

# Prediction of stream advance in furrow irrigation

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## SUMMARY

A theoretical computation of advance of stream in a furrow is made in this paper. The computation is based on the infiltration characteristics of the well drained Reddish-Brown earths at Maha Illuppallama and on some of the hydraulic parameters of the furrow. The computed values are then compared with field observations.

The results show that the method of computation is reliable in furrows of uniform gradients from 0.2 to 0.6 per cent. and length up to 250 ft. Stream size of 11 and 22 gpm. were tested. Hence this method of calculation could be used to compute advance rate for the evaluation of furrow irrigation in the dry zone.

## INTRODUCTION

The design and evaluation of furrow irrigation systems depend largely upon the rate at which water flows from the upper end of a furrow to the lower end. Estimation of this rate of advance for various rates of flow permits the designer or irrigator to select the proper length of run or rate of flow to achieve some uniformity of distribution.

Procedures for field observations to determine the rate of advance has been outlined by Criddle et al (1) and in several U. S. Department of Agriculture soil conservation engineering handbooks. Although field evaluation of advance of water in a furrow is a valuable information, a mathematical expression to predict the advance also has some definite advantages. It might not only allow an irrigation system planner to estimate the rate of advance before the system is constructed, but would also permit a study of the factors upon which rate of advance is dependent and point deficiencies in research data.

A set of mathematical expressions for the rate of advance of water was presented by Davis (2). Although number of assumptions were made in these expressions, the computed values gave fair degree of accuracy of prediction even upto 800' length of furrows. The equation also performed well in furrows of non uniform slopes. However, there are several unknown quantities in this expression and could only be determined by conducting large number of field trials.

AN attempt is made in this paper to simplify the computation of rate of advance, making use of the infiltration characteristics of the soil and the use of some of the parameters affecting the hydraulics of flow in a furrow.

#### MATERIALS AND METHODS

*Intake Characteristics of the Soil.*—Infiltration tests with cylinder infiltrometer were done at Maha Illuppallama, on the well drained reddish brown earth. Side by side and at the same time field observations, to determine the rate of advance of water in the furrows, were carried out. A typical curve of the infiltration rate is given by Patterson (3). The infiltration rate in inches per hour,  $I$ , is expressed as

$$I = 7.6 T^{-(.4)} \text{ — Fig. (1).}$$

where  $T$  is time in minutes.

The infiltration rates converted to gpm/100 ; on 2' spacing of furrow is also given in Fig. 1.

*Furrow Hydraulics.*—Several observations of the furrow cross sections were made at the site. The cross section could be typified by that shown in Fig. (3). Based on Manning's "n" value of .04, the flow area and flow quantity were computed as a function of depth and plotted in Fig. 4 for a slope of .002'/ft. Top width of the wetted section was divided by the 2 feet row spacing, resulting in the per cent. field covered with water. This percentage can be related to the field intake in percentage of cylinder intake according to the empirical relationships developed by Phelan (4). This function has then been plotted, versus depth in Fig. 4. These relationships are used throughout the analysis leading to the development of the theoretical advance curve.

Computing the Advanced hydraulic function and intake relationship determined, it is now possible to theoretically predict the advance of a given stream. It is based on the continuity equation which relates the volume of water introduced to a furrow during a given time is equal to the total volume infiltrated to the soil and the volume stored on the surface during the same period of time.

To compute the storage volumes for the various time elements, it is necessary to adequately describe the surface profile of the furrow. In Fig. 2,  $L$ , is a segment of advance. If the water surface were triangular with depth at the upper end equal to that necessary for a given flow and a depth of zero at the end of segment  $L$ , the volume of water on the sur—ace could be described as

$$V_{s_1} = A_{o_1} L_1 \text{ (.5)}$$

$A_{o_1}$  = cross sectional area in sq. ft. at upper end of reach  $L_1$   $V_{s_1}$  = Volume of surface storage in reach 1. It has however, been found that it is incorrect to

describe the water surface as a triangle. Instead Little (5) empirically determined and used a constant .75 rather than .5 to describe this configuration and the work herein described has been based on this value.

