v) The value of x/L = 0.62 falls between the 16th and 17th trees from the lower end. Thus, as discussed earlier, the manifold should be located to supply 17 trees along the downslope laterals and 10 trees along the upslope laterals.

vi) The maximum pressure-head variation ($\triangle h$) along the pair of laterals can be determined from equation 7–70 by use of the x/L value that represents the actual manifold location selected:

$$\triangle h = 6.48[2.20(0.63)^{2.75} + 0.08 - (0.5 \times 0.63)]$$
$$\triangle h = 2.5 \text{ ft.}$$

To check for the possibility that the maximum $\triangle h$ may occur at the closed end of the downslope lateral, determine

$$\triangle h_c = 0.08 \times 6.48 \qquad \textbf{(7–71a)}$$
$$\triangle h_c = 0.5 \text{ ft.}$$

Lateral inlet pressure head (h_l).—h_a = 44.65 ft, h_{fp} = 14.26 ft, z = x/L = 0.63, $\triangle El$ = 3.24 ft.

For pairs of laterals with a constant diameter, the lateral inlet pressure can be determined by equation 7–63a as

$$h_l = 44.65 + 0.75(14.26)[(0.63)^{3.75} + (1 - 0.63)^{3.75}] - (3.24/2)[2(0.63) - 1]$$
$$h_l = 44.65 + 2.15 - 0.42 = 46.4 \text{ ft.}$$

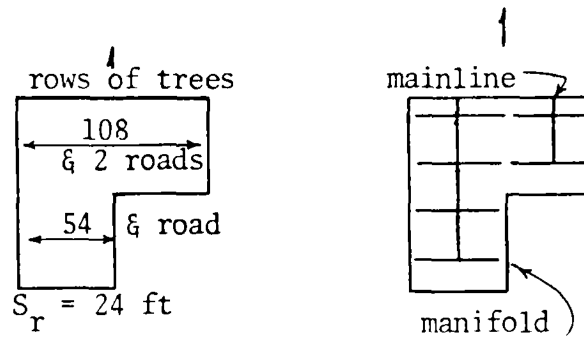
Manifold Design

Selecting pipe size for tapered manifolds involves three criteria:

1. A balance between the pipe's initial cost and the pumping cost over the pipe's expected life (described under Pipeline Hydraulics).
2. A balance between friction loss, change in elevation, and allowable variation in pressure.
3. Maximum permissible velocity.

Pipe sizes selected on the basis of economics are considered acceptable if variations in pressure do not exceed allowable limits. If limits of pressure variation are exceeded, the manifold is tapered by balancing the allowable limit with pipe friction and change in elevation. However, the maximum permissible velocity controls minimum pipe size regardless of the other criteria.

Manifold length and main-line position.



i) For economic reasons and for acceptable $\triangle H$, pairs of manifolds extending in opposite directions from a common main-line connection normally should not exceed a total length of 1,500 ft. Therefore, parallel main lines are needed.

ii) Main lines should be positioned so that starting from a common main-line connection, the minimum pressure in a pair of manifolds is equal (like the manifold position for pairs of laterals as discussed earlier). Because the ground is level in the direction of the laterals, the pair of laterals should be of equal length.

iii) There are access roads in place of the center row of trees in the west 80 acres and in the east 40 acres. Therefore, the length of each manifold is

$$L_m = 27 \times 24 = 648 \text{ ft.}$$

Manifold flow rate (q_m).—q_l = 1.0 gpm, and for a pair of laterals, q_{lp} = 2.0 gpm.

The manifold flow rate is the number of pairs of laterals along each manifold times the flow rate per pair:

$$q_m = 27 \times 2.0 = 54 \text{ gpm.}$$

Economic-chart method of manifold design.— Q_t = 2,686 hr, P_{uc} = \$0.0436/kWh, CRF = 0.205 (20% for 20 yr), EAE = 1.594 (9% inflation), E_p = 75%; BHP/P_u = 1.2 BHP-hr/kWh (taking into consideration the motor transformer and line deficiencies, a power conversion factor of 1.2 is reasonable); P_c = 1.00, Q_s = 54 gpm; q_m = 54.0 gpm, q_{lp} = 2.0; L_m = 648 ft; $\triangle H_s$ = 16.05 ft; $\triangle h'$ = 2.6 ft, from the graphical solution for lateral lines;

l_1 = 648 ft, l_2 = 552 ft, l_3 = 240 ft, l_4 = 120 ft;
q_1 = 54.0 gpm, F_1 = 0.38, q_2 = 46.0 gpm, F_2 = 0.38,
q_3 = 20.0 gpm, F_3 = 0.41, q_4 = 10.0 gpm, F_4 = 0.47.

i) All manifolds in the system serve similar areas, and extra pressure head can be used to reduce sizes of the pipe in all of these.

Therefore, the manifold flow rate (q_m) will be adjusted and used as the adjusted system flow (Q_s') to select the most economical pipe sizes.

ii) First compute the cost per water horsepower per season by equation 7–57:

$$C_{whp} = \frac{2{,}686 \times 0.0436 \times 1.594}{(75/100)(1.2)}$$

$$C_{whp} = \$207/\text{whp per year.}$$

iii) Determine the adjustment factor (A_f) to adjust Q_s to Q_s' for entering the proper unit economic pipe-size selection chart:

$$A_f = \frac{0.001 \times 207}{0.205 \times 1.00} = 1.01, \qquad \textbf{(7–58)}$$

and

$$Q_s' = 1.01 \times 54 \qquad \textbf{(7–59)}$$
$$Q_s' = 55 \text{ gpm.}$$

iv) The maximum pressure in this and most other typical trickle systems is less than 100 psi. Thus PVC pipe with the minimum available (or allowable) pressure rating can be used. Figure 7–33 is the unit economic pipe-size selection chart for this set of PVC pipe sizes.

Enter the vertical axis of figure 7–33 with Q_s' = 55 gpm. Record the flow rate (horizontal axis) where the 55-gpm line intersects the upper limit of each pipe size region, which is:

Pipe size	Chart flow rate	Adjusted[1] flow rate	Number of outlets
	gpm	gpm	
1¼-in.	10.5	q_4 = 10.0	5
1½-in.	20.2	q_3 = 20.0	10
2-in.	45.0	q_2 = 46.0	23
2½-in.	54.0	q_1 = 54.0	27

[1]Flow rates adjusted for nearest whole number of lateral connections.

v) Compute the length of pipe of each size, assuming uniform outlet discharge along the entire length of the manifold by:

$$L_{1¼} = \frac{10.0 - 0}{54.0} \times 648 = 120 \text{ ft} \qquad \textbf{(7–78)}$$

$$L_{1½} = \frac{20.0 - 10.0}{54.0} \times 648 = 120 \text{ ft}$$

$$L_2 = \frac{46.0 - 20.0}{54.0} \times 648 = 312 \text{ ft}$$

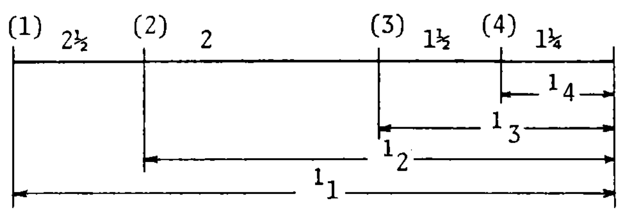
$$L_{2½} = 648 - (120 + 120 + 312) = 96 \text{ ft}$$

vi) Determine the allowable difference in manifold pressure head:

$$(\triangle H_m)_a = 16.05 - 2.6 = 13.5 \text{ ft}, \qquad \textbf{(7–73)}$$

and check this against $\triangle H_m$. To do this, first determine the head loss from pipe friction (H_f), and because there is no slope along the manifold, H_f = $\triangle H_m$ equals the friction loss along the manifold $[(h_f)_m]$.

The numerical method for determining H_f is as follows:



$$H_f = (h_f)_{2½} + (h_f)_2 + (h_f)_{1½} + (h_f)_{1¼}.$$

For 2½-in., J_1 = 1.36, J_2 = 1.02, and

$$(h_f)_{2½} = \frac{1}{100}(J_1F_1l_1 - J_2F_2l_2)$$
$$= \frac{1}{100}[(1.36 \times 0.38 \times 648) - (1.02 \times 0.38 \times 522)]$$
$$(h_f)_{2½} = 1.21 \text{ ft.}$$

For 2-in., $J_2 = 2.55$, $J_3 = 0.58$, and

$$(h_f)_2 = \frac{1}{100}(J_2F_2l_2 - J_3F_3l_3)$$
$$= \frac{1}{100}[(2.55 \times 0.38 \times 552) - (0.58 \times 0.41 \times 240)]$$
$$(h_f)_2 = 4.78 \text{ ft.}$$

For 1½-in., $J_3 = 1.69$, $J_4 = 0.50$, and

$$(h_f)_{1½} = \frac{1}{100}(J_3F_3l_3 - J_4F_4l_4)$$
$$= \frac{1}{100}[(1.69 \times 0.41 \times 240) - (0.50 \times 0.47 \times 120)]$$
$$(h_f)_{1½} = 1.38 \text{ ft.}$$

For 1¼-in., $J_4 = 0.95$ and

$$(h_f)_{1¼} = \frac{1}{100}(J_4F_4l_4)$$
$$= \frac{1}{100}(0.95 \times 0.47 \times 120)$$
$$(h_f)_{1¼} = 0.54 \text{ ft.}$$

The field is level, so $H_f = \triangle H_m$ and

$$\triangle H_m = (h_f)_{2½} + (h_f)_2 + (h_f)_{1½} + (h_f)_{1¼}$$
$$= 1.21 + 4.78 + 1.38 + 0.54$$
$$\triangle H_m = 7.91 \text{ ft.}$$

The graphical method for determining H_f is as follows:

Because the flow rate per outlet along the manifold (q_l) = 2.0 gpm, use figure 7–36 to make the overlay figure 7–47 as described in step 6b of the Economic-Chart Design Method under Manifold Design.

The scale factor for converting graph values plotted from figure 7–36 is

$$k = 648/54(0.1) = 1.2 \qquad \textbf{(7–79a)}$$

Therefore, by equation 7–80,

$$H_f = 1.2(6.6) = 7.9 \text{ ft,}$$

which is almost identical with the value obtained numerically.

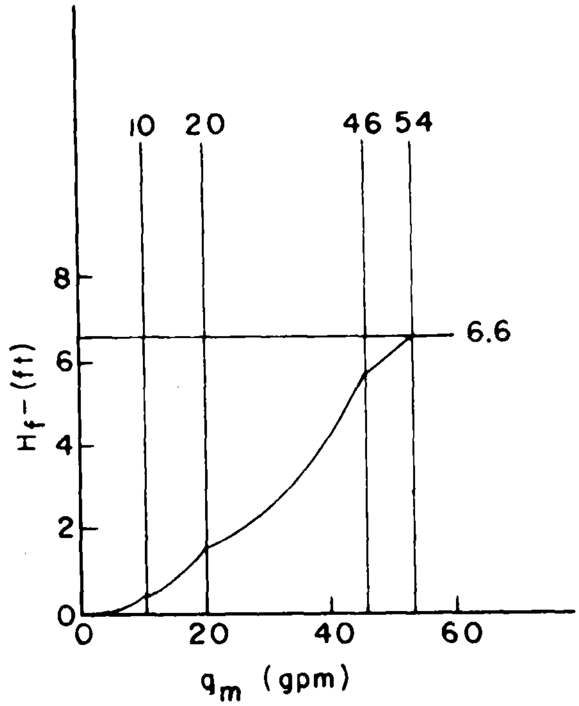


Figure 7–47.—Friction curve overlay to demonstrate graphical solution for determining manifold friction loss (H_f) for a drip system. q_m = manifold flow rate.

This value is less than $(\triangle H_m)_a = 13.5$ ft. Therefore pipe sizes selected by economic criteria are acceptable.

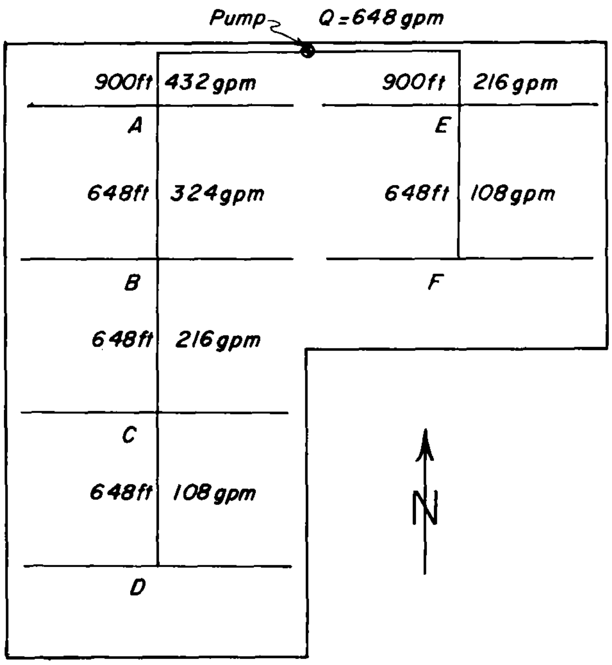
Manifold inlet pressure (H_m).—$h_l = 46.4$ ft, $\triangle H_m = 7.9$ ft; $\triangle H'_m = 0.5H_f + 0.5\triangle El$, $\triangle H'_m = (0.5)(7.9) + 0$, $\triangle H'_m = 4.0$.

$$H_m = 46.4 + 4.0 = 50.4 \text{ ft} \qquad \textbf{(7–76a)}$$

Main-Line Design

Selecting pipe size for main lines is based on economic, pressure, and velocity criteria. After the initial pipe sizes are selected from an economic chart, additional savings are often possible in branching systems by reducing pipe sizes along specific branches to the limits imposed by pressure or velocity criteria. In such cases, sizes may be reduced to take advantage of any excess pressure head that might result from differences in elevation or from higher pressures required for other branches of the system.

Economic pipe-size selection.—Q_s = 432 gpm, A_f = 1.01.



i) First sketch the main-line layout, indicating lengths of pipe and rates of flow along the various sections of pipe.

ii) The unit economic pipe-size selection chart, figure 7–33, is used to select the first set of main-line pipe sizes. Because the flow is divided immediately after the pump, the larger of the two branch flow rates must be adjusted for entering the chart:

$$Q_s' = 1.01 \times 432 \qquad \textbf{(7–59)}$$
$$Q_s' = 436 \text{ gpm.}$$

iii) Enter the vertical axis of figure 7–33 with 436 gpm and determine the most economical size of PVC pipe for each flow section. To hold velocities below 5 ft/s, stay within the solid boundary lines. After selecting the minimum pipe sizes, determine the friction loss in each section as shown in the following table based on equation 7–52.

