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A COMPUTER MODEL FOR TRICKLE IRRIGATION SYSTEM DESIGN

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ABSTRACT

Trickle irrigation systems display the possibility for effective irrigation of rising amount crops and have proven plausible from engineering and agronomic point of view especially in arid and semi-arid zones. A computational model was developed for designing and managing the trickle irrigation systems using the water requirements, irrigation depth, and frequency. The model is composed of several processes as emitter selection according to its discharge and head requirements, determining the allowable variation in subunit pressure head, determining the system configuration and layout (lateral and manifold lengths), positioning of manifolds and designing laterals, designing the manifolds, designing the mainline network and pump unit, and evaluating the trickle system design according to the actual system uniformity. The model was validated by comparing the results with the solved examples. The comparative study revealed that the developed trickle irrigation model achieved good agreements. The developed model is a very helpful tool for water resource engineers for examining and analyzing any design alternatives hydraulically and economically.

Disciplinary: Civil Engineering (Irrigation Engineering).

1. INTRODUCTION

The water scarcity in arid and semi-arid zones makes the agricultural growth is very limited. Improving the performance of irrigation is essential to survive within the earth's soil and water resources limitations. The design of a trickle irrigation system is somewhat of an iterative procedure in which a successive adjustment to the design may be made to correct the deficiency that may be shown up in checking the system design (Bazaraa, 1982). Thus, it is important to computerize the appropriate techniques for trickle irrigation systems and their configuration to ensure accurate design.

Chatterjee et al. (1995) developed a finite element model (ANALYZER-1) to analyze drip

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irrigation systems, taking into account minor losses from fittings or barbs. The analysis involved the determination of downstream pressures and discharges at various nodes for a given inlet pressure.

A simple model was developed by Al-Amoud and Al-Mesned (2000) to plan the trickle-laterals taking into account losses due to friction and emitter connection. The model estimates the discharges of laterals and emitters and the distribution of pressure head over laterals. The model was used to simulate some design charts within practical ranges of normal design variables, including; the effect of length, diameter, slope, discharge-pressure head relations, and uniformity along the laterals.

Zella and Kettab (2002) used numerical methods for the lateral micro-irrigation hydraulic analysis. These methods were the control volumes “CVM” and the Runge-Kutta “RK4”. The CVM method confirms to follow the hydraulic analysis and iterative development; whereas, the RK4 method uses the integration of the differential equations system.

Mohammed (2005) used Visual Basic (VB) 6 to simulate the design and manage drip irrigation systems. The program gives the net water depth and the frequency of irrigation, the maximum number of operation units, the unit operation time and the system capacity. The program gives the number of units per area and the minimum system capacity that can irrigate the whole area at a time.

The computer program of Odd-Shaped Subunits Designer (OSSD) was developed by Mahrous et al. (2008) to predict the emission uniformity in odd-shaped irrigation subunits. The program is dealing with three modules; emitter characteristics, subunit geometry and subunit design. The predicted values of the emission uniformity in equal area of rectangular, trapezoidal and triangular irrigation subunits were in good agreement with field measurement.

Yurdem et al. (2011) use VB6 to estimate the main characteristics and friction losses and to obtain the ideal lateral length in squat time. The software comprised several options for the selection of emitter type based on the pressure.

The program of Graphical User Interface in MATLAB was developed by Philipova et al. (2012) to design the surface drip irrigation system. Two main parts of the crop water requirements and hydraulic system calculations has been included in the program. The crop water requirements have been developed in agro-physical soil properties, characteristics of the corresponding crop, and climatic data. The hydraulic calculations include the design of lateral, manifold, mainline and pump.

An integrated system for automate the drip fertilizing irrigation in greenhouse controlled by PC was introduced by Guerbaoui et al. (2013) to develop the greenhouse production. Water needs are measured by soil humidity sensor. The fertilizing irrigation graphics was developed using LabVIEW.

Agarwal et al. (2015) developed the Drip Irrigation System Design (DISD) software for different locations for horticultural crops. DISD gives ideal sizes of the main line, sub-main laterals, and drippers along with water requirement of different crops and pumps size.

A drip irrigation system was designed and optimized by Dhara et al. (2015) to utilize water and energy to meet the plant requirement and also to have maximum yield at minimum consumption of energy and time. Computational analyses have been made for the multi-loop system and land of alluvial agro-climatic zone with sandy loam type soil and areas of 1 ha. Hazen-Williams formula has been used for finding out the pressure loss. Fruit crop like Mango have been considered for cultivation and its analysis. The analyses use the various sizes of key components, [Extruded HDPE/ rigid PVC; main 63 mm / sub-main 50 mm], manifold [Extruded LDPE 40 mm], lateral [LLDPE; 25/20 mm], drippers (short orifice; 9 lph capacity each and 3 emitters per plant), and no. of plants:

120. All relevant performance parameters have be evaluated through computational simulations and validated with the recognized standards.

Reddy et al. (2017) used VB.NET to design the drip irrigation system based on all designing parameters. A sample run was made with assumed data for different crops e.g. apple, banana, coconut, mango, pomegranate, orange. The design for these crops assigns the emitter spacing, flow in the mainline, and the cost per hectare. In addition the software estimates the pump power and total head required to be operated for each area of the crops grown.

Deekshithulu et al. (2017) used VB6 for designing efficient drip irrigation facilities. The software provides interaction at all stages of the design process and a solution based on the individual's requirements. Design of system arrived by this software was tested with manual calculations at developer's level and results were found satisfactory.

This study aims to develop a computer model to make a detailed design of a trickle irrigation system (point and line sources). The design process presented herein uses numerical solutions rather than requiring graphical charts. The design procedures cover all the system components (outlets, pipes, fittings, line-source and point-source drip systems and pump unit).

2. MATERIALS AND METHODS

The fundamental steps and basic equations that deemed in the programming of the present model were performed. They cover the factors that affect the trickle irrigation design. Design processes reported herein use numerical solutions rather than requiring graphical and interpolation from charts.