In the analysis the following nomenclature will be used :

Qf=Flow rate in gpm at head of furrow

Ao=Cross sectional flow at the upper end of any reach under consideration

Qo=Flow rate in gpm at the upper end of any reach

T<sub>1</sub>, T<sub>2</sub>, etc. = Increments of time in minutes

I<sub>1, 1</sub>, I<sub>1, 2</sub>, etc. = Average intake rate in gpm/100 feet in reach 1 for time period 1, time period 2, etc.

L<sub>1</sub>, L<sub>2</sub>, etc. = are water advance reaches in time period T<sub>1</sub>, T<sub>2</sub> etc.

Vs<sub>1</sub>=Volume of surface storage in gallons in reach 1

VI<sub>1, 1</sub>, VI<sub>1, 2</sub> etc. = Infiltrated volume in gallons for reach 1 in time period 1, time period 2, etc.

The inflow of water in time period 1 is QfT<sub>1</sub> and is equal to the volume of water infiltrated plus the volume stored during that time period.

$$QfT_1 = Vs_1 + VI_{1, 1, 1} \dots \dots \dots \text{Eq. 1}$$

$$\text{and } QfT_2 = Vs_{2, 2} + VI_{1, 2} + VI_{2, 1} \dots \dots \dots \text{Eq. 2}$$

but Vs=Ao×L×.75×7.5 (.75 is water prefile constant and 7.5 is US gallons per cu. ft. and 7.5×0.75=5.6) and VI= $\frac{I \times T \times L}{100}$

$$- QfT = 5.6Ao \times L_1 + \frac{I_{1, 1} \times T_1 \times L_1}{100}$$

$$\text{and } QfT_2 = \frac{I_{1, 2} \times T_2 \times L_1 + 5.6 Ao \times L_2 + I_{2, 1} \times T_2 \times L_2}{100}$$

Similarly the unknown lengths of advance for time period T<sub>3</sub>, T<sub>4</sub> etc., could be computed. Each of the infiltration value I was converted to field intake in percent. of cylinder intake using Fig. 1 and Fig. 4.

Ao is determined from Qo

In the first reach Qf=Qo<sub>1</sub>, 2nd reach Qo<sub>2</sub>=Qf-I<sub>1, 1</sub>, etc. A sample calculation for a theoretical advance of 11 gpm in a furrow with a gradient of .002 ft. is given below :

(1) Qf =11 gmp, T<sub>1</sub>= 10 min.  
 Ao = .068 ft<sup>2</sup>, Percentage I<sub>1, 1</sub> = 80%. I<sub>1, 1</sub> = 6.7 gpm/100'  
 $QfT_1 = 5.6 \times .068 L_1 + (I_{1, 1} + L_1 \times T_1)_{100}$   
 $110 = 5.6 \times .068 L_1 + \frac{6.7 \times L_1 \times 10}{100}$   
 L<sub>1</sub>=104'

$$\begin{aligned}
 (2) \quad T_2 &= 10 \text{ Min, } \% I = 80\%, I = 4 \text{ gpm}/100' \\
 I_{1,2}, \text{ Intake rate in } L_1 &= 4 \times 104/100 = 4.16 \text{ gpm.} \\
 Q_0 &= 11 - 4.16 = 6.84, \text{ then } A_{O_2} = .05 \text{ ft. } I = 76\% \\
 I_{2,1} &= 6.4 \text{ gpm}/100 \\
 Q_1 T_2 &= \frac{I_{1,2} \times L_1 \times T_2}{100} + 5.6 A_{O_2} L_2 + \frac{I_{2,1} \times L_2 \times T_2}{100} \\
 110 &= 43.2 + .28 L_2 \times .64 L_2 \\
 L_2 &= 72.6'
 \end{aligned}$$

This analysis can be carried on through as many reaches as deemed necessary.