Sect.	Flow (gpm)	Pipe (in.)	J'	$\frac{L}{100}$	h_f (ft)
P–A	432	6	0.90	9.00	8.10
A–B	324	6	0.54	6.48	3.50
B–C	216	6	3.26	6.48	1.68
C–D	108	4	0.47	6.48	3.05
P–E	216	6	0.26	9.00	2.34
E–F	108	4	0.47	6.48	3.05

Location of critical manifold inlet.

i) Compute the pressure head required to overcome pipe friction and elevation difference $(H_{fe})_m$ between the pump and each manifold inlet point by using equation 7–60 as follows:

	Section							Point
Point	From–to	Inlet (ft)	+	H_f (ft)	±	△El (ft)	=	$(H_{fe})_m$ (ft)
A	P–A	P=0	+	8.10	–	1.20	=	6.90
B	A–B	6.90	+	3.50	–	3.24	=	7.16[1]
C	B–C	7.16	+	1.68	–	3.24	=	5.60
D	C–D	5.60	+	3.05	–	3.24	=	5.41
E	P–E	P=0	+	2.34	–	1.20	=	1.14
F	E–F	1.14	+	3.05	–	3.24	=	0.95

[1]Critical.

ii) The $(H_{fe})_m$ values in (i) show that the critical manifold inlet is at point B, and the pump must supply $(H_{fe})_m$ = 7.16 ft to overcome pipe friction and elevation along the main lines. Because the manifolds require the same inlet pressure head, if the required H_m = 50.4 ft is supplied at point B, all other requirements for manifold inlet pressure head will be more than satisfied.

iii) Furthermore, the above $(H_{fe})_m$ values clearly show that the pipe sizes in sections B–C and P–E can be reduced or trimmed without increasing the system head requirements.

Reducing main-line pipe size.—$(H_{fe})_m$ = 7.16 ft, $(H_{fe})_C$ = 5.60 ft; J_4 = 1.65, J_6 = 0.26; $(H_{fe})_D$ = 5.41 ft before tapering section B–C; $(H_{fe})_E$ = 1.14 ft before tapering section P–E; J_4 = 1.65, J_6 = 0.26, L_{P-E} = 900 ft.

i) The pipe sizes between the pump and the critical manifold inlet cannot be trimmed without increasing the pump head requirements. However, the pipe sections downstream from the critical inlet point and along other branches can be trimmed so that the corresponding manifold inlet points also require $(H_{fe})_m$ = 7.16 ft.

ii) The gain in pressure head between B and C is:

$$(\triangle H)_{B-C} = 7.16 - 5.60 = 1.56 \text{ ft}$$

This unnecessary gain in pressure head can be eliminated to reduce pipe costs by replacing some of the 6-in. pipe with 4-in. pipe in section B–C. The exact length of the smaller pipe (L_s) that will increase the head loss by $\triangle H$ is

$$(L_4)_{B-C} = \frac{(\triangle H)_{B-C}}{J_4 - J_6} \times 100 \quad \textbf{(7-61)}$$

$$= \frac{1.56 \times 100}{1.65 - 0.26}$$

$$(L_4)_{B-C} = 112 \text{ ft.}$$

iii) With 536 ft of 6-in. and 112 ft of 4-in. pipe in section B–C, the H_{fe} at point C will increase to the system $(H_{fe})_m = 7.16$ ft. The $(H_{fe})_m$ will also increase by 1.56 ft at point D, which gives $(H_{fe})_D = 6.97$ ft. This value is so close to the system $(H_{fe})_m$ that further tapering would require a short length of 3-in. pipe, which might actually increase the system cost because of the additional pipe size, extra fittings, and more complicated construction.

iv) Using the same logic and procedures along the east branch of the system, for $(H_{fe})_m = 7.16$ ft, the friction loss in the 6-in. pipe between P and E can be increased by

$$(\triangle H)_{P-E} = 7.16 - 1.14 = 6.02 \text{ ft,}$$

and the length of 4-in. pipe taper in section P–E from equation 7–61 should be

$$(L_4)_{P-E} = \frac{6.02 \times 100}{1.65 - 0.26}$$

$$(L_4)_{P-E} = 433 \text{ ft.}$$

So the remaining length of 6-in. pipe in section P–E should be

$$(L_6)_{P-E} = 900 - 433 = 467 \text{ ft.}$$

Total Dynamic Head

The total dynamic head (TDH) required of the pump is the sum of the following:

Item		ft
(1) Manifold inlet pressure head	H_m =	50.4
(2) Pressure head to overcome pipe friction and elevation along the main line	H_{fe} =	7.2
(3) Suction friction loss and lift		10.0[1]
(4) Filter—maximum pressure-head differential		23.1[2]
(5) Valve and fitting friction losses:		
Fertilizer injection		—[3]
Flow meter		3.0[4]
Main control valves		0.5[4]
Manifold inlet valve and pressure regulator		6.9[4]
Lateral risers and hose bibs		2.3[4]
Safety screens at manifold or lateral inlets		2.3[4]
Lateral or header pressure regulators		—[5]
(6) Friction-loss safety factor at 10 percent		6.6[6]
(7) Additional pressure head to allow for deterioration of emitters		—[7]
Total		112.3

[1]Assumed value that includes suction screen, friction in suction pipe and foot valve, and elevation from water surface to pump discharge.
[2]Automatic back-flushing filter to be set to flush when pressure differential reaches 10 psi.
[3]Injection pump used.
[4]Taken from manufacturer's or standard charts.
[5]Not used in this system.
[6]Friction-loss safety factor taken as 10 percent of lateral (2.1 ft), manifold (7.9 ft), main line (18.0 ft), and filter (23.1 ft), plus friction losses from valves and fittings.
[7]The flow characteristics of the vortex emitters used in this design are not expected to change with time.

System Design Summary

The final system-design layout is shown in figure 7-44. The design data are presented in figures 7–43 and 7-45. These three figures, along with a brief writeup of the system specifications and a bill of materials, form the complete design package.

For scheduling irrigation, the emission uniformity, the net system application rate, and the peak daily net system application should be:

Final emission uniformity (EU).—$x = 0.42$, $H_m = 50.4$ ft, $\triangle H_m = 7.87$ ft, $\triangle h = 2.68$ ft, $h_a = 44.65$ ft; $e' = 4$, $v = 0.07$.

i) Compute the ratio of minimum emitter discharge to average emitter discharge in a subunit by equations 7–38 and 7–39:

$$q_n/q_a = \left[\frac{50.4 - 7.9 - 2.7}{44.6}\right]^{0.42}$$

$$q_n/q_a = 0.95.$$

ii) Assuming all the manifolds to be adjusted to the same inlet pressures, final or actual expected system EU will be

$$EU = 100(1 - \frac{1.27}{\sqrt{4}}[0.07])0.95 \qquad \textbf{(7–33a)}$$

$$EU = 91\%.$$

Net application rate (F_n).—S_p = 24 ft, S_r = 24 ft, e = 4, q_a = 1.11 gph, EU = 93%.

$$F_n = 1.604 \times \frac{93}{100} \frac{(4 \times 1.11)}{(24 \times 24)} \qquad \textbf{(7–40)}$$

$$F_n = 0.0115 \text{ in./hr}$$

Maximum net daily application rate (F_{mn}).—After a breakdown, the system may be operated 24 hr/day to make up for lost irrigation time. The maximum net daily application rate is

$$F_{mn} = 0.0115 \times 24 = 0.28 \text{ in.}$$

Spray System

The following spray design is for a typical citrus grove. The data that should be collected before beginning a design are summarized in the trickle irrigation design sheet, figure 7–48, and the field layout map, figure 7–49.

In addition to illustrating the general process for designing a spray irrigation system, the example emphasizes the following procedures:

1. Manifold spacing for multistation systems.
2. Economic pipe sizing for tapered manifolds (both graphical and adjusted economic-chart method solutions) on a rectangular field.
3. Pipe sizing for tapered manifolds on a non-rectangular field.

Sample design computations developed under Drip System are presented more briefly in this section.

Design Factors

The values obtained for the spray design factors are presented in figure 7–50. Details for computing most of these values, except the percent area wetted, have already been presented under Drip System.

The particular spray emitter selected wets a "butterfly"-shaped pattern that can be approximated by a circle with two 40° pie-shaped wedges cut out. The wedges are opposite each other and result from water being deflected by supports that hold a deflection cap above a vertical nozzle. The diameter of the wetted circle and the nozzle's discharge are both functions of the operating pressure. From information provided by the manufacturer, the emitter exponent and coefficient of discharge are x = 0.556 and k_d = 1.89, respectively, and the relation between pressure and wetted diameter is plotted as shown in figure 7–51.

Percent area wetted (P_w).—Diameter of surface area taken from figure 7–50 is 14.5 ft; for fine sandy (coarse)-textured soil, s_e' = 2.0 ft; e = 1, S_p = 15 ft, S_r = 25 ft.

i) The surface area (A_s) wetted directly by the spray at the rated pressure of 25 psi is

$$A_s = \frac{(14.5)\pi}{4} \times \frac{280}{360}$$

$$A_s = 128.43 \text{ ft}^2.$$

ii) The total wetted soil area is larger than the surface area wetted because there is some outward soil water movement, as shown in figure 7–20. The total wetted soil area can be estimated by adding one-half of the S_e' value for homogeneous soils taken from table 7–2 to the perimeter of the wetted surface soil (PS). For the "butterfly"-type wetting patterns, PS can be assumed equal to the circumference of the full circle.

$$PS = 14.5\pi = 45.55 \text{ ft.}$$

iii) From equation 7–3,

$$P_w = \frac{1[128 + (2.0/2 \times 46)]}{15 \times 25} \times 100$$

$$P_w = 46.40\%$$

This represents an acceptable design.

Computations for design.

i) $$F_{mn} = \frac{30}{100} \times 0.7 \times 6.0 \times \frac{46.40}{100} \qquad \textbf{(7–4)}$$

$$F_{mn} = 0.58 \text{ in.}$$

ii) $$T_d = 0.25[\frac{75}{100} \times 0.15(1.0 - \frac{75}{100})] \qquad \textbf{(7–5)}$$

$$T_d = 0.20 \text{ in./day}$$

iii) $I_f = 0.58/0.20 = 2.9$ days

I	Project Name--Florida Spray Design	Date-Fall 1978
II	Land and Water Resources	
	a) Field no.	#1
	b) Field area (acres), A	32.23
	c) Average annual effective rainfall (in.), R_e	39.0
	d) Residual stored soil moisture from off-season precipitation (in.), W_s	1.0
	e) Water supply (gpm)	Pit
	f) Water storage (acre-ft)	--
	g) Water quality (mmhos/cm), EC_w	0.3
	h) Water quality classification	Excellent
III	Soil and Crop	
	a) Soil texture	Fine sand
	b) Available water-holding capacity (in./ft), WHC	0.7
	c) Soil depth (ft)	10
	d) Soil limitations	None
	e) Management-allowed deficiency (%), M_{ad}	30
	f) Crop	Citrus
	g) Plant spacing (ft x ft), $S_p \times S_r$	15 x 25
	h) Plant root depth (ft), RZD	6
	i) Percent area shaded (%), P_s	75
	j) Average daily consumptive-use rate for the month of greatest overall water use (in./day), u_d	0.25
	k) Season total crop consumptive-use rate (in.), U	48.0
	l) Leaching requirement (ratio), LR_t	0.02
IV	Emitter	
	a) Type	280° spray
	b) Outlets per emitter	1
	c) Pressure head (psi), h	25.0
	d) Rated discharge @ h (gph), q	11.3
	e) Discharge exponent, x	0.556
	f) Coefficient of variability, v	0.042
	g) Discharge coefficient, k_d	1.89
	h) Connection loss equivalent (ft), f_e	0.4

Figure 7–48.—Spray-system data for a citrus grove in Florida.

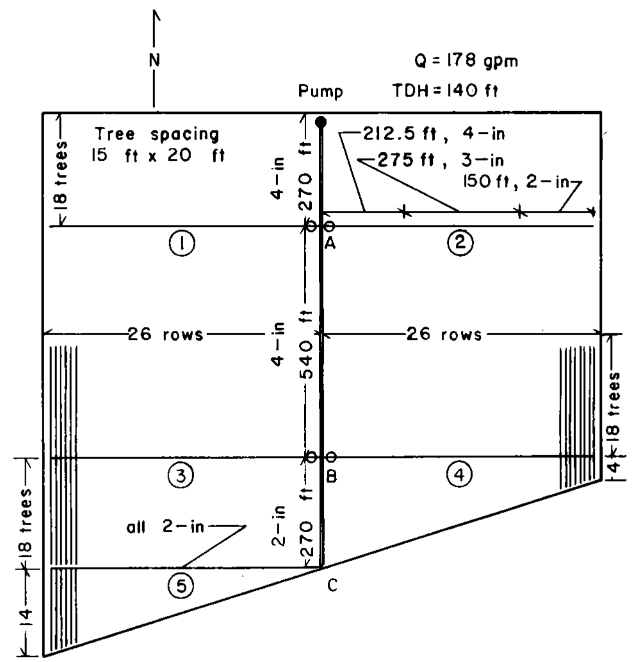


Figure 7–49.—Citrus grove with spray irrigation system. Lateral lines are 0.70-in. polyethylene and manifolds and main lines are polyvinyl chloride pipe.

iv) $F_n = 0.20 \times 1.0 = 0.20$ in. **(7–6)**

v) From table 7–4,

max $EC_c = 8$ mmhos

$$LR_t = \frac{0.3}{2(8)} = 0.02. \quad \textbf{(7–17)}$$

vi) $T_r = 1.00$, assumed EU = 90%.

$$F_g = \frac{0.20 \times 1.00}{90/100} = 0.22 \text{ in.} \quad \textbf{(7–8a)}$$

vii) $$F_{(gp/d)} = \frac{0.623 \times 0.22 \times 15 \times 25}{1} \quad \textbf{(7–9)}$$

$F_{(gp/d)} = 51.40$ gal/day

viii) $$T_a = \frac{51.40}{1.0 \times 11.3} = 4.55 \text{ hr/day} \quad \textbf{(7–30)}$$

Round off to 4.5 hr/day and use N = 4 to give 18 hr/day operation.

ix) From equation 7–30 (rearranged),

$$q_a = \frac{51.40}{1.0 \times 4.5} = 11.42 \text{ gph.}$$

x) $$h_a = \left(\frac{11.42}{1.89}\right)^{1/0.556} \quad \textbf{(7–31)}$$

$h_a = 25.41$ psi or 58.70 ft.

xi) From equation 7–33a (rearranged),

$$q_n = \frac{11.42 \times 90/100}{1.0 - (0.042 \times 1.27\sqrt{1.0})}$$

$q_n = 10.86$ gph.

By equations 7–31 and 7–38,

$$h_n = \left(\frac{10.86}{1.89}\right)^{1/0.556} = 23.20$$

$$\triangle H_s = 2.5(25.41 - 23.20) \quad \textbf{(7–34)}$$

$\triangle H_s = 5.53$ psi or 12.76 ft.

xii) $$Q_s = 726 \times \frac{32.23}{4} \times \frac{11.42}{15 \times 25} \quad \textbf{(7–35)}$$

$Q_s = 178$ gpm.

Seasonal irrigation efficiency (E_s).—EU = 90%, $LR_t = 0.02$.

i) Entering table 7–3 midway between the coarse and very coarse soil-texture columns for humid zones and for root depth over 5 ft plus 0.05 for spray emitters gives

$T_R = 1.20.$

ii) Because $T_R \geq 1/(1.0 - LR_t)$, i.e., $1.20 \geq 1/(1 - 0.02) = 1.02$, use equation 7–12 to compute E_s as

$$E_s = \frac{90}{1.20(1.0 - 0.02)}$$

$E_s = 76.5\%$.

