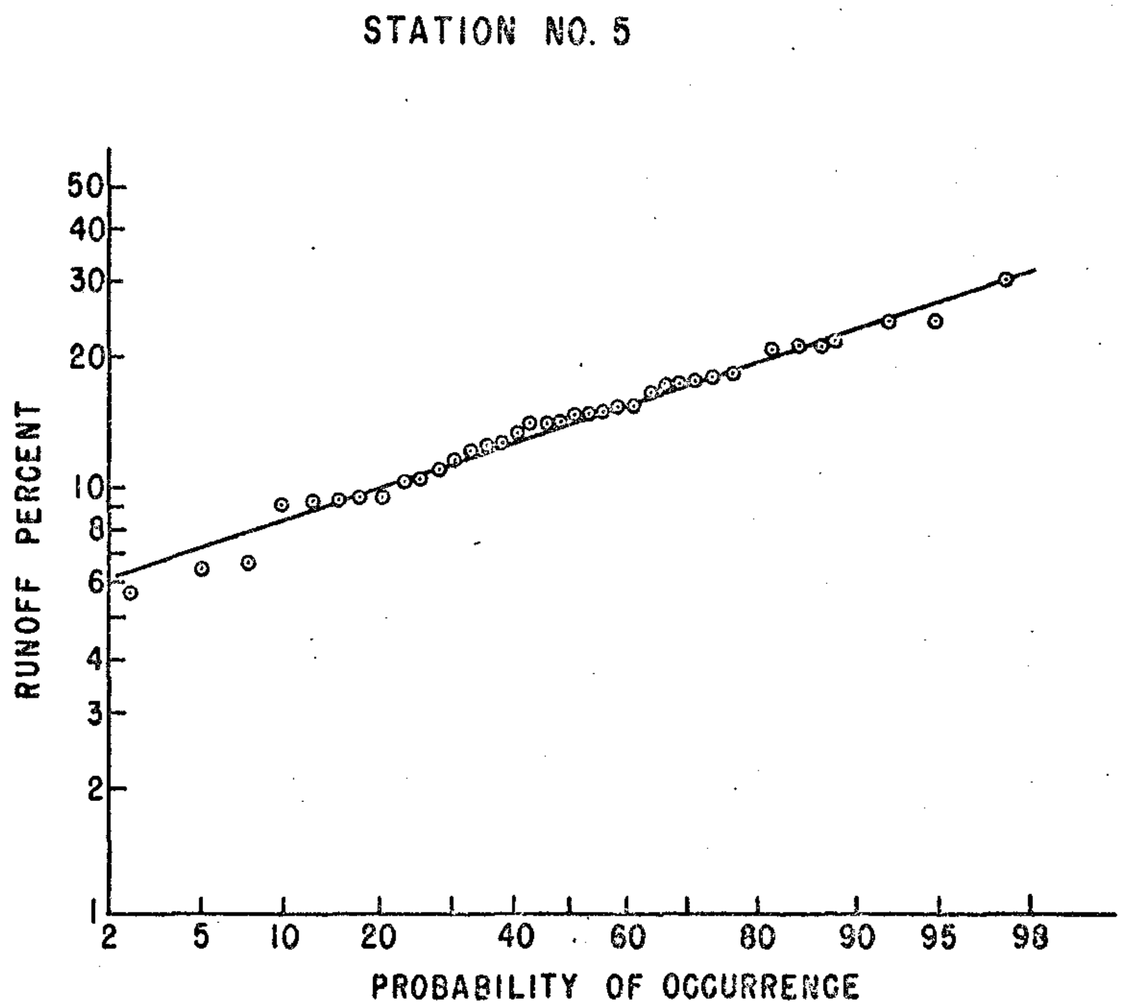

Figure 2. Example Log-Probability Relationship for Individual Set Runoff Percentages

TABLE III

LEVELS OF RUNOFF PERCENT AT COMMON PROBABILITIES

Station Number	Expected Runoff Percent		
	50%	75%	90%
1	20.5	22.8	25.0
2-A	4.3	6.7	10.0
2-B	4.1	6.0	8.5
4-A	23.0	32.0	43.0
4-B	23.0	31.0	40.0
5	14.0	18.2	23.5
6	18.0	23.0	29.0

hydropraph of time versus flow rate for each irrigation set.