2.1 FACTORS AFFECTING PLANNING OF TRICKLE IRRIGATION

2.1.1 NET WATER REQUIREMENTS

The utmost water depth over the crop root and under trickle systems (Id_n) could be computed as

$$Id_n = W_A * Z * Y * \left(\frac{P_W}{100}\right) \quad (1),$$

where W_A is the soil holding water capacity, Z is the depth of crop root, Y is the deficit of allowable moisture, and P_W is the percentage area wetted under trickle. The typical ranges of W_A of the general grouping of soil textural classes were classified according to soil conservation service (SCS, 1970). Considering the dominant soil and suitable grown crops, W_A could be obtained from SCS (1970), Pair et al. (1983), and Doorenbos and Kassam (1979). The grown crop could be estimated as (Y) (Doorenbos and Pruitt, 1977), and Z (Ayers and Westcott, 1985). The appropriate interval of elapsed time between the beginning of two successive irrigation (I_i) could be estimated as

$$I_i = \frac{Id_n}{ET \text{ or } ET_t} \quad (2),$$

where ET is the rate of water use through the summit consumptive period. The potential evapotranspiration could be calculated as in Shawky and Sallam (1996). The crop water requirements were given by Jensen et al. (1990) and Doorenbos and Pruitt (1977). Under trickle irrigation, there are several formulas for determining the average peak daily transpiration rate (ET_t). The simple and accurate one (Sharples et al., 1985) is:

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$$ET_t = ET * [0.1 * (SHA)^{0.5}] \quad (3),$$

where SHA is the canopied soil area percentage at midday (80 % orchard and 50 % vegetables). For estimating purposes, the rectangle wetted area (A_W) has been reported by (Keller and Karmeli, 1974 and 1975; and Keller and Bliesner 1990). The long dimension of (A_W) is (w) while the short dimension (S'_e) is 0.8 of (w) (see Mirzaei et al., 2009). Then, the value of P_w could be estimated as in (Keller and Karmeli, 1974 and 1975):

$$P_w = (N_p * S'_e * w) * \frac{100}{(S_p \times S_r)} \quad \text{for single-laterals} \quad (4),$$

$$P_w = [Np * S'_e * 0.5\,(S'_e + w)] * \frac{100}{(S_p \times S_r)} \quad \text{for dual-laterals} \quad (5),$$

where, (Np) is the number of emitters per plant, S_p and S_r are the spacing between plants in one row and between rows of plants (Doorenbos and Kassam, 1979).

2.1.2 GROSS WATER REQUIREMENTS

Gross water depth of application per irrigation (I_d) can be estimated as in Equations 6 and 7 using the ratio of peak-use-period transmission (T_r) as in Keller and Bliesner (1990). The emission uniformity (EU) recommended by the ASAE (1988) is used.

$$I_d = I_{dn} * \frac{T_r}{EU} \quad \text{where } LR \le 0.1 \quad (6),$$

$$I_d = \frac{I_{dn}}{[(1.0 - LR)(EU)]} \quad \text{where } LR > 0.1 \quad (7),$$

where LR is the irrigation leached salts below the root zone and can be estimated as

$$LR = \frac{EC_w}{(2 * EC_{max})} \quad (8),$$

where EC_w is the water electrical conductivity and EC_{max} is the saturated electrical conductivity that will decrease yield to zero (Ayers and Westcott, 1985).

2.2 TRICKLE SYSTEM DESIGN MODELING

2.2.1 EMITTER SELECTION, DISCHARGE, AND HEAD REQUIREMENTS

The selection of an emitter depends on the soil to be wetted, plant requirements for water, emitter discharge, and water quality. The selected emitters require the following steps:

1. Estimate and select the common emitter kind that preferable suits the requirements of the area to be wetted as a point-source or line-source.
2. According to the required system's discharge, plant spacing and other layout accounts, choose the needful specified emitter.
3. Choose the desired discharge (q_a) and pressure head (H_a) for the average emitter. The most prevalent kind of point-source emitters is 4-lph, and a few manufactures as well as fabricate 2, 6, 8 lph emitters. As well, line source piping commonly has outlets spaced at 15, 20, 30, 45, and 60 cm intervals and the standard extent of available flow rates for each outlet is ranged 0.5 ~2.0 lph.
4. Determine the permissible pressure variation in the subunit (ΔH_a) giving the desired emission uniformity (EU).

5. After selecting a trial emitter, determine the required application time of emitter during the peak use period (number of operating hours per day, T_a) as

$$T_a = G/(N_p * q_a) \quad (9).$$

T_a must not override 21.6 hrs. /day to permit a few limits of safety for the sudden stop. The gross volume of water per plant per day (G) can be estimated as

$$G = S_p x S_r * \frac{I_{dn}}{I_i} \quad (10).$$

6. The average emitter pressure head (H_a) could be determined as

$$H_a = (q_a / C_d)^{1/x} \quad (11),$$

where C_d and x are the emitter discharge coefficients which could be determined by experimental calibration. Usually, x equals 0.5 for orifice and nozzle emitters and sprayers, 0.7-0.8 for long-path emitters, 0.4 for vortex sprayers, and 0.5-0.7 for tortuous path emitters.

2.2.2 ALLOWABLE VARIATION IN SUBUNIT PRESSURE HEAD

The allowable difference in subunit pressure (ΔH_s) that will give a moderately close to the assumed design value of (EU) as in ASAE (1988) could be computed for design purposes as

$$\Delta H_s = 2.5 * (H_a - H_n) \quad (12).$$

The minimum pressure head (H_n) which gives (q_n) can be determined from Equation (11).

2.2.3 TRICKLE SYSTEM CONFIGURATIONS AND ALIGNMENTS

Figures 1 and 2 show the common system configurations. The farm could be divided into a different number of subunits. Subunit dimension depends on; plant and emitter spacing, average emitter discharge, allowable head variations, the desired number of operating stations, length of plant rows in the field, number of plant rows in the field, and field topography and boundaries. The final subunit layout should lead to a minimum number of subunits and pressure-or flow-control points. The pressure head variations can meet the desired emission uniformity.