Gross seasonal volume (V_i).—U = 48.0 in., R_e = 39.0 in., W_s = 1.0 in., $U - R_e - W_s = 8.0$ in.

i) The annual net depth of application from equation 7–10 is

$$F_{an} = 8.0\left[\frac{75}{100} + 0.15\left(1.0 - \frac{75}{100}\right)\right]$$

$F_{an} = 6.3$ in.

ii) From equation 7–14,

I	Project Name--Florida Spray Design	Date-Fall 1978
II	Trial Design	
a)	Emission point layout	St. line
b)	Emitter spacing (ft x ft), $S_e \times S_l$	15 x 25
c)	Emission points per plant, e	1
d)	Percentage area wetted (%), P_w	46.40
e)	Maximum net depth of application (in.), F_{mn}	0.58
f)	Ave. peak transpiration rate (in./day), T_d	0.20
g)	Maximum allowable irrigation interval (days), I_f	2.9
h)	Design irrigation interval (days), I_f	1
i)	Net depth of application (in.), F_n	0.20
j)	Emission uniformity (%), EU	90
k)	Gross water application (in.), F_g	0.22
l)	Gross volume of water required per plant per day (gal/day), $F_{(gp/d)}$	51.40
m)	Time of application (hr/day), T_a	4.55
III	Final Design	
a)	Time of application (hr/day), T_a	4.50
b)	Design irrigation interval (days), I_f	1.0
c)	Gross water application (in.), F_g	0.22
d)	Average emitter discharge (gph), q_a	11.42
e)	Average emitter pressure head (ft), h_a	58.70
f)	Allowable pressure-head variation (ft), ΔH_s	12.75
g)	Emitter spacing (ft x ft), $S_e \times S_l$	15 x 25
h)	Percent area wetted (%), P_w	46
i)	Number of stations, N	4
j)	Total system capacity (gpm), Q_s	178
k)	Seasonal irrigation efficiency (%), E_s	76.5
l)	Gross seasonal volume (acre-ft), V_i	22.0
m)	Seasonal operating time (hr), Q_t	689
n)	Total dynamic head (ft), TDH	140
o)	Actual uniformity (%), EU	90
p)	Net water-application rate (in./hr), F_n	0.044

Figure 7–50.—Spray-system design factors for a citrus grove in Florida.

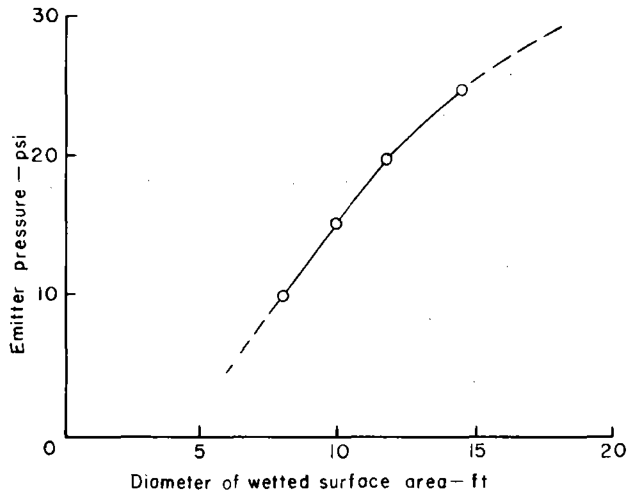


Figure 7–51.—Plot of spray diameter vs. emitter pressure developed from manufacturer's data for 0.04-in.-diameter orifice.

$$V_i = \frac{6.3 \times 32.23}{12(76.5/100)(1 - 0.02)}$$
$$V_i = 22.6 \text{ acre-ft.}$$

iii) From equation 7–37,

$$Q_t = \frac{5{,}430 \times 22.6}{178}$$
$$Q_t = 689 \text{ hr.}$$

Lateral Line Design and System Layout

Lateral-line design procedures are essentially the same for drip and spray irrigation systems. The design procedure includes determining the manifold spacing, the manifold layout, and the maximum pressure-head variation along the laterals.

Manifold spacing (S_m).—S_p = 15 ft; l = 270 ft, $S_e = S_p$ = 15 ft, q_a = 11.43 gph; J = 14.69 from Appendix B, F = 0.39 from table 7–6, f_e = 0.5 ft from figure 7–20; $\triangle H_s$ = 12.76 ft; J = 6.01, f_e = 0.4.

i) There must be at least one manifold for each of the four stations (N = 4) determined in the design factor computations.

The tree rows run north and south, and there is no dominant slope. Therefore, the manifolds should run east and west. No adjustments in manifold position are necessary to compensate for slope effects.

ii) A main line can be placed running north-south midway between the east and west boundaries of the grove. There are 52 rows of trees with an average of 72 trees per row. Two pairs of manifolds plus a fifth manifold for the small triangular section in the southwest corner can be laid out to divide the field into four equal stations, as shown in figure 7–49.

iii) The spacing between the pairs of manifolds and the length of laterals in the rectangular sections is

$$S_m = (72 \times 15)/2 = 540 \text{ ft.}$$

iv) The pressure head difference ($\triangle h$) for the level laterals having 0.58-in. hose and serving 18 trees to either side of each manifold is

$$q_l = \frac{270}{15}\,\frac{11.43}{60} \qquad \textbf{(7–62)}$$
$$q_l = 3.43 \text{ gpm.}$$

From equations 7–51b and 7–52,

$$J' = 14.69\frac{15 + 0.5}{15} = 15.18 \text{ ft/100 ft,}$$

and

$$h_f = 15.18 \times 0.39 \times 270/100$$
$$h_f = 15.98 \text{ ft.}$$

v) This exceeds $0.5\triangle H_s$ = 6.38 ft. Either the laterals must be shortened or larger diameter pipe used. For $h_f \leq$ 6.38 ft, the maximum length of a 0.58-in.-diameter lateral by equation 7–65b is

$$l_b = 270\left(\frac{6.38}{15.98}\right)^{1/2.75} = 193.36 \text{ ft.}$$

This requires dividing the field to operate with either three or six stations. Neither arrangement is satisfactory, because three stations would operate only 13.5 hr/day and six stations would operate 27 hr/day.

vi) Repeating part (iv) with 0.7-in. hose gives

$$J' = 6.01\left(\frac{15 + 0.4}{15}\right) = 6.17 \text{ ft/100 ft}$$
$$h_f = 6.17 \times 0.39 \times 270/100$$
$$h_f = 6.50 \text{ ft.}$$

This is close enough to 6.38 ft to be acceptable for the four-station layout shown in figure 7–49.

Manifold layout.

i) Because the field is nearly level, the manifolds should be laid out to serve laterals of equal length on both sides (except in the triangular areas), as shown in figure 7–49.

ii) The operating sequence for the four stations is:

Station	Manifold	Q_s (gpm)
I	(1)	178
II	(2)	178
III	(3)	178
IV	(4 & 5)	144 + 34 = 178

The flow rates are perfectly balanced as all stations require the same Q_s = 178 gpm.

Maximum variation of lateral pressure head ($\triangle$h).—Because the field is nearly level, $\triangle h = h_f$ = 6.50 ft.

Lateral inlet pressure head (h_l).—$\triangle$El = 0.0 ft, h_a = 58.70 ft, h_f = 6.50 ft (for a single lateral).

For pairs of constant-diameter laterals on level fields, the lateral inlet pressure head can be determined by equation 7–63c, in which the h_f of one single lateral of the pair is known:

$$h_l = h_a + 3/4\ h_f + \frac{\triangle El}{2}$$
$$= 58.70 + 3/4\ (6.50)$$
$$h_l = 63.58 \text{ ft.}$$

Manifold Design

Typically, manifolds are tapered and should have no more than four pipe sizes, with the diameter of the smallest pipe no less than half that of the largest pipe. Manifold pipe size for rectangular subunits can be selected either by the economic-chart method or by the graphical method. For rectangular subunits both the economic-chart method and the alternative graphical method are quick, but only the general graphical method is suitable for tapered manifolds on trapezoidal subunits. In the following example, all three methods will be compared for the design of the rectangular subunits.

Manifold length and main-line position.—S_r = 25 ft, n_r = 52/2 = 26.

i) Because the field is nearly level, the main line should be placed in the center of the field and should supply equal-length manifolds to the east and west.

ii) Because there are 52 rows of trees across the field and no roadway (or missing tree row) along the main line, the manifold length (L_m) by equation 7–75 is

$$L_m = 25(26 - 1/2) = 637.5 \text{ ft.}$$

Allowable manifold pressure-head difference [($\triangle H_m)_a$].—$\triangle$h = 6.50 ft, $\triangle H_s$ = 12.76 ft.

$$(\triangle H_m)_a = 12.76 - 6.50 \qquad \textbf{(7–73)}$$
$$(\triangle H_m)_a = 6.26 \text{ ft.}$$

Manifold flow rates (q_m).

Manifold	q_m (gpm)
(1)	178
(2)	178
(3)	178
(4)	144
(5)	34

Economic-chart method for rectangular subunits.—E_p = 75%, seasonal operation is 689 hr/year, P_{uc} = $0.0436/kWh, BHP-hr/kWh = 1.2; from table 7-8, EAE = 1.594, CRF = 0.205 for n = 20 years and i = 20%, P_c = $1.00/lb; q_l = 3.43 gpm, and for a pair of laterals, q_{lp} = 6.86 gpm; L_m = 637.5 ft, q_m = 178 gpm.

i) Details for using the economic pipe-size selection chart for manifold design are presented under Manifold Design, and an example of the computational procedure is presented under Drip System in Samples of Trickle Irrigation System Designs.

ii) An adjusted system flow rate (Q_s') must be computed for entering the economic pipe-size selection chart, figure 7–33. The steps to compute Q_s' are from equation 7–57:

$$C_{whp} = \frac{689 \times 0.0436 \times 1.594}{75/100 \times 1.2}$$
$$C_{whp} = \$53.20/\text{whp per year;}$$

and from equation 7–58:

$$A_f = \frac{0.001 \times 53.20}{0.205 \times 1.00}$$
$$A_f = 0.26.$$

For the rectangular subunits that are served by manifolds (1), (2), and (3), the system and manifold flow rates are equal:

$$Q_s = q_m = 178 \text{ gpm}.$$

Therefore, from equation 7–77,

$$Q_s' = 0.26 \times 178 = 46 \text{ gpm}.$$

iii) Selecting the pipe sizes and computing the manifold pressure-head variation ($\triangle H_m$) gives

4-in.	112.5 ft
3-in.	300 ft
2½-in.	50 ft
2-in.	175 ft

and

$$\triangle H_m = H_f = 9.2 \text{ ft}.$$

iv) Because $\triangle H_m = 9.2$ ft exceeds $(\triangle H_m)_a = 6.26$ ft, the set of pipe sizes must be increased. The most economical mixture of pipe sizes that will give $\triangle H_m \cong 6$ ft can be obtained by modifying Q_s' and repeating the procedures used in step (iii).

The modified system flow rate, by equation 7–82a, is

$$Q_s'' = \frac{9.21}{6.26}(46) = 68 \text{ gpm}.$$

Enter figure 7–33 with 68 gpm to obtain:

Pipe size (in.)	Chart (gpm)	Adjusted (gpm)	Outlet no.
2	40	41	6
2½	50	48	7
3	120	117	17
4	178	178	26

The computed lengths by equation 7–78a and friction losses from figure 7–37 are:

Pipe size (in.)	Length (ft)	H_f (ft)	Weight (lb)
2	150	1.40	63
2½	25	0.28	15
3	250	2.94	186
4	212.5	1.92	209
Total	637.5	6.54	473

From equation 7–81a for the flat field, $\triangle H_m = H_f = 6.5$ ft. Valves within 10 percent of $(\triangle H_m)_a = 6.26$ ft are close enough so further adjustment is not required. When this calculated value of $\triangle H_m$ exceeds the 10-percent limit, the pipe sizes can be adjusted by inspection or another cut can be made by adjusting Q_s''.

v) Because there is very little 2½-in. pipe called for, replacing it with 3-in. pipe would probably be more economical. This would reduce the final pipe array to:

Pipe size (in.)	Length (ft)	H_f (ft)	Weight (lb)
2	150	1.40	63
3	275	3.05	204
4	212.5	1.92	209
Total	637.5	6.37	476

and

$$\triangle H_m = H_f = 6.4 \text{ ft}.$$

vi) An example of the graphical method for obtaining H_f is presented in figure 7–52. Because $q_{lp} = 6.86$ gpm, the standard manifold curves presented in figure 7–37 were used. By equation 7–79a,

$$k = (637.5/178)(0.1)$$
$$k = 0.36.$$

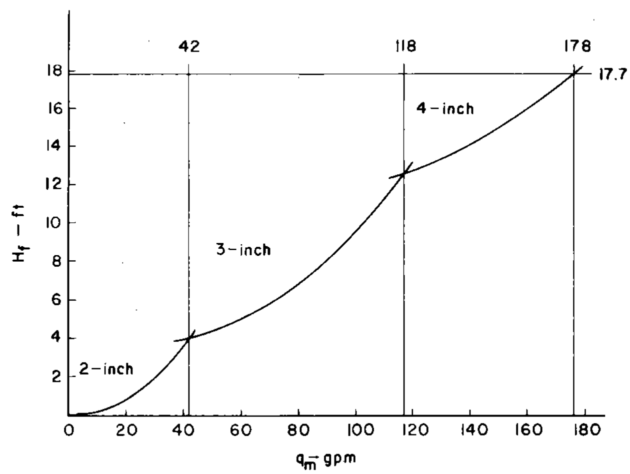


Figure 7–52.--Friction curve overlay to demonstrate graphical solution for determining manifold friction loss (H_f) for a spray system. q_m = manifold flow rate.

From figure 7–51, $H_f = 17.7$ ft, and by equation 7–80,

$$H_f = 0.36(17.7) = 6.37 \text{ ft.}$$

(For more details see figure 7–47 under Drip System.)

General graphical method, rectangular subunits.—From table 7–6, F = 0.38 for 26 outlets; because the subunit is rectangular, $S_f = 1$ by equation 7–83, $F_s = 1$ by equation 7–84, and $F' = F = 0.38$; $(\triangle H_m)_a = 6.26$ ft, $L_m = 647.5$ ft.

i) From the first trial of the economic-chart method, it is apparent that 4-, 3-, 2-1/2-, and 2-in. pipe should be considered.

ii) Determine the JF′ values for each of these pipe sizes for a flow rate of $q_m = 178$ gpm. Using J values from Appendix B:

Pipe size (in.)	J	JF′
4	1.17	0.42
3	4.19	1.59
2-1/2	11.60	4.41
2[1]	28.97	11.09

[1]The J value for the 2-in. pipe was estimated from the J = 28.09 given in Appendix B for the highest flow, at Q = 175 gpm, by

$$J = 28.09\left(\frac{178}{175}\right)^{1.8} \quad \textbf{(7–85)}$$

iii) The rectangular units have a shape factor, $F_s = 1$. Therefore, the scalar JF′ ratios for plotting friction curves for the various-sized pipe are given in the middle column of table 7–9. To construct a dimensionless plot containing a set of curves scaled to represent each of the four sizes of pipe, multiply the scalar JF′ ratios from table 7–9 by the above JF′ values to obtain table 7–10.

iv) Plot x/L vs. the scaled JF′ values given in table 7–10, as shown in figure 7–39. The resulting curves are the dimensionless friction curves scaled for each pipe size under consideration.

v) Determine the dimensionless allowable head-loss ratio by equation 7–86:

$$j = \frac{(\triangle H_m)_a}{L_m/100} = \frac{6.26}{637.5/100} = 0.98.$$

This represents the allowable pipe-friction loss on the same proportional scale as the pipe friction curves of figure 7–39.

vi) Place a transparent overlay on figure 7–39 and trace the horizontal and vertical scales and boundaries, as shown on figure 7–40.