The hydrographs of time versus runoff rate for two typical irrigation sets are shown in Figure 3. These sets will be used to describe the time distribution of surface runoff.

The first set in the series began at 8 A.M. and was 24 hours long. No runoff occurred until the first stream had watered through the field at 7 P.M. The runoff rate increased as additional furrows watered through the field until all furrows were contributing to the runoff or the set was changed. The peak rate of runoff occurred about two hours after the set was moved. After the peak, the rate of runoff decreased rapidly until all the runoff water stored on the field was depleted. The areas under the hydrograph would then represent the volume of runoff from that particular set. The hydrograph from the second irrigation set in the series illustrates that the time distribution for the different sets is very similar. The horizontal dotted lines in Figure 3 represent the average runoff rates if taken over the length of the respective sets.

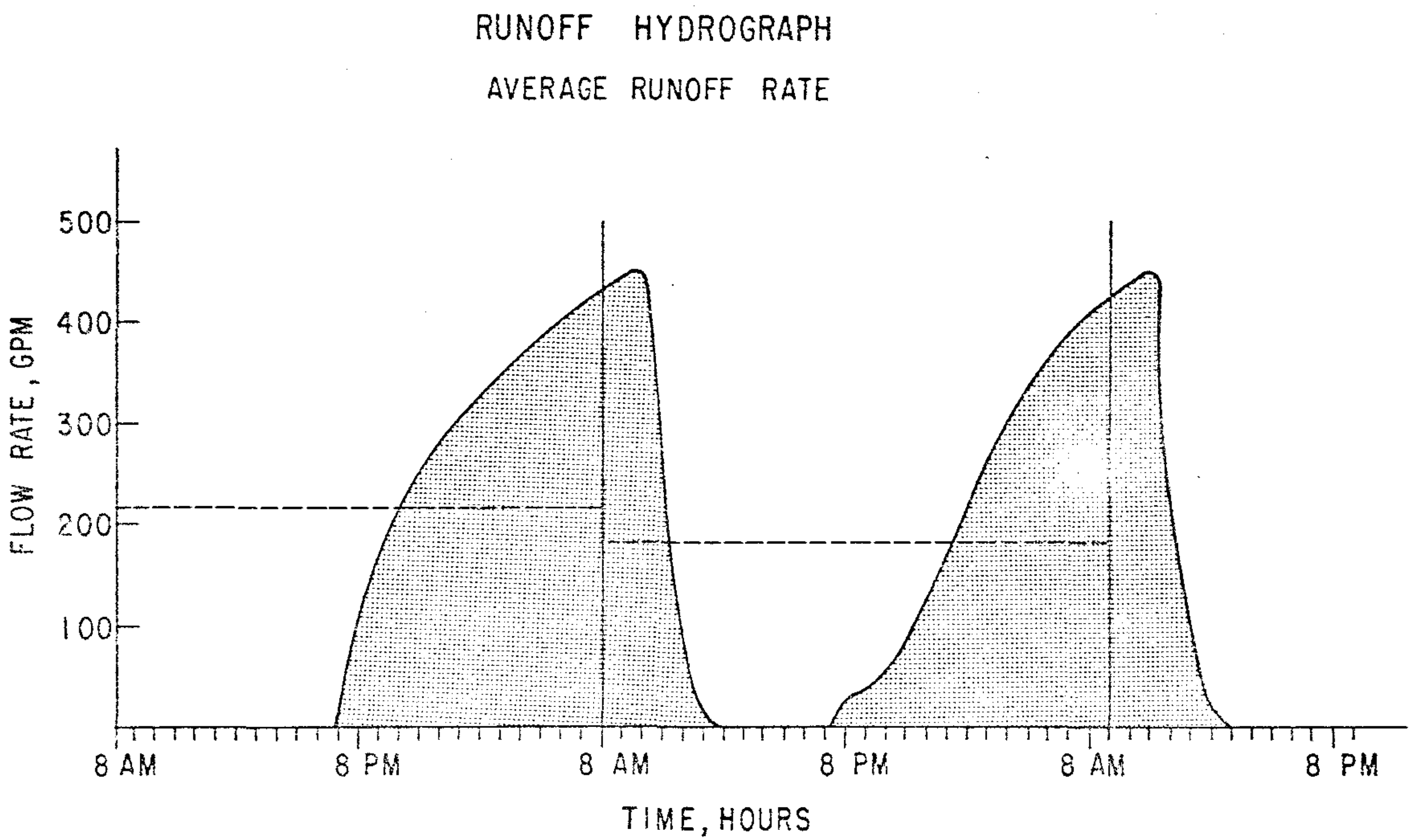

Figure 3. The Runoff Hydrographs from Two Typical Irrigation Sets Showing Characteristics of the Time Distribution

The time distribution of the surface runoff is of interest when considering the possible methods of reusing the water. Two possible methods of returning the runoff water to supplement the main water source will be discussed:

1. Reuse by pumping in cycles, and

2. Reuse by continuous pumping

Since a large percentage of the runoff volume occurs over a time interval smaller than the application time, the reuse of the water by pumping in cycles has some merit. The runoff water could be used to accomplish a cut-back type irrigation system using the runoff water from the previous set to supplement the main water source. If the reuse pump started at the same time as a new set and the water is pumped at a rate such that the total volume of runoff from the previous set could be pumped in a portion of the application time, a cut-back flow would be developed when the reuse pump shut off.

A cycling system with a very small amount of storage, as presently used on some farms, would result in large overflows unless a pump large enough to handle the maximum flow were used. Since runoff would be repumped as it occurred, the additional water would be applied by increasing the furrow stream size after the furrows were wet. This method would accomplish the opposite results of a cut-back system and would decrease the application efficiency.