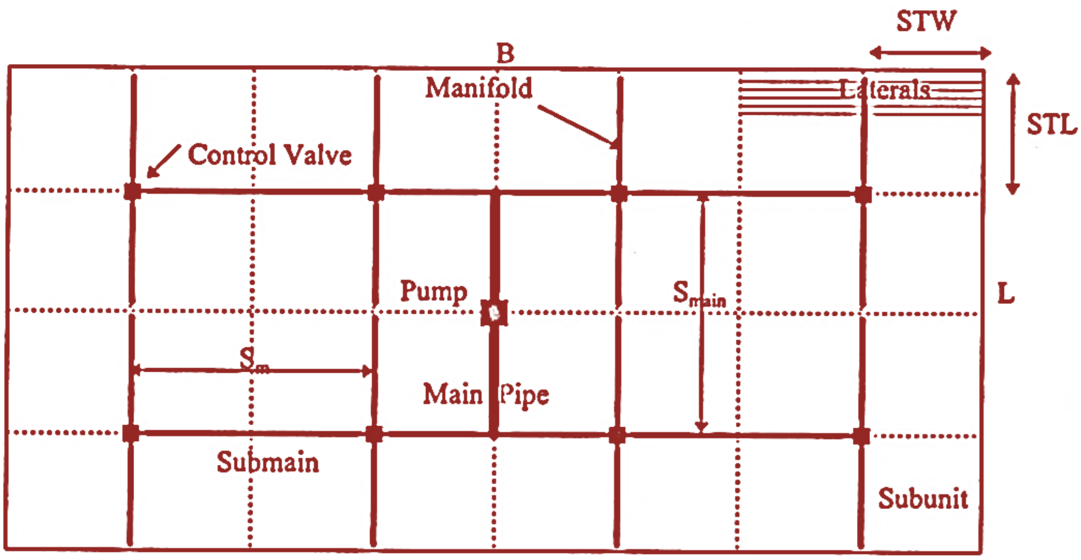

Figure 1: Configuration [1] for Trickle Irrigation Systems.

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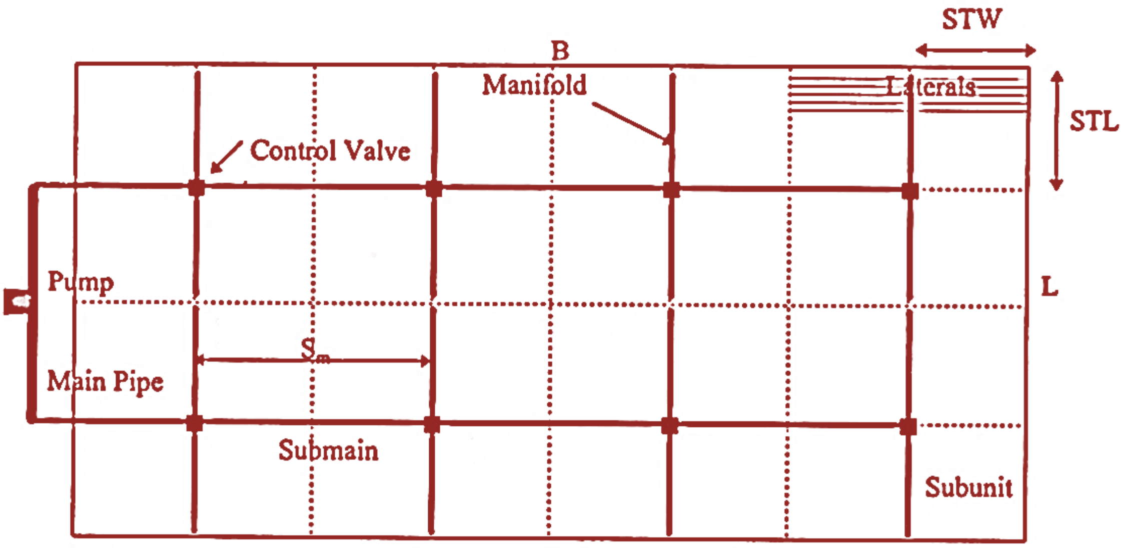

Figure 2: Configuration [2] for Trickle Irrigation Systems.

2.2.4 TRICKLE LATERAL DESIGN

The laterals design depends on the friction head loss as in Watters and Keller (1978)

$$h_f = 7.89 * 10^5 \left(\frac{Q^{1.75}}{D^{4.75}}\right) * L \qquad D \leq 5 \text{ inches} \qquad (13),$$

$$h_f = 9.58 * 10^5 \left(\frac{Q^{1.83}}{D^{4.83}}\right) * L \qquad D > 5 \text{ inches} \qquad (14).$$

The friction head loss in multiple-outlet pipelines may be obtained by using Christiansen's method (1942), which is widely accepted for practical purposes. The hydraulic design is based on a single or pair of laterals having the average discharge in each subunit. The hydraulic design includes determining best lateral inlet locations, average inlet pressure, and maximum pressure variation along the average lateral based on the numerical method of Keller and Rodrigo (1979). The ground slope must be fairly uniform, so it can be represented by a straight line. The average lateral inlet pressure head that gives the average emitter pressure head can be computed as Benami and Ofen (1983) and Keller and Bliesner (1990) based on the lateral sizes and the elevation difference between inlet and closed ends (uphill and downhill laterals) as in Jaiswal et al. (1996) and Asenso et al. (2014).

2.2.5 TRICKLE MANIFOLD DESIGN

As in laterals, the allowable manifold pressure head variation depends on the allowable variation in subunit pressure. The exact manifold lengths are usually functioned of the number of crop rows (laterals) served from a manifold. Manifolds are usually tapered, with up to four different sizes. Manifold design determines the flow rate, best inlet location, pipe sizes, and inlet pressure needed to give the desired average emitter discharge. The best inlet location for tapered manifolds can be estimated as in Keller (1980). The numerical design procedure for selecting diameters and lengths of the manifold uses a hydraulic grade line fitting procedure (Keller and Bliesner, 1990; Keller, 1980; Benami and Ofen, 1983).

2.2.6 MAINLINE NETWORK AND PUMP UNIT DESIGN

After designing the laterals and manifolds, the final subunit dimension and system layout could be determined. The total number of subunits in the farm (NST) could be determined as:

$$NST = NsuL * NsuB \quad (15),$$

where NsuL is the number of subunits on the farm length, NsuB is the number of subunits on the farm width. The procedure for the critical uphill path of the mainline network for drip systems involves the following steps:

1. Compute the total capacity of the system (Q_s) and operating time per season (T_s)

$$Q_s = 2.778 * \left(\frac{A}{N_s}\right) * [(N_p * q_a)/(S_p * S_r)] \quad (16),$$

$$T_s \approx 1.1 * T_a * (D_s/ET_t) \quad (17),$$

   where A is the field area (ha), N_s is the numbers of operating stations, and D_s is the net seasonal irrigation depth (mm).
2. Determine the length, flow rate, and elevation difference for all network's reaches.
3. Select the size for each reach.
4. Compute the friction loss (h_f) in each mainline section for each operating station.
5. Determine the pressure head difference (H_{fe}) due to friction (h_f) and elevation (ΔH_e) between the control head and each manifold inlet

$$H_{fe} = h_f + \Delta H_e \quad (18).$$

6. Compute ($H_{fe} + H_m$) for each manifold. Manifold with larges value establishes the required pressure at the control head. This will be referred to as *the critical manifold inlet*, and the sections of the mainline leading to it as the *critical mainline section*.
7. The critical section of the mainline cannot be changed without increasing the required inlet pressure. However, the pipe sizes in the other parts of the mainline system can be reduced.