Draw a sloping line through the origin and through j = 0.98 at x/L = 1.0, then draw a second sloping line parallel to the first and passing through

$$0.9j = 0.9 \times 0.98 = 0.88$$

at x/L = 1.0, as shown by the dashed line on figure 7–40.

vii) The combination of pipe diameters and lengths that will give a solution close to the most economical solution with a $\triangle H_m = 6.26$ ft will have a friction curve defined by the two sloping lines. The procedure for drawing the composite curve shown on figure 7–40 is given in the Manifold Design section (see step 8 of the General Graphical-Design Method).

viii) A summary of the general graphical design for manifolds (1), (2), and (3) is:

Pipe size (in.)	Length (ft)	Weight (lb)
2	118	50
2½	89	55
3	223	165
4	207.5	204
Totals	637.5	474

and $\triangle H_m = H_f = 6.3$ ft.

Notice that the total weight (and consequently the cost) of the pipe is essentially the same as determined by the economic chart method, but the lengths of the pipes of various sizes are somewhat different.

Alternative graphical method.—k = 0.36, $(\triangle H_m)_a = 6.26$ ft, $q_m = 178$ gpm.

i) In the alternative graphical method, figure 7–38 is used in place of constructing figure 7–39, and the method is applicable only for rectangular subunits. The alternative method saves the time required to construct figure 7–39.

ii) First compute j′ by equation 7–87 to properly scale $(\triangle H_m)_a$:

$$j' = \frac{6.26}{0.36} = 17.4 \text{ ft.}$$

iii) Following steps 6′, 7a′, and 8′ of the Alternative Graphical-Design Method under Manifold

Design, construct figure 7–42. This construction procedure is similar to the procedure that was used to produce figure 7–40.

iv) A summary of the alternative graphical design for manifolds (1), (2), and (3) is:

Pipe size (in.)	Flow range (gpm)	Length (ft)
2	0–28	100
2½	28–58	107.5
3	58–120	222
4	120–178	208
Total		637.5

and $\triangle H_m = H_f = 6.3$ ft.

A sample computation (for the length of 4-in. pipe) by equation 7–79 is

$$L_4 = \frac{(178 - 120)}{178} 637.5 = 208 \text{ ft.}$$

Graphical method, nonrectangular subunits.— From figure 7–44, for manifold (4) $(n_p)_c = 22$ plants and $(n_p)_a = (22 + 36)/2 = 29$ plants, for manifold (5) $(n_p)_c = 14$ plants and $(n_p)_a = (14 + 0)/2 = 7$ plants; $q_a = 11.43$ gph, $S_e = S_p$, $(q_l)_4 = (11.43 \times 29)/60$, $(q_l)_5 = (11.43 \times 7)/60$; $(S_f)_4 = 0.76$; from table 7–6, $F = 0.38$; $(F_s)_4 = 0.88$; $(q_m)_2 = 144$ gpm, $(q_m)_1 = 178$ gpm, $(F_s)_1 = 1.0$, $(F_s)_2 = 0.88$; $F' = 0.59$; from Appendix B, $J = 1.54$ for 34.67 gpm in 2-in. pipe.

i) Manifolds (4) and (5) serve nonrectangular subunits. For manifold (4), the shape factor is

$$(S_f)_4 = \frac{22}{29} = 0.76 \qquad \textbf{(7–83)}$$

and for manifold (5), it is

$$(S_f)_5 = \frac{14}{7} = 2.0.$$

ii) In manifold (4), which serves 26 tree rows, the flow rate is

$$(q_m)_4 = \frac{11.43 \times 29}{60} \times 26$$
$$(q_m)_4 = 143.64 \text{ gpm,}$$

and for manifold (5) it is

$$(q_m)_5 = \frac{11.43 \times 7}{60} \times 26$$
$$(q_m)_5 = 34.67 \text{ gpm.}$$

iii) The general graphical design procedure for nonrectangular subunits is the same as for rectangular subunits. However, the F factors from table 7–6 must be adjusted and the x/L vs. scalar F'J ratios must be selected as outlined in the Manifold Design section of Design Procedures for Trickle Irrigation Systems.

iv) From figure 7–38 the shape adjustment factor for manifold (4) is $F_s = 0.88$; therefore, the adjusted pipe-friction reduction coefficient is

$$F' = 0.88 \times 0.38 = 0.34.$$

A summary of the graphical design results for manifold (4) is:

Pipe size (in.)	Length (ft)	Weight (lb)
2	236	99
2½	76	47
3	226	168
4	99.5	98
Totals	637.5	412

and $\triangle H_m = H_f = 6.3$ ft.

If the pipe sizes and lengths used for manifolds (1), (2), and (3) are also used for manifold (4), the approximate $\triangle H_m$ can be computed by equation 7–89 as

$$(H_f)_2 = \frac{637.5}{637.5}\left(\frac{0.88}{1.0}\right)\left[\frac{144}{178}\right]^{1.8} \times 6.3$$
$$(H_f)_2 = 3.8 \text{ ft} \cong (H_f)_4 = (\triangle H_m)_4.$$

This leaves 2.5 ft of extra pressure head, which cannot be used beneficially, that requires about 62 lb more pipe. The simplification of construction, however, that results from having manifolds (1) through (4) all the same, plus the savings in design effort, should more than offset the material cost difference.

v) For manifold (5), which serves a triangular subunit (F_s = 1.54 and F′ = 0.59), an analysis by the graphical method for manifold (5) yields:

Pipe size (in.)	Length (ft)	Weight (lb)
1¼	100	21
1½	80	22
2	377	158
2½	80.5	50
Totals	637.5	251

and $\triangle H_m = H_f = 6.3$ ft.
For simplicity of design and better flushing capability, manifold (5) could be constructed of all 2-in.-diameter pipe. This would give

$$(\triangle H_m)_5 = 0.59 \times 1.54 \times 6.375 \quad \textbf{(7–84)}$$
$$(\triangle H_m)_5 = 5.79 \text{ ft.}$$

The weight with all 2-in. pipe is 268 lb. The slightly higher cost of materials would be more than offset by eliminating the two sizes of pipe (1¼- and 1½-in.) from the project.

Simplifying the bill of materials, field layout, and installation by minimizing the number of pipe sizes used is important. The cost savings afforded by doing this are significant. Therefore, the recommended final design is:

Manifolds (1) through (4) use 150 ft of 2-in. pipe, 275 ft of 3-in. pipe, and 212.5 ft of 4-in. pipe as shown in part (v) of the section on the economic-chart method.

Manifold (5) uses all 2-in. pipe. This will require only:

Manifold number	Extra pipe (lb)
(1)	2
(2)	2
(3)	2
(4)	64
(5)	17
Total	87

This extra pipe will cost $87, based on $1.00/lb.

Manifold inlet pressure (H_m).—h_l = 63.6 ft, $(\triangle H_m)_1$ = 6.4 ft (3 pipe sizes), $(\triangle H'_m)_1$ = 0.5(6.4) = 3.2 ft; $(\triangle H_m)_5$ = 5.8 ft (all 2-in.), $(\triangle H'_m)_5$ = 0.75(5.8) = 4.4 ft.

i) For manifolds (1), (2), and (3),

$$H_m = 63.6 + 3.2 = 66.8 \text{ ft.} \quad \textbf{(7–76a)}$$

ii) For manifold (5),

$$H_m = 63.6 + 4.4 = 68.0 \text{ ft.}$$

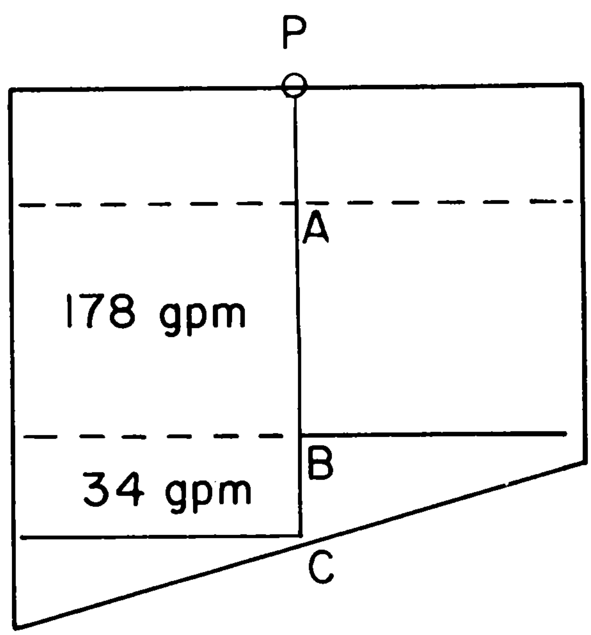
Main-Line Design

Selecting pipe sizes for main lines is based on economic, pressure, and velocity criteria. A detailed example of the use of the economic-chart method of main-line design was presented under Drip System. Therefore, only a summary of the design procedure will be presented here.

Economic pipe-size selection.

i) The highest main-line friction loss will occur at Station IV when manifolds (4) and (5) are in operation. (This is obvious, because all stations have the same flow rate, and the field is nearly level.)

When Station IV is operating, the flow is:



ii) Compute the h_f for each main-line pipe section. Use the economic pipe-size selection chart, figure 7–33, and equation 7–52 with J values from Appendix B. (The value of Q'_s = 46 gpm was computed for the manifold design in the section on the economic-chart method for rectangular subunits part [ii].)

Section	Flow (gpm)	Pipe (in.)	J	L/100	h_f (ft)
P–A	178	4	1.17[1]	2.70	3.16
A–B	178	4	1.17[1]	5.40	6.32
B–C	34	2	1.54	2.70	4.16

[1]Pipe selection controlled by 5 ft/s velocity restriction.

iii) The pressure head required to overcome pipe friction and elevation differences with $\triangle El = 0$ $[(H_{fe})_m]$ between the pump and each manifold is:

Point	Section From–to	Inlet (ft)	+	h_f (ft)	=	Point $(H_{fe})_m$ (ft)
A	P–A	0		8.0		8.0
B	A–B	8.0		6.3		14.3
C	B–C	14.3		2.7		17.0

Total Dynamic Head

The total dynamic head (TDH) required of the pump is the sum of the following pressure-head requirements:

Item	ft[1]
(1) Manifold (5) inlet pressure head	68.0
(2) Pressure head to overcome pipe friction and elevation along the main line	17.0
(3) Suction line, friction and lift	10.0
(4) Filter—maximum pressure differential	23.1
(5) Valve and fitting friction losses:	
Fertilizer injection	—
Flowmeter	3.0
Main-line control valve	—
Manifold inlet valve and pressure regulator	7.5
Lateral risers and hose bibs	2.3
Safety screens at manifold or lateral inlets	2.3
Lateral or header pressure regulators	—
(6) Friction loss safety factor at 10 percent	6.8
(7) Additional pressure head to allow for emitter deterioration	—
Total	140.0

[1]See Drip System for comments.

System Design Summary

The final design layout is shown in figure 7–49. The design data are presented in figures 7–48 and 7–50. These three figures, along with a brief write-up of system specifications and a bill of materials, form the complete design package.

For irrigation scheduling the emission uniformity, net system application rate, and peak daily net system application should be:

Final emission uniformity (EU).—$H_m = 66.8$, $\triangle H_m = 6.4$, $\triangle h = 6.5$, $h_a = 58.7$, $x = 0.556$; for manifolds (1), (2), and (3), $v = 0.042$, $e = 1$.

i) Compute the ratio of the minimum emitter discharge to average emitter discharge by equations 7–38 and 7–39:

$$q_n/q_a = [\frac{66.8 - 6.4 - 6.5}{58.7}]^{0.556}$$

$$q_n/q_a = 0.95.$$

ii) If all manifolds are adjusted to have the same inlet pressure,

$$EU = 100[1 - (\frac{1.27}{\sqrt{1}} \times 0.042)]0.95 \qquad \textbf{(7–33a)}$$

$$EU = 90\%.$$

Net application rates (F_n and F_{mn}).—$S_p = 15$ ft, $S_r = 25$ ft, $e = 1$, $q_a = 11.43$ gph.

i) $$F_n = 1.604(\frac{90 \times 1 \times 11.43}{100 \times 15 \times 25}) \qquad \textbf{(7–40)}$$

$$F_n = 0.044 \text{ in./hr}$$

ii) After a system breakdown, each of the four stations can be operated 6 hr/day to give

$$F_{mn} = 0.044 \times 6$$

$$F_{mn} = 0.26 \text{ in./day.}$$

Line-Source System

The following line-source system design is for a typical field of staked tomatoes in Texas. The data that should be collected before beginning a design are summarized in the trickle irrigation design sheet, figure 7–53, and the field layout map, figure 7–54.

In addition to illustrating the general process of line-source irrigation design, the example emphasizes the following procedures:

1. Calculation of emission uniformity for line-source tubing.
2. Graphical design of downhill manifold so that friction slope closely follows ground slope.

The design computations that follow are made as brief as possible except for concepts that have not already been dealt with under Drip System and Spray System.

I	Project Name--Texas Line-Source Design	Date-Spring 1978
II	Land and Water Resources	
	a) Field no.	#1
	b) Field area (acres), A	4.70
	c) Average annual effective rainfall (in.), R_e	1.0
	d) Residual stored soil moisture from off-season precipitation (in.), W_s	0
	e) Water supply (gpm)	200+
	f) Water storage (acre-ft)	---
	g) Water quality (mmhos/cm), EC_w	1.0
	h) Water quality classification	Good
III	Soil and Crop	
	a) Soil texture	Clay loam
	b) Available water-holding capacity (in./ft), WHC	2.1
	c) Soil depth (ft)	6+
	d) Soil limitations	None
	e) Management-allowed deficiency (%), M_{ad}	30
	f) Crop	Tomato
	g) Plant spacing (ft x ft), $S_p \times S_r$	3 x 5
	h) Plant root depth (ft), RZD	2.5
	i) Percent area shaded (%), P_s	50
	j) Average daily consumptive-use rate for the month of greatest overall water use (in./day), u_d	0.35
	k) Seasonal total crop consumptive-use rate (in.), U	25
	l) Leaching requirement (ratio), LR_t	0.04
IV	Emitter	
	a) Type	Mono-wall tubing
	b) Outlets per emitter	1
	c) Pressure head (psi), h	4.0
	d) Rated discharge @ h (gpm), q	0.0065
	e) Discharge exponent, x	0.48
	f) Coefficient of variability, v	0.12
	g) Discharge coefficient, k_d	0.00332
	h) Connection loss equivalent (ft), f_e	N/A

Figure 7-53.—Line-source-system data for Texas tomato field.

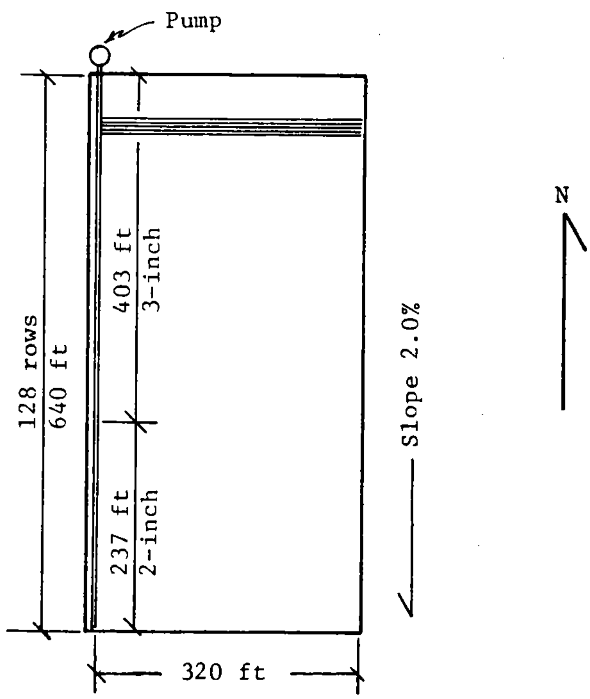


Figure 7–54.—Tomato field with line-source drip irrigation. Lateral lines are single-chamber 0.625-in. (ID) polyethylene tubing that discharge 0.4333 gpm/100 ft; the manifold is buried polyvinyl chloride pipe.