Another alternative for the design of a reuse system would be to pump the runoff water continuously and use this water to supplement the main water source. This would require a much smaller size pump than for the cycling method. The storage volume necessary would also be less.

Storage Routing of Runoff

A storage routing computer program was written to determine the effect of storage size and pumping rate on storage reservoir overflow and unused pump capacity. Unused pump capacity is defined as the volume of water that would have been pumped during the time interval if water were available.

Calculation of overflow or unused pump capacity was made at each 15 minute time interval and summed over the entire series of sets for each station. This was done at a constant pumping rate and storage size. If the runoff rate exceeded the pumping rate for an extended period of time, the storage reservoir would overflow. And conversely, if the pumping rate exceeded the runoff rate long enough to deplete the water in storage, water would be unavailable for pumping and unused pump capacity would result.

The effect of various pumping rates and storage capacities was checked for each station with the storage routing program. Figure 5 shows the volume of overflow that would be lost for three constant pumping rates and different storage sizes using the runoff data from one station. Overflow decreases with both an increase in storage capacity and pumping rate.

Using the same data, Figure 4 shows the volume of unused pump capacity for the same range of storage sizes and pumping rates. Notice that the unused pump capacity also decreases with increasing storage capacity; however, the larger pumping rates have larger unused pump capacities.

A comparison of Figures 4 and 5 would indicate that an increase in storage capacity would be more advantageous than an increase in pumping rate to minimize both overflow and unused pump capacity.

Economic Analysis

Calculations were made to determine the cost of installing a reuse system at each of the stations studied. Table IV shows the cost of recirculated water on a cost per acre foot basis.

Fixed costs were calculated using 1970 prices for installed low head plastic pipe and Gorman-Rupp self priming centrifugal pumps with Wisconsin internal combustion engines. Storage pit construction was based on $.20 per cubic yard and miscellaneous items were assumed to cost $100 for each installation. The pipeline was 1/2 mile long for each installation except Station 1, where 1/4 mile rows were used.