The total dynamic head (TDH) for trickle systems is the sum of *dynamic suction lift; supply system losses; control head losses; critical or larger* ($H_{fe} + H_m$)*; various losses in subunits; 10% safety factor of the sum of friction losses; and pressure head allowance for emitter deterioration.*

2.2.7 UNIFORMITY EVALUATION AND NET APPLICATION RATE

Normally, pressure regulation is provided at each manifold inlet. Therefore, the application uniformity within the subunit having the poorest water distribution is the system uniformity. Once a drip system has been designed, its actual emission uniformity (EU_s) should be estimated by Equation (19) (Keller and Karmeli, 1975). The trial design is acceptable since EU_s is within ±2% of the assumed (EU) (Al-Madhhachi et al., 2011)

$$EU_s = 100\left[1.0 - \left(1.27 * v\sqrt{N'_p}\right)\right]\left(\frac{q_n}{q_a}\right) \quad (19),$$

where N'_p is the minimum number of emitters around each plant, q_n is the minimum emission rate computed from Equation (11), and v is the emitter coefficient of manufacturing variation. Line-source may have only one outlet per plant ($N'_p = 1$); however because of the close spacing of outlets, each plant may receive its water from two outlets ($N'_p = 2$). Soloman (1977, 1979, and 1985) classified the quality of emitters according to the coefficient (v), that v should be less than 0.07 for point-source emitters and less than 0.2 line-source tubings. The net application rate (AR) is important

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for scheduling because it is needed to calculate the number of hours the system must operate to apply a specific water depth. AR for the designed system can be computed as

$$AR = (EU_s/100) * [(N_p * q_a)/(S_p * S_r)] \quad (20).$$

2.3 COMPUTER PROGRAM DESCRIPTION

A computer program was developed using FORTRAN to design the trickle irrigation systems and their configurations for each specific site situation. The line-source and point-source systems are the most common types of trickle irrigation methods. The developed model designs the trickle irrigation systems under all possible conditions according to the existing farm parameters. The model consists of the main program and twelve subroutines. The input is provided by user-created ASCII text files. The executable model was produced by FTN77 Version 4.03 compiler (Silverfrost, 2006). The main program is named Trickle Irrigation Systems Design (TISD). The TISD program joins between the different subroutines. Figure 3 shows the flowchart of the main program.

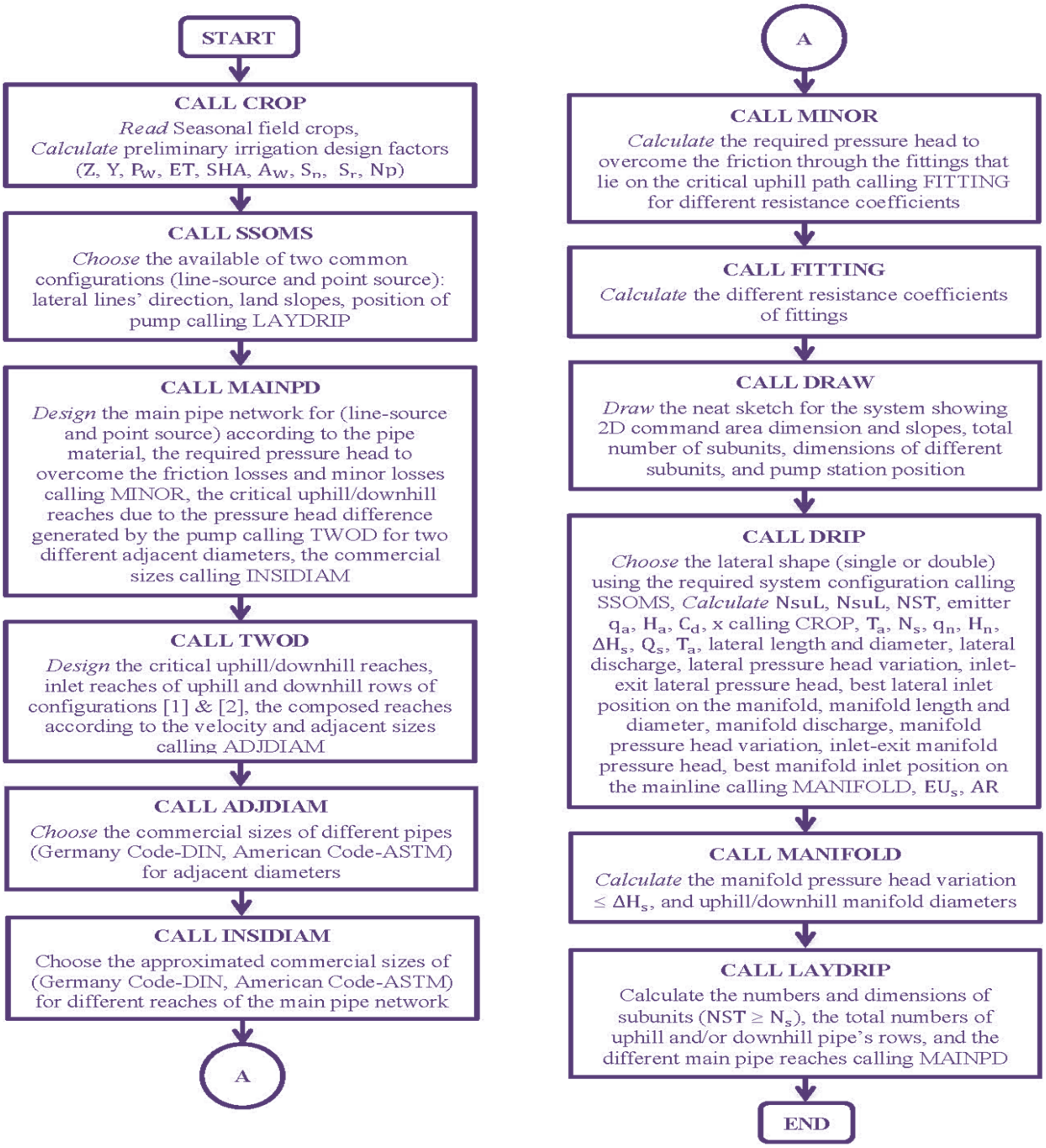

Figure 3: Flowchart of TISD program.