Design Factors

For a small field with a large water supply, it is really not necessary to compute all of the design factor details in figure 7–55, because the entire system can be operated simultaneously, and the irrigation only takes about 3 hr/day. Thus, irrigation could be achieved with a water supply one-sixth as large as that available, or six times as much land could be irrigated with the same water supply. If the water supply were much smaller or the area irrigated significantly larger, the design factor details would be needed. Therefore, figure 7–55 has been filled out, and a brief summary of the computations is included.

Computations for design.

i) From table 7–2 (fine-stratified) for equation 7–1,

$$P_w = \frac{2 \times 1.5 \times 5}{3 \times 5} \times 100$$

$$P_w = 100\%.$$

ii) $$F_{mn} = \frac{30}{100} \times 2.1 \times 2.5 \times \frac{100}{100} \quad \textbf{(7–4)}$$

$$F_{mn} = 1.6 \text{ in.}$$

iii) $$T_d = 0.35[\frac{50}{100} + 0.15(1.0 - \frac{50}{100})] \quad \textbf{(7–5)}$$

$$T_d = 0.20 \text{ in./day}$$

iv) From table 7–4,

max EC_e = 12.5 mmhos,

and

$$LR_t = \frac{1.0}{2(12.5)} = 0.04. \quad \textbf{(7–17)}$$

v) T_r = 1.00; assumed EU = 80%

$$F_g = \frac{0.20 \times 1.00}{80/100} = 0.25 \text{ in.} \quad \textbf{(7–8a)}$$

vi) $$F_{(gp/d)} = \frac{0.623 \times 0.25 \times 3.0 \times 5.0}{1.0} \quad \textbf{(7–9)}$$

$$F_{(gp/d)} = 2.34 \text{ gal/day.}$$

vii) $$T_a = \frac{2.34}{2 \times 0.39} = 3.00 \text{ hr/day} \quad \textbf{(7–30)}$$

viii) Lines a), b), c), d), e), g), and h) in the Final Design, Part II of figure 7–55, are repeats of the data already computed, because no adjustments in the application time were called for.

ix) Although there is only one orifice per plant, the water spread is more than 4 ft, so that each tomato plant will have access to water from at least three outlets. Thus, e′ = 3 in equation 7–33a, and

$$q_n = \frac{0.0065 \times 80/100}{1.0 - 0.12 \times 1.27/\sqrt{3}}$$

$$q_n = 0.0057 \text{ gpm.}$$

$$h_n = 4.0(\frac{0.0057}{0.0065})^{1/0.48} = 3.04 \text{ psi} \quad \textbf{(7–31)}$$

$$\triangle H_s = 2.5(4.0 - 3.04) \quad \textbf{(7–34)}$$

$$\triangle H_s = 2.4 \text{ psi or } 5.54 \text{ ft.}$$

x) $$Q_s = 726 \times \frac{4.70}{1} \times \frac{0.39}{1.5 \times 5.0} \quad \textbf{(7–35b)}$$

$$Q_s = 177 \text{ gpm.}$$

I	Project Name--Texas Line-Source Design	Date-Spring 1978
II	Trial Design	
	a) Emission point layout	Line-source
	b) Emitter spacing (ft x ft), $S_e \times S_1$	1.5 x 5.0
	c) Emission points per plant, e	2
	d) Percent area wetted (%), P_w	100
	e) Maximum net depth of application (in.), F_{mn}	1.6
	f) Ave. peak transpiration rate (in./day), T_d	0.20
	g) Maximum allowable irrigation interval (days), I_f	8
	h) Design irrigation interval (days), I_f	1
	i) Net depth of application (in.), F_n	0.20
	j) Emission uniformity (%), EU	80
	k) Gross water application (in.), F_g	0.25
	l) Gross volume of water required per plant per day (gal/day), $F_{(gp/d)}$	1.17
	m) Time of application (hr/day), T_a	3.00
III	Final Design	
	a) Time of application (hr/day), T_a	3.00
	b) Design irrigation interval (days), I_f	1
	c) Gross water application (in.), F_g	0.25
	d) Average emitter discharge (gph), q_a	0.39
	e) Average emitter head (ft), h_a	9.24
	f) Allowable pressure-head variation (ft), ΔH_s	5.54
	g) Emitter spacing (ft x ft), $S_e \times S_1$	1.5 x 5.0
	h) Percent area wetted (%), P_w	100
	i) Number of stations, N	1
	j) Total system capacity (gpm), Q_s	177
	k) Seasonal irrigation efficiency (%), E_s	80
	l) Gross seasonal volume (acre-ft), V_i	7.0
	m) Seasonal operating time (hr), Q_t	215
	n) Total dynamic head (ft), TDH	131
	o) Actual uniformity (%), EU	86
	p) Net water-application rate (in./hr), F_n	0.0717

Figure 7-55.—Line-source-system design factors for Texas tomato field.

xi) From table 7–3 (fine, 2.5 ft),

$T_R < 1/(1.0 - LR_t)$,

and with excellent scheduling,

$$E_s = EU = 80\% \quad (7\text{–}11)$$

xii) $F_{(an)} = (25 - 1)[\frac{50}{100} + 0.075]$ **(7–10)**

$F_{(an)} = 13.8$ in.

$$V_i = \frac{13.8 \times 4.70}{12(1 - 0.04)(80/100)} \quad (7\text{–}14)$$

$V_i = 7.0$ acre-ft.

$$Q_t = \frac{5{,}430 \times 7.0}{177} \quad (7\text{–}37)$$

$Q_t = 215$ hr/year

Lateral Line Design and System Layout

Lateral-line design procedures are essentially the same for all trickle irrigation systems. The procedure includes determining the manifold spacing, the manifold layout, the lateral size (or sizes in the case of tapered laterals), and the maximum variation of pressure head along the laterals.

Single-chamber tubing was recommended for this design because it can be flushed. Clogging problems were anticipated because the irrigation water contains 3 ppm of iron, even though chlorination was used.

Because the water supply is large, it was decided that to simplify operation and maintenance only one operating station would be used. Furthermore, the farmer wanted the tomato rows to run east-west and the manifold to be buried along the west side of the field. This established the system layout (the manifold spacing and layout), as shown in figure 7–54.

Lateral-pipe size selection and head variation ($\triangle h$).—$q_a = 0.39$ gph, $S_e = 1.5$ ft, $l = 319.5$ ft; from table 7–6, $F = 0.36$; $\triangle H_s = 5.54$ ft.

i) The lateral flow rate is:

$$q_l = \frac{319.5}{1.5} \times \frac{0.39}{60} \quad (7\text{–}62)$$

$q_l = 1.38$ gpm.

ii) Both 0.625-in. and 0.824-in. ID single-chamber tubing are available. Trying the 0.625-in. tubing first, compute the J value by equation 7–49a (because there is not a table for 0.625-in. ID tubing in Appendix B):

$$J = 0.133 \times \frac{(1.38)^{1.75}}{(0.625)^{4.75}}$$

$J = 2.18$.

iii) Because the laterals are laid on the contour, $\triangle h = h_f$ and

$$\triangle h = 2.18 \times 0.36 \times \frac{319.5}{100}$$

$\triangle h = 2.51$ ft.

iv) The 0.625-in. tubing should be satisfactory because

$$\triangle h < 0.5\triangle H_s = 2.77 \text{ ft},$$

which leaves

$$(\triangle H_m)_a = 3.03 \text{ ft}.$$

Lateral inlet pressure head (h_l).—$h_a = 9.24$ ft, $h_f = 2.51$ ft, $\triangle El = 0$.

For a single lateral with a constant diameter on a level field,

$$h_l = 9.24 + 3/4(2.51) = 11.1 \text{ ft}. \quad (7\text{–}63c)$$

Manifold Design

Three possible manifold configurations that will stay within the small allowable $(\triangle H_m)_a = 3.03$ ft on the relatively steep 2-percent slope are:

1. A tapered manifold carefully selected so that the friction slope closely follows the ground slope.
2. Headers and pressure (or flow) regulators used as shown in figure 7–5.
3. Flow regulators or jumper tubes of various lengths used to compensate for excessive pressure variations.

It was decided that a carefully tapered manifold would be ideal for meeting the farm's long-term requirements, provided that the desired design precision could be achieved, i.e., an EU of at least 80 percent. A tapered manifold system should be cheaper, simpler, and more durable than a system requiring flow or pressure regulators.

The graphical methods of designing manifolds are better than the economic-chart method for designing downhill lines with a small $(\triangle H_m)_a$. With the graphical methods the $\triangle H_m$ can be accurately controlled; this control is difficult with the economic method. Inasmuch as the field is rectangular, the alternative graphical method was used because it is much faster than the general graphical method.

Alternative graphical method.—$S_l = 5.0$ ft, $q_l = 1.38$ gpm; $(\triangle H_m)_a = 3.03$ ft; S = 2%. To determine the lengths of different-diameter pipes from figure 7–34: for 1.5-in., (27.4/177) × 640 = 99 ft; for 2-in., 48.7 − 27.4 = 21.3 and (21.3/177) × 640 = 77 ft. k = 0.36; weight of original solution = 385 lb.

i) Because $q_l = 1.38$ gpm, the standard manifold curves presented in figure 7–36 were used.

By equation 7–79a,

$$k = (\frac{5.0}{1.38})(0.1)$$
$$k = 0.36.$$

ii) Because the manifold serves 128 rows, the flow rate is

$$q_m = 128 \times 1.38 = 177 \text{ gpm},$$

and the length of the manifold is

$$L_m = 128 \times 5.0 = 640 \text{ ft}$$

because the length to the first outlet was a full (rather than a half) row spacing.

iii) In accordance with the instructions in step 5′ in the Alternative Graphical Design Method under Manifold Design, which are discussed under Spray System, determine j′ by equation 7–87:

$$j' = \frac{3.03}{0.36} = 8.4 \text{ ft};$$

and S′ by equation 7–88:

$$S' = \frac{2 \times 177}{10} = 35.4 \text{ ft}.$$

iv) Following steps 6′, 7b′, and 8′ in the Alternative Graphical Design Method, construct figure 7–41. Step 7b′ was used because S′ > 3j′, i.e., 35.4 > 3(8.4). The solid sloping line from the origin to S′ = 35.4 ft at $q_m = 177$ gpm represents the ground slope drawn to the same scale as the standard manifold friction curves in figure 7–36. The sloping dashed line which is j′ = 8.4 ft above the slope line represents the upper limit of pressure variation. Any combination of lengths of pipe of different diameters that will satisfy the design requirements will have a composite friction curve defined by the two sloping lines. The procedure for drawing the least-cost composite curve is given in step 8′.

v) One design possibility, involving four pipe sizes, is:

Pipe size (in.)	Length (ft)	Weight (lb)
1½	99	27
2	77	32
2½	144	89
3	320	237
Total	640	385

This design produces a pressure head variation of

$$\triangle H_m = 0.36 \times 6.1$$
$$\triangle H_m = 2.2 \text{ ft}.$$

A simple manifold configuration would be a combination of 2- and 3-in. pipe, as indicated by the dashed curve extensions on figure 7–41. A summary of the two-pipe-size design is:

Pipe size (in.)	Length (ft)	Weight (lb)
2	237	99
3	403	299
Total	640	398

The two-pipe design would have the same pressure-head variation ($\triangle H_m = 2.2$ ft) as the original design, but would require 13 lb more pipe. The savings in layout and installation costs afforded by eliminating two sizes of pipes would probably more than offset the extra cost for pipe.

Manifold inlet pressure (H_m).—k = 0.36; $h_l = 11.1$ ft.

i) The amount the manifold inlet pressure differs from h_l $(\triangle H_m')$ can be estimated graphically as demonstrated on figure 7–41 for the 2- and 3-in. pipe-size design. The thin line parallel to and above the ground-slope line is the average lateral emitter pressure line. It is positioned so that the cross-hatched areas (defined by it and the 2- and 3-in. pipe-friction curves) above and below it are about equal. The manifold inlet pressure is 4.6 graph units above it, therefore

$$\triangle H'_m = 0.36 \times 4.6$$
$$\triangle H'_m = 1.7 \text{ ft},$$

and by equation 7–76a,

$$H_m = 1.11 + 1.7 = 12.8 \text{ ft}.$$

Main-Line Design

For the tomato field layout (fig. 7–54) there are only a few feet of main line and this should be 3-in. pipe.

Total Dynamic Head

The total dynamic head (TDH) required is the sum of the following pressure head requirements:

Item		ft[1]
(1)	Manifold inlet pressure	12.8
(2)	Main line	—
(3)	Dynamic lift from well	78.0
(4)	Filter—maximum pressure differential	23.1
(5)	Valve and fitting losses	9.2
(6)	Friction-loss safety factor	3.7
(7)	Additional pressure head to allow for emitter deterioration	4.6
Total		131.4

[1]See Drip System for comments.

System Design Summary

The final design layout is shown in figure 7–54. The design data are presented in figures 7–53 and 7–55. These three figures, along with a brief writeup of system specifications and a bill of materials, form the complete design package.

For irrigation scheduling the emission uniformity, net system application rate, and peak daily net application should be:

Final emission uniformity (EU).—$H_m = 12.8$ ft, $\triangle H_m = 2.2$ ft, $\triangle h = 2.51$ ft, $x = 0.48$; $h_a = 9.24$ ft; $v = 0.12$; use $e' = 2$ because of over-lapping spread of water.

i) compute q_n/q_a by equations 7–38 and 7–39:

$$\frac{q_n}{q_a} = [\frac{12.8 - 2.2 - 2.5}{9.2}]^{0.48}$$
$$\frac{q_n}{q_a} = 0.94.$$

ii) Compute EU by equation 7–33a:

$$EU = 100 \times [1 - \frac{1.27}{\sqrt{3}} \times 0.12] \times 0.94$$
$$EU = 86\%.$$

Net application rates (F_n and F_{mn}).—$S_p = 3$ ft, $S_r = 5$ ft, $e = 2$, $q_a = 0.39$ gph, EU = 86%.

i) By equation 7–40,

$$F_n = 1.604 \times \frac{86}{100} \times \frac{2 \times 0.39}{3 \times 5}$$
$$F_n = 0.0717 \text{ in/hr}.$$

ii) In a 24-hr period the system could apply

$$F_{mn} = 24 \times 0.0717 = 1.72 \text{ in/day}.$$

This is far higher than necessary for meeting contingencies, and the system can be expanded to cover more than six times as much land with the same water supply.

Field Evaluation

Successful trickle irrigation requires that the frequency and quantity of water application be scheduled accurately. Uniformity of field emission (EU') must be known to manage the quantity of application. Unfortunately, EU' often changes with time; therefore, the system's performance must be checked periodically.

The data needed for fully evaluating a trickle irrigation system are:

1. Duration, frequency, and operation sequence of a normal irrigation cycle.
2. Soil moisture deficit (S_{md}) and management-allowed deficit (M_{ad}) in the wetted volume.
3. Rate of discharge at the emission points and pressure near several emitters spaced throughout the system.
4. Changes in rate of discharge from emitters after cleaning or other repair.
5. Percentage of soil volume wetted.
6. Spacing and size of trees or other plants being irrigated.
7. Location of emission points relative to trees, vines, or other plants, and uniformity of emission point spacing.
8. Losses of pressure at the filters.
9. General topography.
10. Additional data indicated on figure 7–56.