The annual cost was figured using a capital recovery factor based on 7 percent interest and a 20 year equipment life. Fuel costs were based on 30 cents per 1000 cubic foot of natural gas, which was available in the study area. Repairs and upkeep were figured as $35 per year.

The systems designed would probably be profitable except for Number 2-A which had a low rate of runoff. The extra construction cost incurred with the larger storage pits was offset by the additional water saved. The value of the additional land used may need to be considered in some cases, but this would usually only involve around .2 acres.

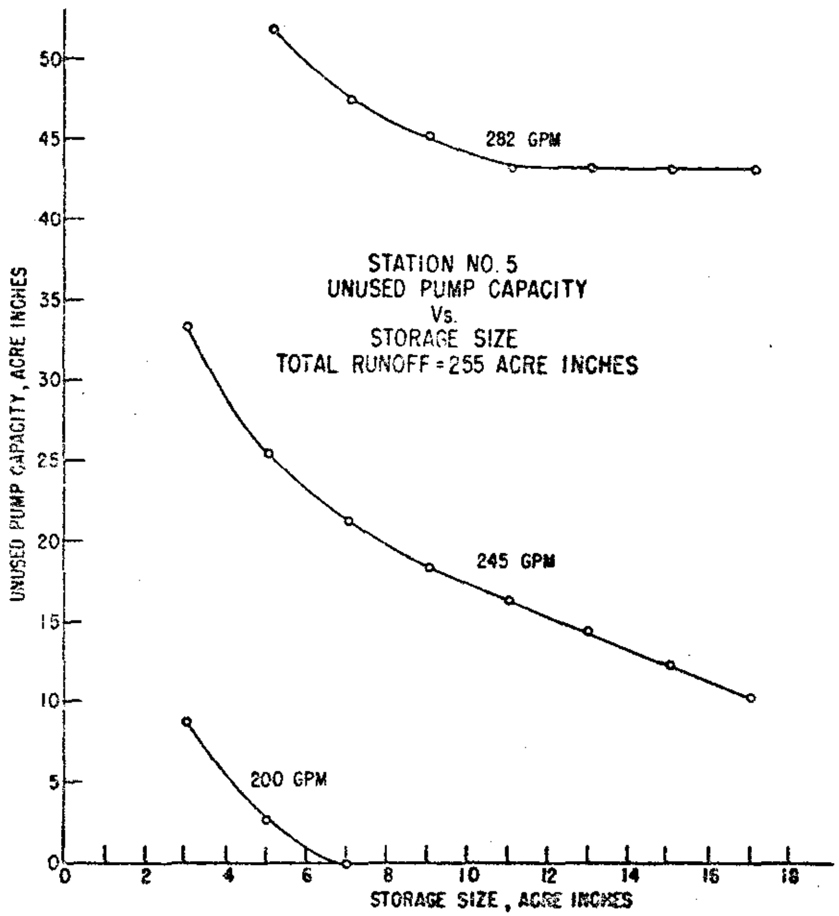

Figure 4. Unused Pump Capacity for Station No. 5

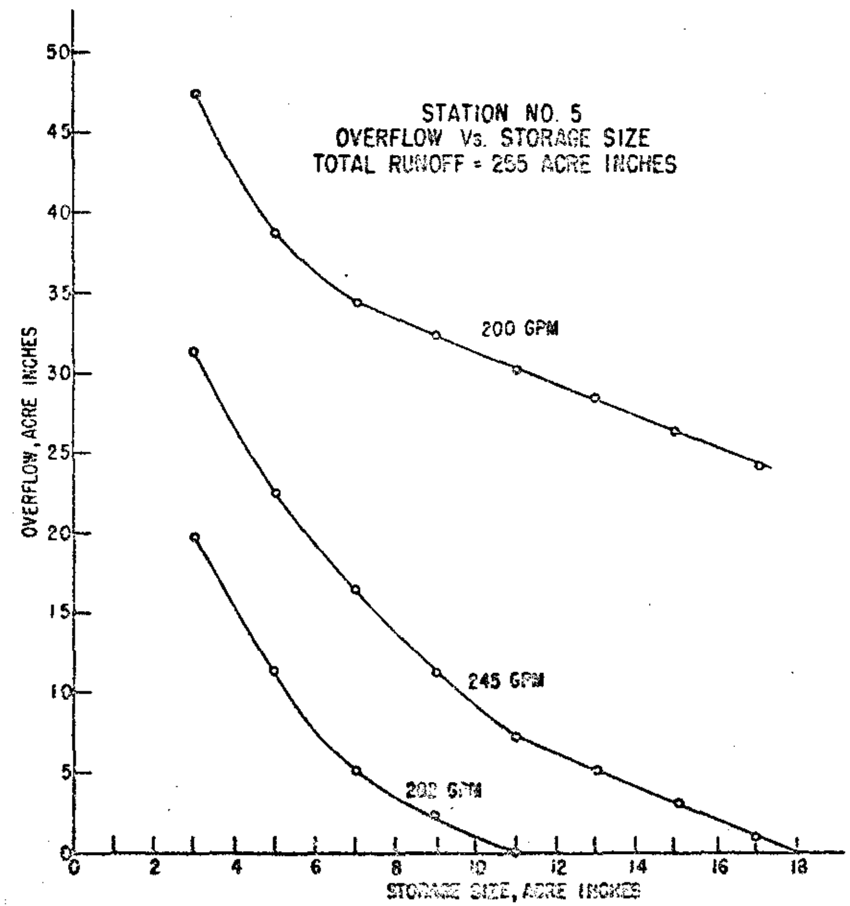

Figure 5. Overflow for Station No. 5

TABLE IV

COST ANALYSIS

Station Number	Total Annual Runoff ac.ft.	Pump Size gpm	Pipe Size inches	Storage Size 10% Overflow ac. in.	Annual Cost $/ac. ft.	Storage Size No Overflow ac. in.	Annual Cost $/ac. ft.
1	40	190	6	7.4	6.20	11.2	6.25
2-A	15	80	4	2.7	20.40	4.5	19.30
4-A	85	450	8	24.0	6.65	35.0	6.65
5	60	245	6	5.8	7.30	17.5	7.25
6	43	138	4	6.7	8.45	14.0	8.40

The feasibility of installing a reuse system would depend on the individual situation. The potential yield production and the availability of additional water from the main water well needs to be considered. In areas where an eventual groundwater shortage is expected, the value of runoff water may need to be based on future production potential.

The cost of reusing runoff can be reduced significantly if it can be used downstream rather than returning the water to the upper end of the field from which it occurs.

Water Quality

Water samples were taken twice during the irrigation season from the well and runoff measuring devices at three of the irrigated fields. The purpose was to determine if there is a change in water quality during surface flow.

Table V summarizes the data collected. The odd-numbered samples were taken at the head of the field and the even-numbered samples from runoff water at the end of the field. The a and b subscripts represents duplicate samples. Samples 1 and 2 were taken from Station No. 1, and 3 and 4 from Station No. 2, and 5 and 6 from Station No. 6. Water class is based on percent sodium and conductivity. It refers to the suitability of the water for irrigation purposes.

SUMMARY

The surface runoff from six furrow irrigated fields in the Oklahoma Panhandle was measured. A relationship was developed to predict the average volume of runoff from fields with similar slopes and row lengths.

The variation in runoff from irrigation sets of the same field was studied. The runoff percentages for the individual irrigation sets were found to approximate a log-normal distribution. The log-probability relationships can be used to predict the runoff percentage expected for the desired recurrence interval.