3. RESULTS AND DISCUSSION

3.1 MODEL VERIFICATION PLANNING

TISD is developed to design the trickle irrigation systems and their common configurations. The verification of the developed model, TISD, was made by comparing the results from the model to the solved example calculations reported by Keller and Bliesner (1990); and Benami and Ofen (1983). The model verification processes were made for both point-source and line-source drip systems. The collected data to begin the design computations for the two systems are summarized in Table 1. Figures 4, 5, and 6 show the field shapes and topographies of the study problems. The comparisons between the predicted values of preliminary irrigation design factors and that calculated by Keller and Bliesner (1990) and Benami and Ofen (1983) are listed in Table 2.

Table 1: Data of trickle irrigation design for considered problems.

Study plan	Point-Source (Keller and Bliesner, 1990)	Point-Source (Benami and Ofen, 1983)	Line-Source (Keller and Bliesner, 1990)
Measurement unit	English units	SI units	English units
Water and Land			
Field number	Figure (4-left)	Figure (4-right)	Figure (4)
Field area – ha (acre) A	115.7	64.75	4.7
Water supply – lps (gpm)	800	95	200
Water quality - dS/m (mmhos/cm) EC_w	1.4	0.0	1.0
Soil and Crop			
Texture of soil	Silty loam	Clay loam	Clay loam
Soil holding water capacity mm/m (in. /ft.) W_A	1.8	108	2.11
Management allowed deficiency % Y	30	30	30
Plant spacing – m x m (ft. x ft.) S_p x S_r	24 x 24	6.1 x 6.1	3 x 5
Plant root depth – m (ft.) Z	6.0	1.5	2.5
Percentage shaded area % SHA	66	72	50
Average rate of water use – mm/day (in./day) ET	0.28	7.6	0.28
Seasonal water requirements – mm (in.) ET_s	36.7	812.0	25.0
Leaching requirement ratio LR	0.10	0.0	0.04
Emitter			
Type	Vortex	Multi-exit	Mana-wall tubing
Emitter outlets	1	6	1
Pressure head – kPa [m] (psi [ft.]) H_a	15.0	10.0 m	4.0
Rated discharge @ H_a – L/hr. (gph) q_a	1.0	6.0	0.39
Discharge exponent x	0.42	0.68	0.48
Coefficient of variability v	0.07	0.033	0.12
Discharge coefficient C_d	0.32	-	0.20
Connection loss equivalent – m (ft.)	0.4	1.6	NA

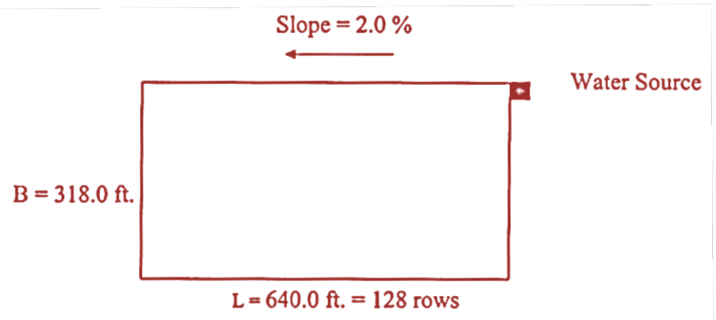

Figure 4: Tomato Field with Line-Source Drip Irrigation System [Keller and Bliesner, 1990].

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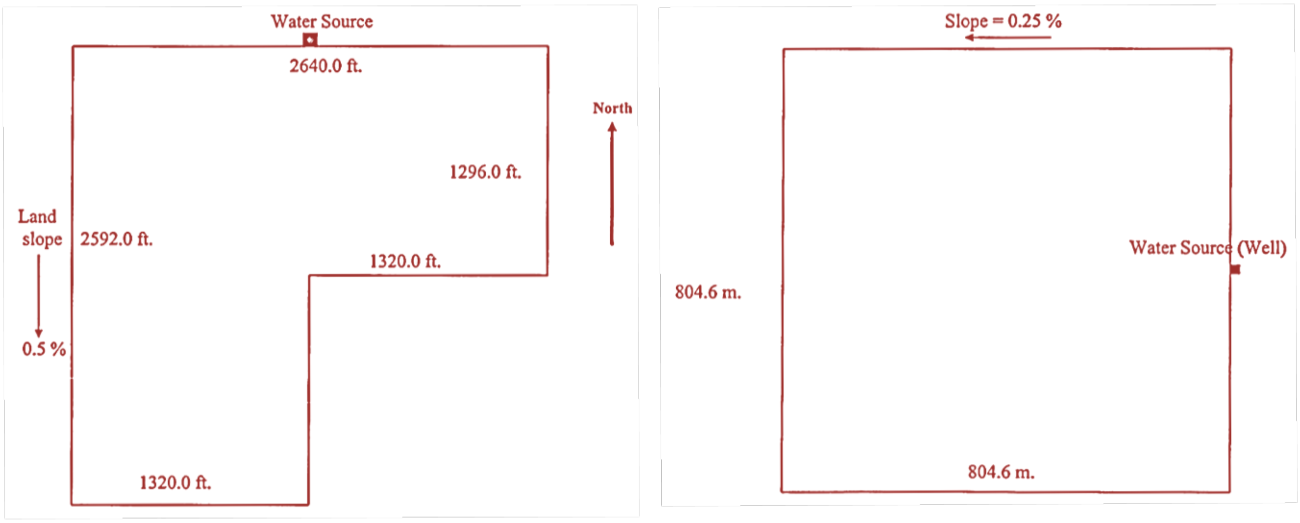

[Keller and Bliesner, 1990] [Benami and Ofen, 1983]

Figure 5: Orchard Field for Point-Source Drip Irrigation System.

Table 2: Comparison between model and reported irrigation design factors of drip systems.