Equipment Needed

The equipment needed for collecting the necessary field data includes:

1. Pressure gage (0- to 5-psi range) with "T" adapters for temporary installation at either end of the lateral hoses.
2. Stopwatch or watch with an easily visible second hand.
3. Graduated cylinder with 250-ml capacity.
4. Measuring tape 10 to 20 ft long.
5. Funnel with 3- to 6-in. diameter.
6. Shovel and soil auger or probe.
7. Manufacturer's emitter performance charts showing the relation between discharge and pressure, plus recommended operating pressures and filter requirements.
8. Sheet metal or plastic trough 3 ft long for measuring the discharge from several outlets in a perforated hose simultaneously or the discharge from a 3-ft length of porous tubing. (A piece of 1- or 2-in. PVC pipe cut in half lengthwise makes a good trough.)
9. Copies of figure 7–56 for recording data.

Field Procedure

The following field procedure is suitable for evaluating systems that have individually manufactured emitters (or sprayers) and systems that use perforated or porous lateral hose. Fill in the blanks of figure 7–56 while conducting the field procedure.

1. Fill in parts 1, 2, and 3 concerning the general soil and crop characteristics throughout the field.
2. Determine from the operator the duration and frequency of irrigation and his estimate of the management-allowed deficit (M_{ad}) to complete part 4.
3. Check and note in part 5 the pressures at the inlet and outlet of the filter, and if practical, inspect the screens for breaks and the screen fittings for passages allowing contaminants to bypass the screens.
4. Fill in parts 6, 7, and 8, which deal with the emitter and lateral hose characteristics. (When perforated or porous tubing is tested, the discharge may be rated by the manufacturer in flow per unit length.)
5. Locate four emitter laterals along an operating manifold (see figure 7–27); one should be near the inlet, two near the one-third points, and the fourth near the outer end. Sketch the system layout and note in part 9 the general topography, manifold in operation, and manifold where the discharge test will be conducted.
6. Record the system discharge rate (if the system is provided with a water meter) and the numbers of manifolds and blocks or stations. The number of blocks is the total number of manifolds divided by the number of manifolds in operation at any one time.
7. For laterals having individual emitters, measure the discharge at two adjacent emission points (denote as A and B in part 14) at each of four tree or plant locations on each of the four selected test laterals. (See figure 7–57.) Collect the flow for a few minutes to obtain a volume between 100 and 250 ml for each emission point tested. Convert each reading to milliliters per minute before entering the data in part 14. To convert milliliters per minute to gallons per hour, divide by 63.

These steps will produce eight pressure readings and 32 discharge volumes at 16 plant locations for individual emission points used in wide-spaced crops that have two or more points per plant.

For perforated hose or porous tubing, use the 3-ft trough and collect a discharge reading at each of the 16 locations described above. Because these are already averages from two or more outlets, only one reading is needed at each location.

For relatively wide-spaced crops such as grapes, where one single outlet emitter may serve one or more plants, collect a discharge reading at each of the 16 locations described above. Because the plants are served by only a single emission point, only one reading should be made at each location.

8. Measure and record in part 15 the water pressures at the inlet and downstream ends of each lateral tested in part 14 under normal operation. On the inlet end this requires disconnecting the hose before reading the pressure. On the downstream end the pressure can be read after connecting the pressure gage in the simplest way possible.

9. Check the percentage of the soil that is wetted at one of the tree locations on each test lateral and record it in part 16. It is best to select a tree at a different relative location on each lateral. Use the probe, soil auger, or shovel—whichever seems to work best—for estimating the real extent of the wetted zone about 6 to 12 in. below the surface around each tree. Determine the percent area wetted by dividing the wetted area by the total surface area between four trees.

10. If an interval of several days between irrigations is being used, check the soil moisture deficit (S_{md}) in the wetted volume near a few representative trees in the next block to be irrigated, and record it in part 17. This measurement is difficult and requires averaging samples taken from several positions around each tree.

11. Determine the minimum lateral inlet pressure (MLIP) along each operating manifold and record it in part 18. For level or uphill manifolds, the MLIP will be at the far end of the manifold. For downhill manifolds it is often about two-thirds down the manifold. For manifolds on undulating terrain it is usually on a knoll or high point. When evaluating a system that has two or more operating stations, the MLIP on each manifold should be determined. This requires cycling the system.

12. Determine the discharge correction factor (DCF) to adjust the average emission-point discharges for the tested manifold. This adjustment is needed if the tested manifold happened to be operating with a higher or lower MLIP than the system average MLIP. If the emitter discharge exponent (x) is known, use the second formula printed in part 19.

13. Determine the average and adjusted average emission-point discharges according to the equations in part 11 and 12.

Using Field Data

In trickle irrigation all the system flow is delivered to individual trees, vines, shrubs, or other plants. Essentially no water is lost except at the tree or plant locations. Therefore, if the pattern of plant distribution or spacing is uniform, uniformity of emission is of primary concern. Locations of individual emission points, or the tree locations where several emitters are closely spaced, can be thought of in much the same manner as the container positions in tests of sprinkler performance.

Average Depth of Application

The average depth applied per irrigation to the wetted area (F'_{aw}), inches, is useful for estimating M_{ad}. It can be computed by equation 7–90.

$$F'_{aw} = \frac{1.604 e q'_a T_a}{A_w} \qquad \textbf{(7–90)}$$

Where

- e = number of emission points per tree.
- q'_a = adjusted average emission-point discharge of the system, taken from part 12, figure 7–56, gallons per hour.
- T_a = application time per irrigation, hours.
- A_w = area wetted per tree or plant from part 16, figure 7–56, square feet.

The average depth applied per irrigation to the total cropped area (F'_a), inches, can be found by substituting the plant and row spacing ($S_p \times S_r$) for A_w in equation 7–90. Therefore, F'_a can be computed by equation 7–91.

$$F'_a = \frac{1.604 e q'_a T_a}{S_p \times S_r} \qquad \textbf{(7–91)}$$

1. Location ____________, observer ____________, date ____________

2. Crop: type ____________, age ________ years, spacing ____________ ft

root depth ______ ft, percentage of area covered or shaded ____ %

3. Soil: texture ________________, available moisture ________ in/ft

4. Irrig: duration ____ hr, frequency _____ days, M_{ad} _____ %, ________ in

5. Filter pressure: inlet _____ psi, outlet _____ psi, loss __________ psi

6. Emitter: make ____________, type ________, point spacing _____ ft

7. Rated discharge per emission point ______ gph at ______________ psi

Emission points per plant ______, giving _______ gal. per plant per day

8. Hose: diameter ____ in, material ______, length ____ ft, spacing _____ ft

9. System layout, general topography, and test locations:

10. System discharge _____ gpm, no. of manifolds ______ and blocks ________

11. Average test manifold emission-point discharges at ____________ psi

$$\text{Manifold} = \frac{(\text{sum of all averages} \_\_\_\_\_\_ \text{gph})}{(\text{number of averages} \_\_\_\_\_\_)} = \_\_\_\_\_\_\_\_\_\_\ \text{gph}$$

$$\text{Low } 1/4 = \frac{(\text{sum of low } 1/4 \text{ averages} \_\_\_\_\_\_ \text{gph})}{(\text{number of low } 1/4 \text{ averages} \_\_\_\_\_\_)} = \_\_\_\_\_\_\_\_\_\_\ \text{gph}$$

Figure 7-56.—Form for evaluation data.

12. Adjusted average emission-point discharges at __________ psi

System = (DCF[1] _____) X (manifold average _______ gph) = _______ gph

Low 1/4 = (DCF _____) X (manifold low 1/4 _______ gph) = _______ gph

13. Comments: ______________________________

____

____

____

14. Discharge test volume collected in _______ min (1.0 gph = 63 ml/min)

Outlet location on lateral		Lateral location on the manifold: inlet end ml	inlet end gph	1/3 down ml	1/3 down gph	2/3 down ml	2/3 down gph	far end ml	far end gph
inlet end	A								
	B								
	Ave.								
1/3 down	A								
	B								
	Ave.								
2/3 down	A								
	B								
	Ave.								
far end	A								
	B								
	Ave.								

1/See item 19.

Figure 7–56.—Form for evaluation data (continued).

15. Lateral inlet ______ psi ______ psi ______ psi ______ psi

Closed end ______ psi ______ psi ______ psi ______ psi

16. Wetted area ______ ft^2 ______ ft^2 ______ ft^2 ______ ft^2

per plant ______ % ______ % ______ % ______ %

17. Estimated average S_{md} in wetted soil volume ______________ in

18. Minimum lateral inlet pressure (MLIP) on all operating manifolds:

Manifold:	Test	A	B	C	D	E	F	G	Ave.
Pressure-psi:	___	___	___	___	___	___	___	___	___

19. Discharge correction factor (DCF) for the system is:

$$DCF = \frac{2.5 \text{ X (average MLIP \_\_\_\_\_\_ psi)}}{\text{average MLIP \_\_\_\_\_\_ psi} + 1.5 \text{ X (test MLIP \_\_\_\_\_\_ psi)}} = \_\_\_\_\_\_$$

or if the emitter discharge exponent x = ______________ is known,

$$DCF = \left[\frac{\text{(average MLIP \_\_\_\_\_\_ psi)}}{\text{(test MLIP \_\_\_\_\_\_ psi)}}\right]^x = \_\_\_\_\_\_ = \_\_\_\_\_\_$$

Figure 7-56.—Form for evaluation data (continued).

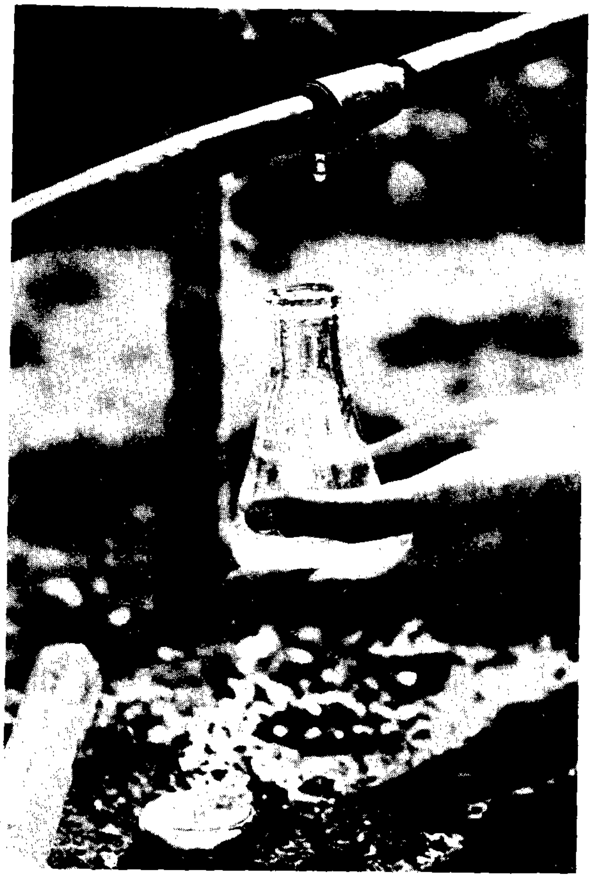


Figure 7–57.—Field measurement of discharge from an emitter.

Volume Per Day

The average volume of water applied per day for each tree or plant [$F'_{(gp/d)}$], gallons per day, can be computed by equation 7–92.

$$F'_{(gp/d)} = \frac{e q_a' T_a}{I_f} \quad \textbf{(7–92)}$$

Where

- e = number of emission points per tree.
- q_a' = adjusted average emission-point discharge of the system, taken from part 12, figure 7–56, gallons per hour.
- T_a = application time per irrigation, hours.
- I_f = design irrigation interval, days.

Emission Uniformity

The actual field-emission uniformity (EU′) is needed to determine the system's operating efficiency and to estimate gross requirements for water application. The EU′ is a function of the emission uniformity in the tested area and of the pressure variations throughout the entire system. Where the data on emitter discharge are from an area served by a single manifold, the field emission uniformity of the manifold area tested (EU_m'), percent, can be computed by equation 7–93.

$$EU_m' = 100\, q_n'/q_a' \quad \textbf{(7–93)}$$

Where

- q_n' and q_a' = system low-quarter and overall average emitter discharges, taken from part 12, figure 7–56, gallons per hour.

Some trickle irrigation systems are fitted with pressure-compensating emitters or have pressure or flow regulation at the inlet to each lateral. However, most systems are provided with a means for pressure control or regulation only at the inlets to the manifolds. If the manifold inlet pressures vary more than a few percent because of design, management, or both, the overall EU′ will be lower than the EU_m' of the tested manifold.

An estimate of this efficiency reduction factor (ERF) can be computed from the minimum lateral inlet pressure along each manifold (MLIP), pounds per square inch, throughout the system by equations 7–94a and 7–94b.

$$ERF = \frac{\text{average MLIP} + (1.5 \text{ minimum MLIP})}{2.5(\text{average MLIP})} \quad \textbf{(7–94a)}$$

Where

- Average MLIP = average of the individual MLIP's along each manifold, pounds per square inch.
- Minimum MLIP = lowest lateral inlet pressure in the system, pounds per square inch.

The ERF may be estimated more precisely by equation 7–94b.

$$ERF = (\frac{\text{minimum MLIP}}{\text{average MLIP}})^x \quad (7\text{–}94b)$$

In systems where the variations in pressure are relatively small and the emitter discharge exponent $(x) \cong 0.5$, the two methods for computing ERF give essentially equal results; however, for variations in pressure greater than 0.2 times the average emitter pressure head (h_a) or x values higher than 0.6 or lower than 0.4, the differences may be significant.

The value of x can be estimated from field data as follows:

Step 1. Determine the average discharge and pressure of a group of at least six emitters along a lateral where the operating pressure is uniform.

Step 2. Reduce the operating pressure by adjusting the lateral inlet valve, and again determine the average discharge and pressure of the same group of emitters.

Step 3. Determine x by equation 7–21, using the average discharge and pressure-head values found in steps 1 and 2.

Step 4. Repeat steps 1, 2, and 3 at two other locations and average the x values for the three tests.

The ERF approximately equals the ratio between the average emission-point discharge in the area served by the manifold with the minimum MLIP and the average emission-point discharge for the system. Therefore, the system EU′ can be approximated by equation 7–95.

$$EU' = (ERF)(EU'_m) \quad (7\text{–}95)$$

General criteria for EU′ values for systems that have been operated for one or more seasons are: greater than 90 percent, excellent; between 80 percent and 90 percent, good; 70 to 80 percent, fair; and less than 70 percent, poor.

Gross Application Required

Because trickle irrigation wets only a small portion of the soil volume, the soil moisture deficit (S_{md}) must be replaced frequently. It is always difficult to estimate S_{md} because some regions of the wetted part of the root zone often remain near field capacity even when the interval between irrigations is several days. For this reason, S_{md} must be estimated from weather data or from information obtained from evaporation devices. Such estimates are subject to error, and because there is no practical way to check for slight underirrigation, some margin for safety should be allowed. As a general rule, the minimum gross depth of application (F_g) should be equal to or slightly greater than the values obtained by equation 7–8a or 7–8b.

When estimating F_g by equation 7–8a or 7–8b for scheduling irrigations, let EU be the field value (EU′) and estimate the net depth of irrigation to apply (F_n) as follows:

1. Estimate the depth of water that could have been consumed by a full-canopy crop since the previous irrigation (F'_n), inches. This can be estimated by standard techniques based on weather data or pan evaporation data.
2. Subtract the depth of effective rainfall since the last irrigation (R'_e), inches.
3. Calculate F_n by equation 7–96.

$$F_n = (F'_n - R'_e)[\frac{P_s}{100} + 0.15(1.0 - \frac{P_s}{100})] \quad (7\text{–}96)$$

Where

P_s = percent shaded.