The time distribution of the runoff was investigated. The rate of runoff increases gradually as furrows water through the field until the set is changed. The peak rate of runoff occurs between one and two hours after the set is changed and will be approximately twice the average runoff rate. Between 60 and 80 percent of the runoff has occurred by the time the set is changed. After the peak, the rate of runoff decreases rapidly.

TABLE V SUMMARY OF DATA FROM WATER SAMPLES

SAMPLE	CALCIUM PPM	MAGNESIUM PPM	SODIUM PPM	CHLORIDE PPM	SULPHATE PPM	CARBONATE PPM	BICARBONATE PPM	TOTAL DISSOLVED SOLIDS PPM	SODIUM ADSORPTION (SAR) PPM	WATER CLASS
1a	37.5	28.3	43.0	36.0	95.0	0	220.0	350.0	1.3	GOOD
1b	36.3	28.3	43.4	18.0	100.0	0	207.0	350.0	1.3	GOOD
2a	49.1	25.6	42.2	18.0	100.0	0	238.0	450.0	1.2	GOOD
2b	48.9	25.8	41.8	53.0	92.5	0	220.0	350.0	1.2	GOOD
3a	34.8	26.1	25.9	36.0	70.0	0	183.0	200.0	.8	EXCELLENT
3b	25.9	25.5	25.8	18.0	62.5	0	159.0	225.0	.8	EXCELLENT
4a	48.9	25.0	27.0	36.0	67.5	0	220.0	350.0	.8	GOOD
4b	47.6	24.9	27.1	36.0	70.0	0	220.0	450.0	.7	GOOD
5a	47.6	19.7	25.2	18.0	70.0	0	238.0	350.0	.7	EXCELLENT
5b	25.0	19.2	25.0	18.0	90.0	0	134.0	300.0	.8	EXCELLENT
6a	48.9	22.5	25.0	0	70.0	0	220.0	350.0	.8	EXCELLENT
6b	49.3	22.6	25.0	18.0	80.0	0	238.0	400.0	.7	EXCELLENT

A system may be designed with either a cycling or continuously operated pump using the information from the time distribution study and the log-probability relationships.

The cycling type reuse system can incorporate a cut-back type irrigation; however, this type of system will require a larger pump size and will have a higher annual cost.

Systems with continuously operated pumps were designed for several stations on the basis of the time distribution and log-probability results. Overflow and unused pump capacity were calculated with a reservoir storage routing program. Systems designed to pump the average runoff rate and to store a maximum of 60% of the water from the largest set expected, resulted in 3.8 to 7.7 percent overflow at the 90 percent confidence level. Approximately double this design storage capacity was necessary to reduce the overflow to zero.

The annual cost per acre foot for installation and operation was calculated for systems with two storage reservoir sizes. The systems designed to eliminate overflow had a higher total cost, but the cost per acre foot was equal or lower than the systems designed on the 90 percent confidence level since more water was pumped when overflow was eliminated.

CONCLUSIONS

1. The average volume of runoff expected from furrow irrigated fields is mainly a function of the average volume of water applied per unit area.

2. The volume of water expected from an individual set is a function of several additional variables; however, the runoff percentages are approximately normally distributed, although each field may have a different mean and standard deviation.

3. Systems can be designed to reuse runoff water with little or no overflow and still be within functional and economic restraints.

4. Surface runoff water from furrow irrigation can provide an additional source of irrigation water at a cost competitive with other sources.

5. The reuse of runoff water will extend the life of ground water supplies in areas where water is being removed by pumping at a higher rate than it is recharged.

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Publications

A masters thesis has resulted from this project. No publications have resulted from this research but a paper has been submitted for publication.

Project Status

The project was completed June 30, 1972

Application of Research Results

The results of this research have been made available to the Soil Conservation Service and Extension Service. The field engineers have the information to help farmers design efficient systems for reclaiming runoff losses from irrigation. This practice reduces or eliminates excess water in roadside ditches and neighbor's fields.

An educational program by the Extension Service and other media and technical service from the Soil Conservation Service to get this information applied has a potential of saving 32 billion gallons of water per year in western Oklahoma.