Study plan	Point-Source		Point-Source		Line-Source	
	K.&B.	Model	B.&O.	Model	K.&B.	Model
Field number	Figure 4 (left)		Figure 4 (right)		Figure 5	
Measurement unit	English units		SI units		English units	
Trial Design						
Emission point layout	Straight line		Multi-exit		Straight line	
Emitter spacing - m x m (ft. x ft.) S_p x S_r	6 x 24	6 x 24	1.5 x 6.1	1.5 x 6.1	1.5 x 5	1.51 x 5
Emission point per plant N_p	4	4	6	6	2	2
Percentage of wetted area % P_w	35	35.42	42	39.3	100	100
Maximum net depth – mm (in.) I_{dn}	1.15	1.137	20.4	19.35	1.6	1.58
Ave. peak transpiration – mm/day (in./day) ET_t	0.23	0.228	6.5	6.45	0.20	0.198
Maximum irrigation interval – days I_i	5	5	3	3	8	8
Irrigation Frequency – days I_i	1	1	1	1	1	1
Net depth per irrigation – mm (in.)	0.23	0.228	6.5	6.45	0.20	0.198
Assumed uniformity % EU	90	90	92	90	80	80
Gross depth per irrigation – mm (in.) I_d	0.25	0.253	23.6	21.5	0.25	0.2475
Gross water per plant L/day (gal/day) G	93.3	90.251	272.8	292.8	2.34	2.313
Application time – hr. T_a	23.3	21.0	25.75	8.0	3.00	2.967
Final Design						
Application time – hr. T_a	21.0	21.0	8.0	8.0	3.0	2.967
Irrigation interval – days I_i	1	1	1	1	1	1
Gross depth per irrigation – mm (in.) I_d	0.26	0.253	23.6	21.5	0.25	0.2475
Average emitter discharge - lph (gph) q_a	1.11	1.081	5.83	6.1	0.39	0.391
Average emitter head – m (ft.) H_a	44.5	41.73	10.0	10.26	9.2	9.252
Allowable head variation – m (ft.) ΔH_s	16.0	13.864	-	2.39	5.8	5.53
Emitter spacing - m x m (ft. x ft.) S_e x S_r	6 x 24	6 x 24	1.5 x 6.1	1.5 x 6.1	1.5 x 5	1.51 x 5
Percentage of wetted area % P_w	35	35.42	42.38	39.3	100	100
Number of stations N_s	1	1	3	3	1	1
System capacity – lps (gpm) Q_s	648	641.85	59.0	58.95	177	177.38
Seasonal efficiency % EU_s	90	91	88	90	80	87
Seasonal operation time – hr. O_t	2680	2656.5	2548	2772	215	208.89
Total dynamic head – m (ft.) TDH	115	119.46	30.4	34.261	82.0	81.5
Actual uniformity % EU	91.5	91	90	90	81	86

3.2 MODEL VERIFICATION FOR POINT-SOURCE DRIP SYSTEM

TISD designs the orchard field shown in Figure 5 using the site data (Table 1). According to

Table 2, the comparison between the model and Keller and Bliesner designs for lateral and manifold lines are shown in Tables 3 and 4, respectively. The farm alignment and main pipe network are shown in Figure 6a&b. In this regard, it could be noted that the differences between the results of the trial and final designs are very negligible (Table 2). The lateral design (Table 3) shows insignificant differences between the results. The model uses the German specifications (DIN, 13.6 mm) in sizing lateral line, but Keller and Bliesner use the American specifications (ASTM, 0.58 inch). The model selects a small inside diameter (due to exact discharge), which increases the friction loss and changes the pressures' values within the lateral and consequently changes the lateral inlet position on the manifold. The manifold design (Table 4) shows small differences in the uphill and downhill manifold lengths (12.0 ft.). The model always assumes that for any two adjacent subunits, there is a road in between. So, the model considers the farm has four roads of 24.0 ft. width (Figure 6a), but Keller and Bliesner consider only two roads of 24.0 ft. width (Figure 6b). The differences in uphill and downhill manifold lengths and lateral discharge and its inlet pressure lead to the differences in the manifold discharge, friction losses, and inlet pressure. There is also is a small difference in the sizes of the manifold reaches (lower part of the table) referring to the system alignment and model accuracy. In addition, there is a difference between the model and Keller and Bliesner for main pipe network design because the farm alignments and lateral inlet positions are not identical for both.

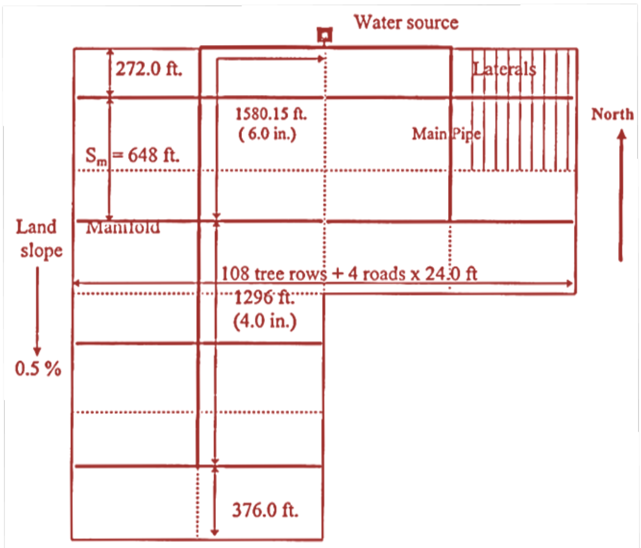

Figure 6a: Model design for farm layout and main pipe network (laterals are 16 mm PE, manifolds are SDR 26 PVC, and main lines are SDR 41 PVC).

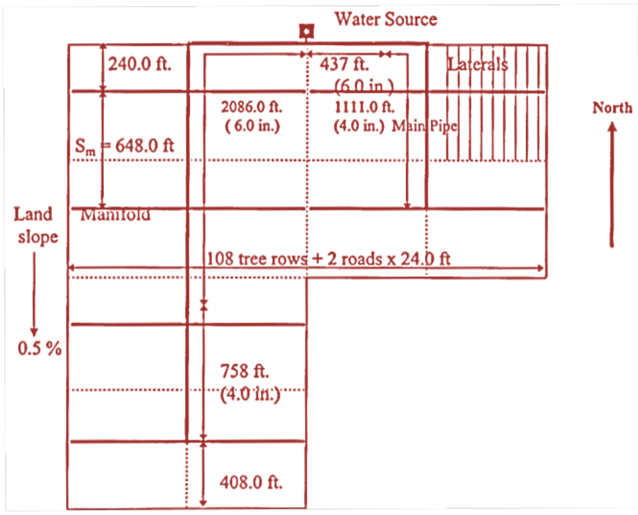

Figure 6b: Keller and Bliesner design for farm layout and main pipe network (laterals are 0.58-inch PE, manifolds are SDR 26 PVC, and main lines are SDR 41 PVC).

Figure 6: Comparison between model and Keller and Bliesner (1990) designs for farm layout and main pipe network of point-source drip system.

Table 3: Comparison between model and Keller and Bliesner (1990) for lateral line design of point-source drip system.

	Lateral length (ft.)	Lateral ID (mm)	Q_l (gmp)	Slope (%)	Head loss (ft.)	Uphill length (ft.)	Downhill length (ft.)	Inlet press. (ft.)	Min. press. (ft.)	Exit press. (ft.)	Press. variation (ft.)	No. of emitters
Model	648	13.6	1.94	0.50	3.67	272	376	44.6	40.94	40.94	3.64	54
K.&B.	648	14.73	2.0	0.5	2.20	240	408	46.4	44.0	44.0	2.40	54

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Table 4: Comparison between model and Keller and Bliesner (1990) for manifold design of point-source drip system.