Using F_g computed by equation 7–8a or 7–8b, the average daily gross volume of water required per plant per day $[F_{(gp/d)}]$ can be computed by equation 7–9.

The average volume of water actually being applied per plant each day $[F'_{(gp/d)}]$ is computed by equation 7–92. If $F_{(gp/d)} < F'_{(gp/d)}$, the field is being overirrigated, and if $F_{(gp/d)} > F'_{(gp/d)}$, it is underirrigated.

Application Efficiencies

A concept called "potential application efficiency" (of the low quarter) (PE_{lq}) is useful for estimating how well a system can perform. It is a function of the peak-use transpiration ratio (T_r), the leaching requirement (LR_t), and the uniformity of field emission (EU′). When the unavoidable water losses are greater than the leaching water requirements, T_r >

$1/(1.0 - LR_t)$, PE_{lq} can be computed by equation 7–97a

$$PE_{lq} = \frac{EU'}{T_r(1.0 - LR_t)} \qquad \textbf{(7–97a)}$$

and when $T_r < 1/(1.0 - LR_t)$, PE_{lq} can be computed by equation 7–97b.

$$PE_{lq} = EU' \qquad \textbf{(7–97b)}$$

The values of T_r appear in conjunction with equation 7–8a, and those of LR_t, with equation 7–16.

A trickle irrigation system has no field boundary effects or pressure variations along the manifold tested that are not taken into account in the field estimate of EU′. Therefore, the PE_{lq} estimated with the system EU′ is an overall value for the field, except for possible minor water losses from leaks, draining of lines, and flushing (unless leaks are excessive) (see equation 7–95).

The system PE_{lq} may be low because the manifold inlet pressures are not properly set and ERF (see equations 7–94a and 7–94b) is low. In such a system the manifold inlet pressures should be adjusted to increase the uniformity of pressure and consequently ERF. When an area is overirrigated, the actual application efficiency of the low quarter (E_{lq}) is less than PE_{lq}. In such areas the E_{lq} can be estimated by equation 7–98.

$$E_{lq} = \frac{100G}{F'_{(gp/d)}} \qquad \textbf{(7–98)}$$

Where

G	=	gross water required per plant during the peak use period, gallons per day.
$F'_{(gp/d)}$	=	average volume of water applied per plant per day, gallons per day.

When an area is underirrigated and $F'_{(gp/d)}$ is less than the average daily gross volume of water required per plant per day $[F_{(gp/d)}]$, then E_{lq} will approach the system EU′. In such areas the LR_t, the T_r, or both will not be satisfied. This may cause either excessive buildup of salt along the perimeters of wetted areas or a reduced volume of wetted soil.

Appendix A—Nomenclature

a = flow cross-section area (square inches)
A = field area under the system (acres)
A_f = system flow-rate adjustment factor
A_s = soil surface area directly wetted by the sprayer (square feet)
A_w = horizontal area wetted about 1 ft below soil surface (square feet)

BHP = brake horsepower

c = concentration of the desired component in liquid chemical concentrate (percent)
c = number of pipe sizes used in the manifold
C = desired dosage of chlorine or acid (parts per million)
C = friction coefficient for continuous section of pipe
C = cost of the irrigation system
c_q = coefficient that depends on the characteristics of the nozzle
c_t = required tank capacity (gallons)
C_{whp} = annual cost per water horsepower (dollars per water horsepower-season)
CRF = capital recovery factor

d = flow cross-section diameter (inches)
D = inside diameter of pipe (inches)
DCF = discharge correction factor

e = number of emission points or sprayers per plant
e' = minimum number of emitters or sprayers from which each plant can obtain water
E = present annual power cost
E' = equivalent annual cost of the rising (9 percent per year) energy cost
E_{lq} = actual application efficiency of the low quarter
E_p = pump efficiency
E_s = seasonal irrigation efficiency
EAE(r) = equivalent annualized factor of the rising energy cost at rate r
EC_{dw} = electrical conductivity of the drainage effluent (mmhos per centimeter)
EC_e = electrical conductivity of the saturated extract (mmhos per centimeter)
EC_w = electrical conductivity of the irrigation water (mmhos per centimeter)
$\triangle El$ = change in elevation; positive for laterals running uphill from the inlet and negative for downhill laterals (feet)
$\triangle El$ = difference in elevation between the pump and manifold; positive if uphill to manifold and negative if downhill (feet)
ERF = efficiency reduction factor
EU = design emission uniformity (percent)
EU′ = uniformity of field emission (percent)
EU'_m = field emission uniformity of the manifold area tested (percent)

f = Darcy-Weisbach pipe-friction factor
F = reduction coefficient to compensate for the discharge along the pipe
F'_a = average depth applied per irrigation to the total cropped area (inches)
F_{an} = annual net depth of application (inches)
F'_{aw} = average depth applied per irrigation to the wetted area (inches)
F_c = concentration of nutrients in liquid fertilizer (pounds per gallon)
f_e = emitter-connection loss equivalent length (feet)
F_g = gross depth of application at each irrigation (inches)
$F_{(gal/d)}$ = gross volume of water required per day (gallons per day)
$F_{(gp/d)}$ = average volume of water applied per plant per day (gallons per day)
F_{mn} = maximum net depth of application (inches)
F_n = net application rate (inches per hour)
F_n = net depth of application (inches)
F'_n = depth of water consumed by full canopy crop since previous irrigation (inches)
F_r = rate of fertilizing (pounds per acre)
F_s = manifold pipe-friction adjustment factor
$(F_s)_1$ = friction adjustment factor for the original manifold
$(F_s)_2$ = friction adjustment factor for the manifold for which $(H_f)_2$ is being estimated
$F_{(sg)}$ = gross seasonal depth of application (inches)

g = acceleration of gravity (32.2 feet per second squared)
G = gross water required per plant during the peak use period (gallons per day)

h = working pressure head of inner main chamber (feet)
h = working pressure head at the emitter (pounds per square inch)
H = time of actual irrigating per irrigation cycle (hours)

$\triangle H$ = desired pressure-head increase between two points (feet)
$\triangle h$ = difference in pressure head along the laterals (feet)
$\triangle h'$ = amount the lateral inlet pressure differs from h_a (feet)
$(100\ \triangle h/L)'$ = maximum scalar distance between the friction curve and the ground surface line in the graphical solution
h_a = pressure head that will give the q_a (feet)
H_a = average manifold pressure
h_c = pressure head at the closed end of the lateral (feet)
$\triangle h_c$ = difference between the downstream-end and minimum pressure heads (feet)
h_e = friction head loss caused by a specific fitting (feet)
H_f = pressure-head loss in the manifold from pipe friction (feet)
h_f = lateral head loss from pipe friction (feet)
$\sum_{1}^{m} h_f$ = sum of the pipe-friction losses between the pump and manifold inlet at m (feet)
$(h_f)_a$ = original lateral pipe-friction loss (feet)
$(h_f)_b$ = new lateral pipe-friction loss (feet)
$h_{f(a,b)}$ = difference in head loss between adjacent pipes of different sizes (feet)
$(H_{fe})_m$ = pressure head to overcome pipe friction and elevation along the main line (feet)
$(h_f)_m$ = friction loss along the manifold (feet)
h_{fp} = friction loss in a lateral with length (L) (feet)
h_{fx} = head loss from a point "x" to the closed end of a multiple-outlet pipeline (feet)
$(H_f)_1$ = pressure-head loss from pipe friction for the manifold (feet)
$(H_f)_2$ = estimate being made of the pressure-head loss from pipe friction for the manifold (feet)
h_l = lateral inlet pressure that will give h_a (feet)
H_m = manifold inlet pressure head (feet)
$\triangle H_m$ = difference in pressure head along the manifold (feet)
$\triangle H_m'$ = amount the manifold inlet pressure differs from h_1 (feet)
$(\triangle H_m)_a$ = allowable manifold pressure variation (feet)
h_n = pressure head that will give the q_n required to satisfy the EU (feet)
H_r = ratio between fertilizing time and time of actual irrigating per irrigation cycle
$\triangle H_s$ = allowable subunit pressure-head variation that will give an EU reasonably close to the desired design value (feet)

h^1 = working pressure of the secondary chamber (feet)
h_1, h_2 = pressure heads corresponding to q_1, q_2, respectively (pounds per square inch)

i = annual interest rate
I_f = maximum allowable irrigation interval (days)
I_f = design irrigation interval (days)

j = dimensionless allowable head-loss ratio
J = head-loss gradient of a pipe (feet per 100 feet)
j' = $(\triangle H_m)_a$ value properly scaled for the manifold under study (feet)
J' = equivalent head-loss gradient of the lateral with emitters (feet per 100 feet)
J_l = head-loss gradient of the larger pipe (feet per 100 feet)
J_s = head-loss gradient of the smaller pipe (feet per 100 feet)
J_x = J value from Appendix B for the largest flow rate in the table for the required pipe size (feet per 100 feet)
JF' = scalar ratio for field shape
$J'F$ = friction gradient found in step 1 of the graphical solution

k = scale factor for adjusting manifold pressure-head values taken from standard manifold curves
k_d = constant of proportionality (discharge coefficient) that characterizes each emitter
K_f = friction head-loss coefficient for a specific fitting

l = length of a lateral (feet)
L = length of a pipeline (feet)
l' = equivalent length of the lateral with emitter (feet)
l_a = original lateral pipe length (feet)
l_b = new lateral pipe length (feet)
l_c = length of the flow path in the emitter (feet)
L_d = length of pipe with diameter d (feet)
L_m = length of a single manifold (feet)
L_n = net leaching requirement for net application (inches)
L_N = annual leaching requirement for net seasonal application (inches)
L_p = length of a pair of manifolds (feet)
L_s = length of the smaller pipe that will increase the head loss by $\triangle H$ (feet)
LR_t = leaching requirement ratio

L_1 = length of pipe in the original manifold (feet)
L_2 = length of pipe in the manifold for which $(H_f)_2$ is being estimated (feet)

m = number of orifices in the secondary chamber per orifice in the main chamber
m′ = number of orifices in series in the emitter
M_{ad} = management-allowed deficit, which is the desired soil-moisture deficit at the time of irrigation (percent)
MLIP = minimum lateral inlet pressure (pounds per square inch)
average MLIP = average of the individual MLIP's along each manifold (pounds per square inch)
minimum MLIP = lowest lateral inlet pressure in the system (pounds per square inch)

n = number of emitters in the sample
n = expected life of the item (years)
N = number of operating stations
n_e = number of emitters along the lateral
$(n_p)_a$ = number of plants in the average row in the subunit
$(n_p)_c$ = number of plants in the row at the closed end of the manifold
n_r = number of row (or lateral) spacings served by the manifold
N_R = Reynolds number
$(n_r)_p$ = number of row (or lateral) spacings served from a common inlet point

P_c = pipe cost (dollars per pound)
P_s = average horizontal area shaded by the crop canopy as a percentage of the total crop area (percent)
P_u = unit of power
P_{uc} = unit cost of power (dollars per kilowatt hour)
P_w = average horizontal area wetted in the top part of the crop root zone as a percentage of the total crop area (percent)
PE_{lq} = potential application efficiency of the lower quarter
PS = perimeter of the area directly wetted by a sprayer (feet)
PW(r) = present worth factor with energy cost rising at rate r

q = emitter discharge rate (gallons per hour)
$\bar{q}$ = average discharge rate of the emitter sampled (gallons per hour)

Q = flow rate in the pipe (gallons per minute)
q_a = average of design emitter discharge rate (gallons per hour)
q_a' = average of all the field-data emitter discharges (gallons per hour)
q_c = rate of injection of the chemical into the system (gallons per hour)
q_d = upper limit flow rate for the pipe with diameter d (gallons per minute)
q_{d-1} = upper limit flow rate for the pipe with the next smaller diameter (gallons per minute)
q_f = rate of injection of liquid fertilizer into the system (gallons per hour)
q_l = lateral flow rate (gallons per minute)
$(q_l)_a$ = average lateral (pair) flow rate along the manifold (gallons per minute)
$(q_l)_c$ = flow rate into the lateral (pair) at the closed end of the manifold (gallons per minute)
q_{lp} = flow rate for pair of laterals (gallons per minute)
q_m = flow rate in the manifold (gallons per minute)
q_n = minimum emission rate computed from the minimum pressure in the system (gallons per hour)
q_n' = average discharge of the lowest quarter of the field-data discharge reading (gallons per hour)
Q_s = total system capacity or flow rate (gallons per minute)
Q_s' = adjusted flow rate for entering the economic design chart (gallons per minute)
Q_s'' = modified adjusted system flow rate (gallons per minute)
Q_t = average pump-operating time per season (hours)
q_x = largest flow rate (Q) in the respective table for pipe size in Appendix B (gallons per minute)
q_1 = flow rate in the original manifold (gallons per minute)
q_2 = flow rate in the manifold for which $(H_f)_2$ is being estimated (gallons per minute)
q_1, q_2 = discharges (gallons per hour)
$q_1, q_2 \ldots q_n$ = individual emitter discharge rates (gallons per hour)

r = annual rate of rising energy cost
R_e = effective rainfall during the growing season (inches)
R_e' = effective rainfall since the last irrigation (inches)

RZD = depth of the soil profile occupied by plant roots (feet)

S = unbiased standard deviation of the discharge rates of the sample
S = average slope of the ground line (percent)
S = slope of the manifold or lateral (feet per foot)
S′ = unusable slope component, which is the amount the friction curve needs to be raised (feet)
S′ = elevation (due to the slope, S, along the manifold) properly scaled for the manifold under study (feet)
S_e = spacing between emitters or emission points along a line (feet)
S_e' = optimum emitter spacing; drip emitter spacing that provides 80 percent of the wetted diameter estimated from field tests or table 7–2 (feet)
S_f = shape factor of the subunit
S_l = lateral spacing (feet)
S_m = manifold spacing (feet)
S_{md} = soil moisture deficit; difference between field capacity and the actual soil moisture in the root zone soil at any given time (inches)
S_p = plant spacing in the row (feet)
S_r = row spacing (feet)
S_w = width of the wetted strip (feet)
sg = specific gravity of the chemical concentrate

T_a = irrigation application time required during the peak use period (hours per day)
T_d = average daily transpiration rate for the month of greatest water use (inches per day)
T_r = peak-use period transpiration ratio
T_R = seasonal transpiration ratio
T_s = seasonal transpiration (inches)
TDH = total dynamic head (feet)
TDR = temperature-discharge ratio

U = seasonal total crop consumptive use (inches)
u_d = average daily consumptive-use rate for the month of greatest overall water use (inches per day)
u_m = total consumptive use rate for month (inches)

v = coefficient of manufacturing variation of the emitter
v = velocity of flow in the pipe (feet per second)
V_i = gross seasonal volume of irrigation water required (acre-feet)
V_s = system coefficient of manufacturing variation
$V^2/2g$ = velocity head: the energy head from the velocity of flow (feet)

W_s = residual stored moisture from off-season precipitation (inches)
WHC = water-holding capacity of the soil (inches per foot)

x = emitter discharge exponent
x = any position along the length
x = distance from the closed end (feet)
x/L = relative distance from the closed downstream end compared to the total length of a pair of laterals or manifolds

Y = theoretical reduction in yield (percent)
Y = tangent location

z = location of the inlet to the pair of laterals that gives equal minimum pressures in both the uphill and downhill members (ratio of the length of the downhill lateral to L)

ν = kinematic viscosity of water (feet squared per second)

Appendix B—Pipe Friction-Loss Tables (Smallest Standard Dimension Ratio Numbers)

Appendix Table 7-1.—Friction loss in trickle irrigation hose, nominal diameter 0.580 in.