*Field Observation.*—The advance rate of water was measured in the field by clocking the time for water to advance in a furrow at different time intervals. The observed values are plotted in Fig. 5 for two different slopes and two different stream sizes. These data are also given in the Mahaweli Ganga Feasibility Studies (6).

#### RESULTS

*Results.*—The computed theoretical advance for streams, 11 gpm. and 22 gpm, on furrow gradients of .2% and .4% are plotted in Fig. 5. The observed values in Fig. 5 do not vary much from the computed values.

The recommended parameters for furrow irrigation, such as furrow length gradient and stream size, to irrigate efficiently a wide range of crops in the dry zone, are within the range selected for the theoretical computation. Hence, this method of analysis could be used for the evaluation of furrow irrigation in the dry zone.

#### ACKNOWLEDGEMENTS

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PREDICTION OF STREAM ADVANCE IN FURROW IRRIGATION

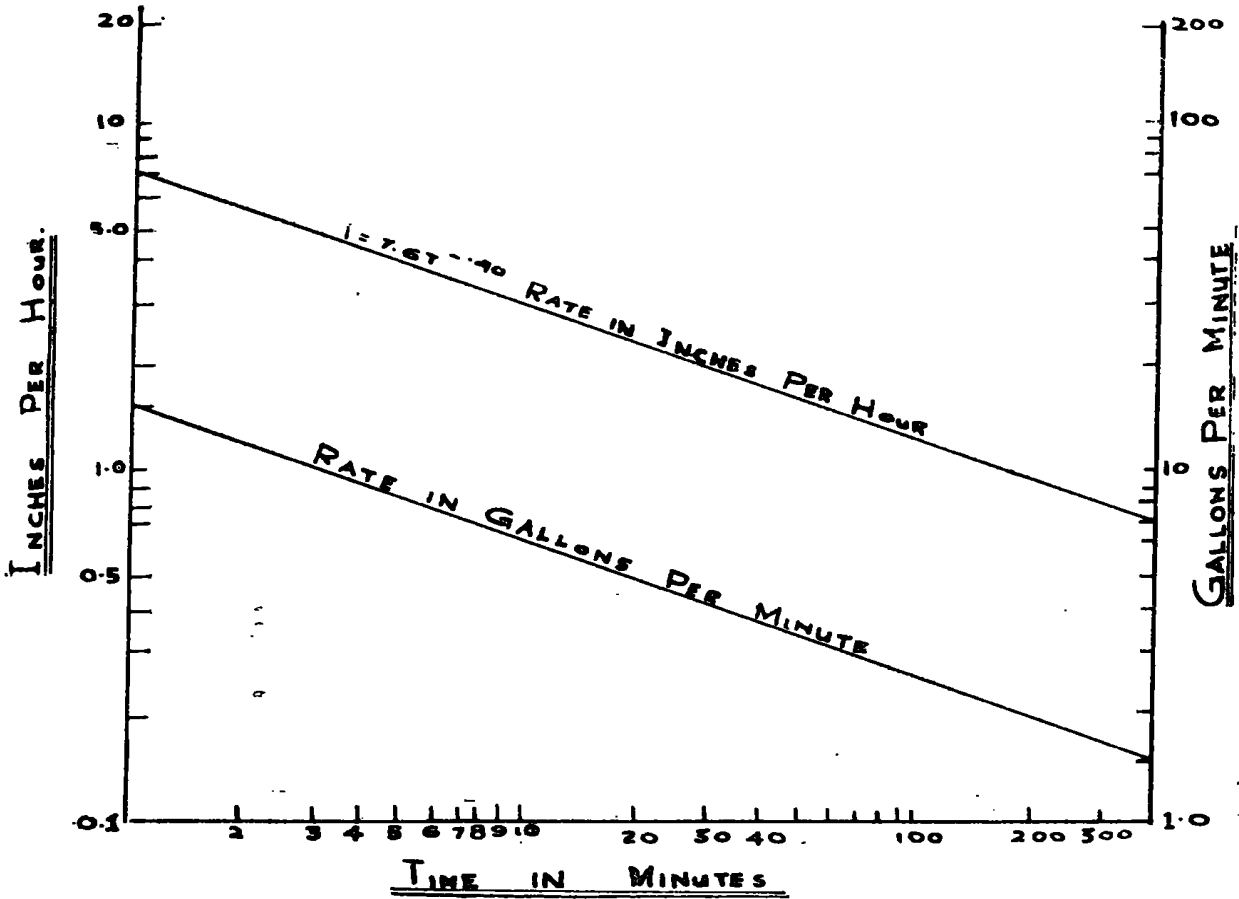


FIG. 1 CYLINDER INFILTRMETER TEST  
SOIL TYPE :- REDDISH BROWN EARTH WELL DRAINED

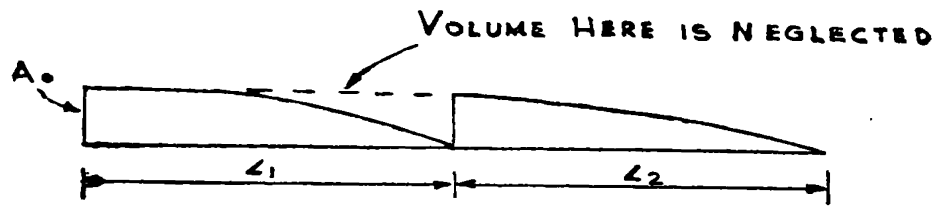


FIG. 2. STREAM ADVANCE

DEPTH ft	A AREA ft <sup>2</sup>	P WETTED PERIMET ER ft	$R = \frac{A}{P}$	$R^{2/3}$	Q c.f.s	$\frac{Q}{9.450}$ g.p.m (us)
.05	.022	.55	.04	.12	.0043	1.93
.10	.05	.70	.072	.178	.015	6.75
.15	.08	.92	.092	.210	.03	13.5
.20	.128	1.07	.12	.248	.052	23.67
.25	.212	1.25	.169	.310	.128	57.87
	SLOPE	OF	FURROW	$S =$	$0.002'/ft$	
				$S^{1/2} =$	$0.045$	

TABLE 1 HYDRAULIC PARAMETER OF FURROW

PREDICTION OF STREAM ADVANCE IN FURROW IRRIGATION

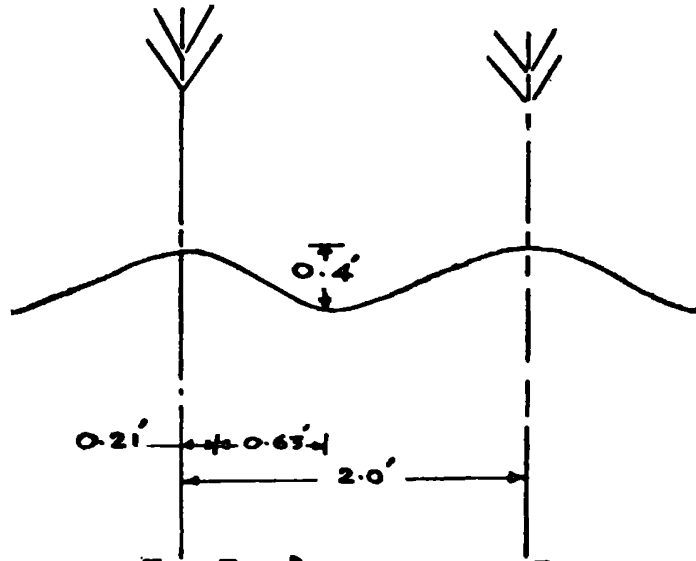


FIG. 3. PROFILE OF FURROW C.S.