Pair of Manifold Design							
	Manifold portion	Length (ft.)	Q_m (gmp)	Slope (%)	Inlet press. (ft.)	Head loss (ft.)	No. of laterals
Model	Uphill	636.0	52.47	0.0	48.03	6.92	27
	Downhill	636.0	52.47	0.0	48.03	6.92	27
K.&B.	Uphill	648.0	54.06	0.0	50.2	7.5	27
	Downhill	648.0	54.06	0.0	50.2	7.5	27

Uphill and Downhill Manifold Design									
	Manifold Length (ft.)	Manifold reaches							
		Reach (1)		Reach (2)		Reach (3)		Reach (4)	
		Length (ft.)	Size (in.)	Length (ft.)	Size (in.)	Length (ft.)	Size (in.)	Length (ft.)	Size (in.)
Model	636.0	108.0	2.50	288.0	2.00	120.0	1.50	120.0	1.25
K.&B.	648.0	96.0	2.50	312.0	2.00	120.0	1.50	120.0	1.25

Further, Table 2 shows the comparisons between the predicted values of preliminary irrigation design factors and that calculated by Benami and Ofen (1983) for Figure 5-right. The laterals and manifolds design can be shown in Tables 5 and 6. The farm alignment and main pipe are shown in Figure 7a&b. In this regard, it could be noted that the differences between the trial and final designs of preliminary irrigation design factors (Table 2) are very small due to the accuracy of the developed model. For the lateral line design (Table 5); there are insignificant differences between the results whereas the lateral length that predicted by the model was 132.0 m in length and less than that determined by Benami and Ofen (134.0 m). The model uses the German specifications (DIN, 15.6 mm) in sizing lateral line, but Benami and Ofen use the American specifications (ASTM, 0.58 inch). For the manifold line design (Table 6); there are big differences in the uphill and downhill manifold lengths (upper part of the table). These differences refer to the farm alignment. Benami and Ofen ignore the effect of land slopes in the manifold direction, and consequently, the best manifold position with the main pipe are neglected (i.e., the uphill and downhill manifold lengths are equals). There is a big difference in the sizes of the manifold reaches (lower part of Table 6). These differences are because Benami and Ofen use one size manifold leading the model design for manifold is more accurate and economic. Furthermore, there are some differences in the farm alignments and main pipe network design (Figure 7a&b). These differences refer to the effect of land slopes that neglected by Benami and Ofen in the manifold inlet position. Further, these differences may refer to the model accuracy through the design, where Benami and Ofen do not use the economic-pipe-size-method in the design of the main pipe network reaches. Therefore, the developed model results for the farm alignment and the main pipe network design are more accurate and economic.

Table 5: Comparison between model and Benami and Ofen (1983) for lateral line design of point-source drip system.

	Lateral length (m)	Lateral ID (mm)	Q_l (L/s)	Slope (%)	Head loss (m)	Uphill length (m)	Downhill length (m)	Inlet press. (m)	Min. press. (m)	Exit press. (m)	Press. variation (m)	No. of emitters
Model	132.0	15.6	0.22	0.0	1.05	66.0	66.0	11.05	9.99	9.99	1.05	65
B.&O.	134.0	14.7	0.224	0.0	1.30	67.0	67.0	13.20	NA	NA	1.30	66

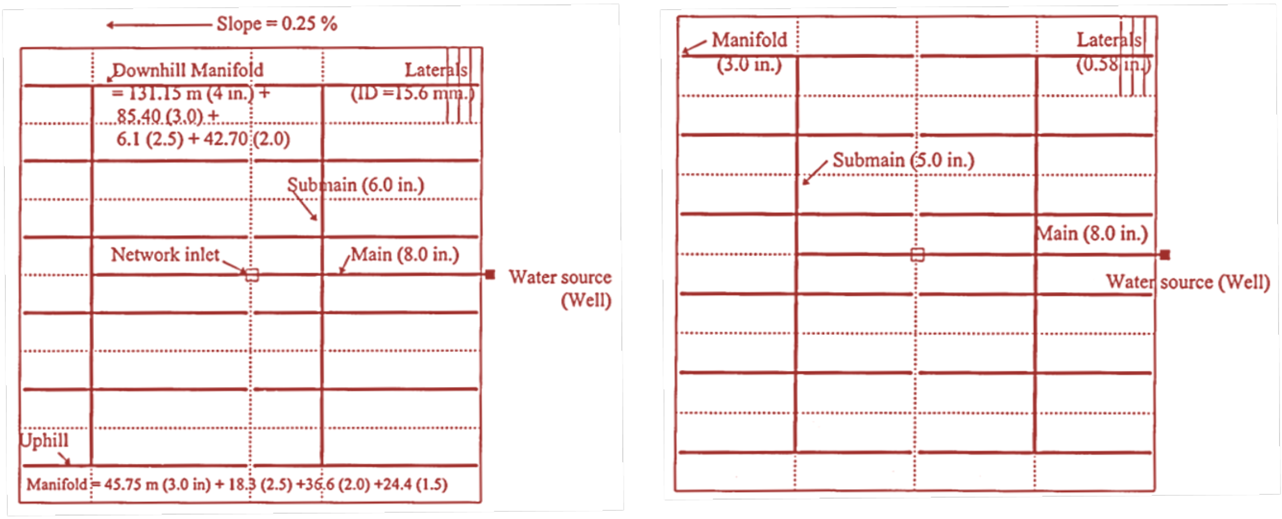

Figure 7a: Model design for farm layout and main pipe network (laterals are 18 mm PE, manifolds are SDR 26 PVC, and main lines are SDR 41 PVC).

Figure 7b: Benami and Ofen design for farm layout and main pipe network (laterals are 0.58-inch PE, manifolds are IPS, and main lines are SDR 41 PVC Class 100 psi).

Figure 7: Comparison between model and Benami and Ofen (1983) designs for system layout and main pipe network of point-source drip system.

Table 6: Comparison between model and Benami and Ofen (1983) for the manifold design of point-source drip system.

Pair of Manifold Design							
	Manifold portion	Length (m)	Q_m (L/s)	Slope (%)	Inlet pressure (m)	Head loss (m)	No. of laterals
Model	Uphill	125.05	4.62	0.25	11.63	0.86	21
	Downhill	265.35	9.69	-0.25	11.38	1.33	44
Ben. & Ofen	Uphill	201.17	7.40	0.25	14.4	1.20	33
	Downhill	201.17	7.40	-0.25	14.4	1.20	33

Uphill and Downhill Manifold Design									
		Manifold reaches							
	Manifold portion	Reach (1)		Reach (2)		Reach (3)		Reach (4)	
		Length (m)	Size (in.)	Length (m)	Size (in.)	Length (m)	Size (in.)	Length (m)	Size (in.)
Model	Uphill	45.75	3.0	18.30	2.5	36.60	2.0	24.40	1.50
	Downhill	131.15	4.0	85.40	3.0	6.1	2.5	42.70	2.0
Ben. & Ofen	Uphill	201.17	3.0	Uphill manifold was designed as one size					
	Downhill	201.17	3.0	Downhill manifold was designed as one size					

3.3 MODEL VERIFICATION FOR LINE-SOURCE DRIP SYSTEM

TISD designs the Tomato field shown in Figure 4 by using the site data listed in Table 1. The comparisons between the predicted values of preliminary irrigation design factors and calculated by Keller and Bliesner (1990) are listed in Table 2. These comparisons for lateral and manifold lines are shown in Tables 7 and 8. The farm alignment is shown in Figure 8. Regarding, it could be noted that for the trial and final designs of preliminary irrigation design factors (Table 2); the differences between the results are very negligible. These differences refer basically to the developed model accuracy through the design calculations. Also, there are insignificant differences between the results of the lateral line design (Table 7). Therefore, the model uses the German specifications (DIN, 15.6 mm) in sizing lateral line, but Keller and Bliesner use the American specifications (ASTM, 0.625

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inch). In the manifold line design (Table 8); there are small differences in the manifold length. The model assumes that; the subunit has a load of 2.5 ft., but Keller and Bliesner consider no roads are required. The difference between the model and Keller and Bliesner for manifold length and the lateral inlet pressure lead to the differences in the manifold discharges, friction losses, and inlet pressures. There is also a difference in the sizes of the manifold reaches (lower part of the table). These differences refer basically to the used design method and the model accuracy where Keller and Bliesner use the graphical method and the economic selection chart in their design steps.

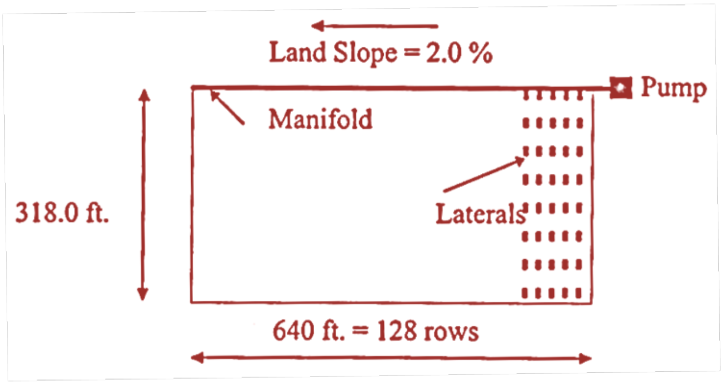

Figure 8: Model and Keller and Bliesner design for farm layout with Line-Source Drip System (Lateral lines are Single Chamber 0.625-inch (15.6 mm for model) ID-PE Tubing which discharges 26 gph/100 ft.; the manifold is buried PVC pipe).

Table (7): Comparison between model and Keller and Bliesner design for Lateral Line of Line-Source Drip System (Figure 4)

	Lateral length (ft.)	Lateral ID (mm)	Q_l (gmp)	Slope (%)	Head loss (ft.)	Uphill length (ft.)	Downhill length (ft.)	Inlet press. (ft.)	Min. press. (ft.)	Exit press. (ft.)	Press. variation (ft.)	No. of emitters
Model	318.0	15.6	1.38	0.0	2.69	0	318.0	11.29	8.56	8.56	2.69	212
K.&B.	318.0	15.875	1.38	0.0	2.50	0	318.0	11.10	9.20	9.20	2.50	212

Table (8): Comparison between model and Keller and Bliesner design for Manifold of Line-Source Drip System (Figure 4)

Single of Manifold Design							
	Manifold portion	Length (ft.)	Q_m (gmp)	Slope (%)	Inlet pressure (ft.)	Head loss (ft.)	No. of laterals
Model	Downhill	637.5	176.4	-2.0	10.7	11.614	128
K.&B.	Downhill	640.0	177.0	-2.0	13.0	NA	128

Downhill Manifold Design									
	Manifold Length (ft.)	Manifold reaches							
		Reach (1)		Reach (2)		Reach (3)		Reach (4)	
		Length (ft.)	Size (in.)	Length (ft.)	Size (in.)	Length (ft.)	Size (in.)	Length (ft.)	Size (in.)
Model	637.5	12.5	4	375.0	3	55.0	2.5	195.0	2
K.&B.	640.0	296.0	3	141.0	2.5	87.0	2	116.0	1.5

4. CONCLUSION

Trickle irrigation can water straightway to the crop root zone. So, it is a common irrigation method in arid and semi-arid areas. In this study, a computer program (TISD) was developed to design the trickle irrigation systems and their configurations for each specific site situation. The line-source and point-source systems are the most common types of trickle irrigation methods. The developed model designs the trickle irrigation systems under all possible conditions according to the existing parameters of the farm. The model consists of the main program and twelve subroutines. It is written using FORTRAN language as it is a practical language, with input provided by user-created ASCII text files. The executable model was produced by the FTN77 Version 4.03 compiler. The model processes the design of drip system through the following steps:

1. Selecting the emitter spacing, the duration of application, the number of stations, and the average emitter discharge and operating pressure head;
2. Determining the allowable variation in the pressure head of subunit (ΔH_s) that will produce the desired emission uniformity (EU);
3. Determining the system configuration and layout (lateral and manifold lengths);
4. Positioning of manifolds and designing laterals;
5. Designing the manifold and selecting a size for manifolds and mainlines;
6. Computing system capacity and total dynamic operating head requirements;
7. Evaluating the system design according to the actual system uniformity;
8. Scheduling the system operation by calculating the net application rate.

The model was verified using two literature data information. The verification results are in good agreement with the literature. The model can be extended for more economic interest design of drip irrigation using the benefit and cost analysis. The program can be compiled to work in Windows. The study can also be modified for sprinkler irrigation systems.

5. AVAILABILITY OF DATA AND MATERIAL

All relevant data are already included in this article.

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