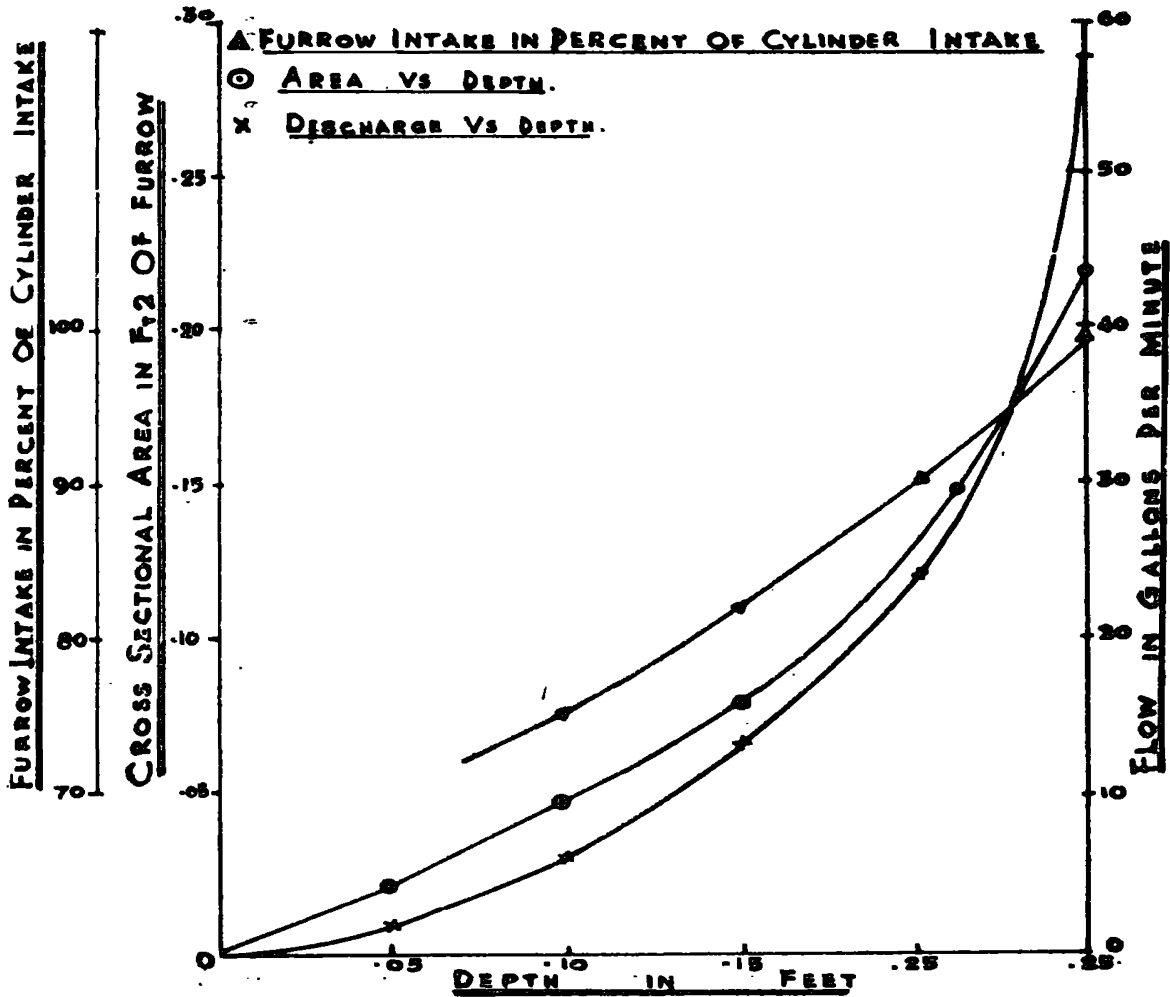
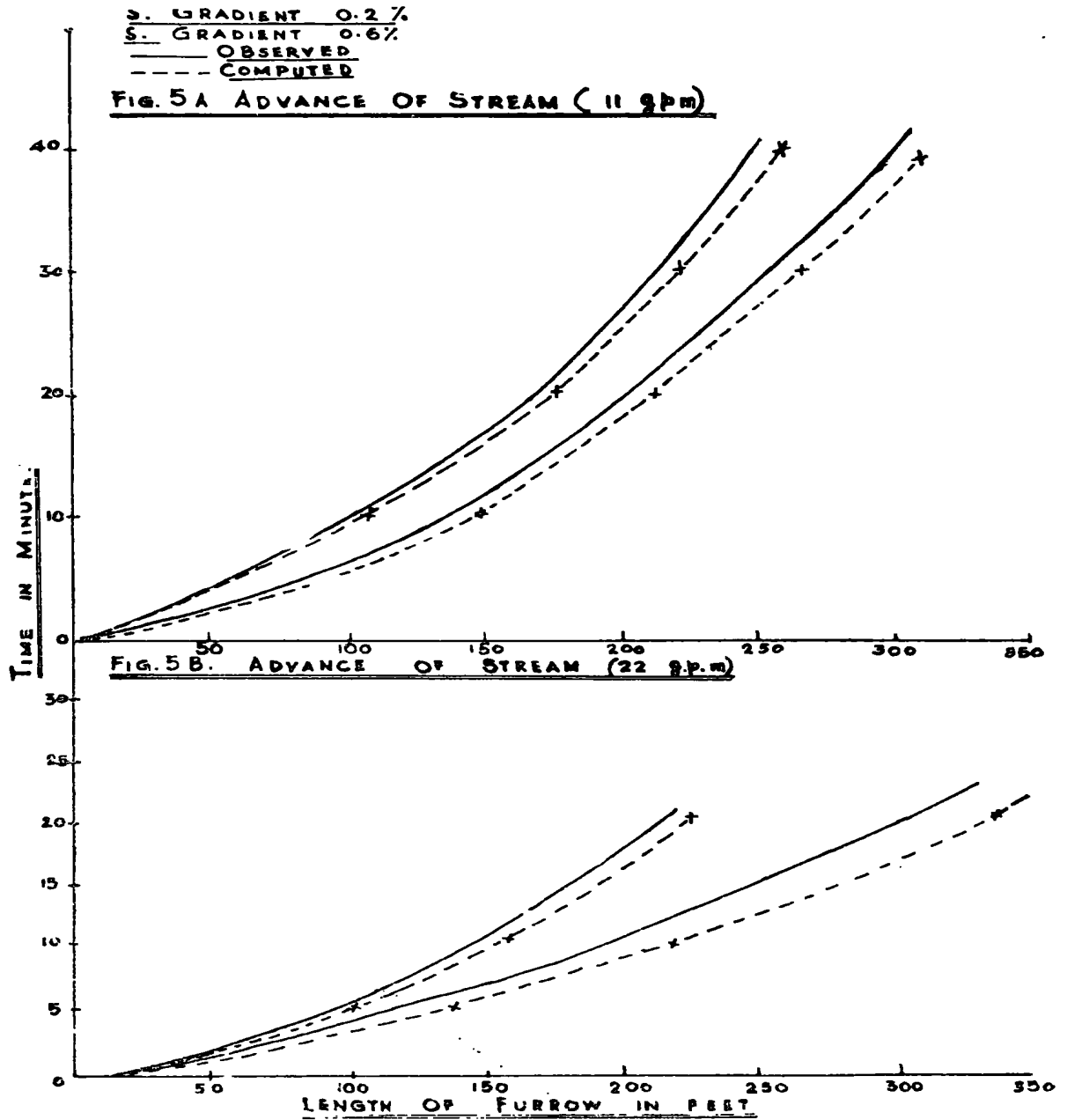


FIG. 4. HYDRAULICS PARAMETERS OF THE FURROW VS: DEPTH



*Note.* The upper two lines in each diagram represent  $S_1$  gradient (0.2%) and the lower two lines the  $S_2$  gradient (0.4%).