[Inside diameter 0.580 in., discharge increment 0.05 gal/min]

Flow (Q) gal/min	Flow (Q) gal/hr	Friction loss (J) ft/100 ft
.05	3.00	.03
.10	6.00	.05
.15	9.00	.08
.20	12.00	.11
.25	15.00	.14
.30	18.00	.17
.35	21.00	.20
.40	24.00	.37
.45	27.00	.45
.50	30.00	.53
.55	33.00	.62
.60	36.00	.72
.65	39.00	.83
.70	42.00	.94
.75	45.00	1.06
.80	48.00	1.18
.85	51.00	1.31
.90	54.00	1.45
.95	57.00	1.59
1.00	60.00	1.73
1.05	63.00	1.88
1.10	66.00	2.04
1.15	69.00	2.20
1.20	72.00	2.37
1.25	75.00	2.54
1.30	78.00	2.72
1.35	81.00	2.90
1.40	84.00	3.09
1.45	87.00	3.28
1.50	90.00	3.48
1.55	93.00	3.68
1.60	96.00	3.89
1.65	99.00	4.10
1.70	102.00	4.32
1.75	105.00	4.54
1.80	108.00	4.77
1.85	111.00	5.00
1.90	114.00	5.24
1.95	117.00	5.48
2.00	120.00	5.73
2.05	123.00	5.98
2.10	126.00	6.24
2.15	129.00	6.50
2.20	132.00	6.76
2.25	135.00	7.03
2.30	138.00	7.31
2.35	141.00	7.58
2.40	144.00	7.87
2.45	147.00	8.16
2.50	150.00	8.45
2.55	153.00	8.75
2.60	156.00	9.05
2.65	159.00	9.35
2.70	162.00	9.66
2.75	165.00	9.98
2.80	168.00	10.30
2.85	171.00	10.62
2.90	174.00	10.95
2.95	177.00	11.28
3.00	180.00	11.62
3.05	183.00	11.96
3.10	186.00	12.30
3.15	189.00	12.65
3.20	192.00	13.01
3.25	195.00	13.36
3.30	198.00	13.73
3.35	201.00	14.09
3.40	204.00	14.46
3.45	207.00	14.84
3.50	210.00	15.22
3.55	213.00	15.60
3.60	216.00	15.99
3.65	219.00	16.38
3.70	222.00	16.77
3.75	225.00	17.17
3.80	228.00	17.58
3.85	231.00	17.99
3.90	234.00	18.40
3.95	237.00	18.81
4.00	240.00	19.23
4.05	243.00	19.66
4.10	246.00	20.09
4.15	249.00	20.52
4.20	252.00	20.96
4.25	255.00	21.40
4.30	258.00	21.84
4.35	261.00	22.29
4.40	264.00	22.74
4.45	267.00	23.20
4.50	270.00	23.66
4.55	273.00	24.13
4.60	276.00	24.59
4.65	279.00	25.07
4.70	282.00	25.54
4.75	285.00	26.02
4.80	288.00	26.51
4.85	291.00	27.00
4.90	294.00	27.49
4.95	297.00	27.99
5.00	300.00	28.49
5.05	303.00	28.99
5.10	306.00	29.50
5.15	309.00	30.01
5.20	312.00	30.52
5.25	315.00	31.04
5.30	318.00	31.57
5.35	321.00	32.09
5.40	324.00	32.63
5.45	327.00	33.15
5.50	330.00	33.70
5.55	333.00	34.24
5.60	336.00	34.79
5.65	339.00	35.34
5.70	342.00	35.89
5.75	345.00	36.45
5.80	348.00	37.01
5.85	351.00	37.58
5.90	354.00	38.15
5.95	357.00	38.72
6.00	360.00	39.30
6.05	363.00	39.88
6.10	366.00	40.46
6.15	369.00	41.05
6.20	372.00	41.64
6.25	375.00	42.24
6.30	378.00	42.84
6.35	381.00	43.44
6.40	384.00	44.05
6.45	387.00	44.66
6.50	390.00	45.27
6.55	393.00	45.89
6.60	396.00	46.51
6.65	399.00	47.13
6.70	402.00	47.76
6.75	405.00	48.40
6.80	408.00	49.03
6.85	411.00	49.67
6.90	414.00	50.32
6.95	417.00	50.96
7.00	420.00	51.61
7.05	423.00	52.27
7.10	426.00	52.93
7.15	429.00	53.59
7.20	432.00	54.25
7.25	435.00	54.92
7.30	438.00	55.60
7.35	441.00	56.27
7.40	444.00	56.95
7.45	447.00	57.64
7.50	450.00	58.32
7.55	453.00	59.01
7.60	456.00	59.71
7.65	459.00	60.41
7.70	462.00	61.11
7.75	465.00	61.81
7.80	468.00	62.52
7.85	471.00	63.23
7.90	474.00	63.95
7.95	477.00	64.67
8.00	480.00	65.39

Appendix Table 7-2.—Friction loss in polyvinyl chloride (iron pipe size) hose, nominal diameter 1.25 in.

[Inside diameter 1.532 in., discharge increment 0.50 gal/min]

Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft	Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft	Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft
.50	.09	.01	29.50	5.13	6.42	58.00	10.09	21.50
1.00	.17	.01	30.00	5.22	6.62	58.50	10.18	21.84
1.50	.26	.04	30.50	5.31	6.81	59.00	10.27	22.17
2.00	.35	.06	31.00	5.39	7.01	59.50	10.35	22.51
2.50	.43	.09	31.50	5.48	7.22	60.00	10.44	22.85
3.00	.52	.12	32.00	5.57	7.42	60.50	10.53	23.20
3.50	.61	.15	32.50	5.65	7.63	61.00	10.61	23.54
4.00	.70	.19	33.00	5.74	7.84	61.50	10.70	23.89
4.50	.78	.24	33.50	5.83	8.05	62.00	10.79	24.24
5.00	.87	.28	34.00	5.92	8.27	62.50	10.87	24.59
5.50	.96	.33	34.50	6.00	8.49	63.00	10.96	24.95
6.00	1.04	.39	35.00	6.09	8.71	63.50	11.05	25.30
6.50	1.13	.45	35.50	6.18	8.93	64.00	11.13	25.66
7.00	1.22	.51	36.00	6.26	9.16	64.50	11.22	26.02
7.50	1.30	.57	36.50	6.35	9.39	65.00	11.31	26.39
8.00	1.39	.64	37.00	6.44	9.62	65.50	11.40	26.75
8.50	1.48	.71	37.50	6.52	9.85	66.00	11.48	27.12
9.00	1.57	.79	38.00	6.61	10.09	66.50	11.57	27.49
9.50	1.65	.87	38.50	6.70	10.32	67.00	11.66	27.86
10.00	1.74	.95	39.00	6.79	10.57	67.50	11.74	28.24
10.50	1.83	1.03	39.50	6.87	10.81	68.00	11.83	28.62
11.00	1.91	1.12	40.00	6.96	11.05	68.50	11.92	29.00
11.50	2.00	1.21	40.50	7.05	11.30	69.00	12.00	29.38
12.00	2.09	1.31	41.00	7.13	11.55	69.50	12.09	29.76
12.50	2.17	1.40	41.50	7.22	11.81	70.00	12.18	30.15
13.00	2.26	1.50	42.00	7.31	12.06	70.50	12.27	30.54
13.50	2.35	1.61	42.50	7.39	12.32	71.00	12.35	30.93
14.00	2.44	1.71	43.00	7.48	12.58	71.50	12.44	31.32
14.50	2.52	1.82	43.50	7.57	12.84	72.00	12.53	31.71
15.00	2.61	1.93	44.00	7.66	13.11	72.50	12.61	32.11
15.50	2.70	2.05	44.50	7.74	13.38	73.00	12.70	32.51
16.00	2.78	2.17	45.00	7.83	13.65	73.50	12.79	32.91
16.50	2.87	2.29	45.50	7.92	13.92	74.00	12.87	33.32
17.00	2.96	2.41	46.00	8.00	14.19	74.50	12.96	33.72
17.50	3.04	2.54	46.50	8.09	14.47	75.00	13.05	34.13
18.00	3.13	2.67	47.00	8.18	14.75	75.50	13.14	34.54
18.50	3.22	2.80	47.50	8.26	15.03	76.00	13.22	34.95
19.00	3.31	2.94	48.00	8.35	15.32	76.50	13.31	35.37
19.50	3.39	3.08	48.50	8.44	15.60	77.00	13.40	35.79
20.00	3.48	3.22	49.00	8.53	15.89	77.50	13.48	36.20
20.50	3.57	3.36	49.50	8.61	16.19	78.00	13.57	36.63
21.00	3.65	3.51	50.00	8.70	16.48	78.50	13.66	37.05
21.50	3.74	3.66	50.50	8.79	16.78	79.00	13.74	37.48
22.00	3.83	3.81	51.00	8.87	17.07	79.50	13.83	37.90
22.50	3.91	3.97	51.50	8.96	17.38	80.00	13.92	38.33
23.00	4.00	4.12	52.00	9.05	17.68	80.50	14.01	38.77
23.50	4.09	4.28	52.50	9.13	17.99	81.00	14.09	39.20
24.00	4.18	4.45	53.00	9.22	18.29	81.50	14.18	39.64
24.50	4.26	4.61	53.50	9.31	18.60	82.00	14.27	40.08
25.00	4.35	4.78	54.00	9.40	18.92	82.50	14.35	40.52
25.50	4.44	4.95	54.50	9.48	19.23	83.00	14.44	40.96
26.00	4.52	5.13	55.00	9.57	19.55	83.50	14.53	41.41
26.50	4.61	5.31	55.50	9.66	19.87	84.00	14.61	41.86
27.00	4.70	5.48	56.00	9.74	20.19	84.50	14.70	42.31
27.50	4.79	5.67	56.50	9.83	20.52	85.00	14.79	42.76
28.00	4.87	5.85	57.00	9.92	20.84	85.50	14.88	43.21
28.50	4.96	6.04	57.50	10.00	21.17	86.00	14.96	43.67
29.00	5.05	6.23						

Appendix Table 7-3.—Friction loss in trickle irrigation hose, nominal diameter 0.700 in.

[Inside diameter 0.700 in., discharge increment 0.10 gal/min]

Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft	Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft	Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft
.10	6.00	.03	5.50	330.00	13.76	10.80	648.00	45.39
.20	12.00	.05	5.60	336.00	14.20	10.90	654.00	46.13
.30	18.00	.08	5.70	342.00	14.65	11.00	660.00	46.89
.40	24.00	.11	5.80	349.00	15.11	11.10	666.00	47.65
.50	30.00	.22	5.90	354.00	15.57	11.20	672.00	48.41
.60	36.00	.30	6.00	360.00	16.04	11.30	678.00	49.18
.70	42.00	.39	6.10	366.00	16.51	11.40	684.00	49.96
.80	48.00	.49	6.20	372.00	17.00	11.50	690.00	50.74
.90	54.00	.60	6.30	378.00	17.43	11.60	696.00	51.53
1.00	60.00	.71	6.40	384.00	17.97	11.70	702.00	52.32
1.10	66.00	.84	6.50	390.00	18.47	11.80	708.00	53.12
1.20	72.00	.98	6.60	396.00	18.98	11.90	714.00	53.92
1.30	78.00	1.12	6.70	402.00	19.49	12.00	720.00	54.73
1.40	84.00	1.27	6.80	403.00	20.00	12.10	726.00	55.54
1.50	90.00	1.43	6.90	414.00	20.53	12.20	732.00	56.36
1.60	96.00	1.60	7.00	420.00	21.05	12.30	738.00	57.19
1.70	102.00	1.78	7.10	426.00	21.59	12.40	744.00	58.02
1.80	103.00	1.96	7.20	432.00	22.13	12.50	750.00	58.85
1.90	114.00	2.15	7.30	438.00	22.67	12.60	756.00	59.69
2.00	120.00	2.35	7.40	444.00	23.23	12.70	762.00	60.54
2.10	126.00	2.56	7.50	450.00	23.79	12.80	768.00	61.39
2.20	132.00	2.77	7.60	456.00	24.35	12.90	774.00	62.25
2.30	138.00	3.00	7.70	462.00	24.92	13.00	780.00	63.11
2.40	144.00	3.23	7.80	468.00	25.49	13.10	796.00	63.97
2.50	150.00	3.46	7.90	474.00	26.07	13.20	792.00	64.85
2.60	156.00	3.71	8.00	480.00	26.66	13.30	798.00	65.72
2.70	162.00	3.96	8.10	486.00	27.25	13.40	804.00	66.61
2.80	163.00	4.22	8.20	492.00	27.85	13.50	910.00	67.49
2.90	174.00	4.48	8.30	498.00	28.45	13.60	816.00	68.39
3.00	180.00	4.76	8.40	504.00	29.06	13.70	822.00	69.29
3.10	186.00	5.04	8.50	510.00	29.68	13.80	828.00	70.19
3.20	192.00	5.33	9.60	516.00	30.30	13.90	834.00	71.10
3.30	198.00	5.62	8.70	522.00	30.93	14.00	840.00	72.01
3.40	204.00	5.92	8.80	528.00	31.56	14.10	846.00	72.93
3.50	210.00	6.23	8.90	534.00	32.20	14.20	852.00	73.85
3.60	216.00	6.54	9.00	540.00	32.84	14.30	858.00	74.78
3.70	222.00	6.86	9.10	546.00	33.49	14.40	864.00	75.72
3.80	228.00	7.19	9.20	552.00	34.15	14.50	870.00	76.66
3.90	234.00	7.53	9.30	558.00	34.81	14.60	876.00	77.60
4.00	240.00	7.87	9.40	564.00	35.47	14.70	882.00	78.55
4.10	246.00	8.21	9.50	570.00	36.14	14.80	888.00	79.51
4.20	252.00	8.57	9.60	576.00	36.82	14.90	894.00	80.47
4.30	258.00	8.93	9.70	582.00	37.51	15.00	900.00	81.44
4.40	264.00	9.30	9.80	588.00	38.19	15.10	906.00	82.41
4.50	270.00	9.67	9.90	594.00	38.89	15.20	912.00	83.38
4.60	276.00	10.05	10.00	600.00	39.59	15.30	918.00	84.36
4.70	282.00	10.44	10.10	605.00	40.29	15.40	924.00	85.35
4.90	294.00	11.23	10.20	612.00	41.00	15.50	930.00	86.34
5.00	300.00	11.64	10.30	613.00	41.72	15.60	936.00	87.34
5.10	306.00	12.05	10.40	624.00	42.44	15.70	942.00	88.34
5.20	312.00	12.47	10.50	630.00	43.17	15.80	943.00	89.34
5.30	318.00	12.89	10.60	636.00	43.90	15.90	954.00	90.36
5.40	324.00	13.32	10.70	642.00	44.64	16.00	960.00	91.37

Appendix Table 7–4.—Friction loss in trickle irrigation hose, nominal diameter 1.5 in.

[Inside diameter 1.754 in., discharge increment 1.00 gal/min]

Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft	Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft
1.00	.13	.01	58.00	7.70	11.24
2.00	.27	.03	59.00	7.83	11.59
3.00	.40	.06	60.00	7.96	11.95
4.00	.53	.10	61.00	8.10	12.31
5.00	.66	.15	62.00	8.23	12.67
6.00	.80	.20	63.00	8.36	13.04
7.00	.93	.27	64.00	8.49	13.41
8.00	1.06	.34	65.00	8.63	13.79
9.00	1.19	.41	66.00	8.76	14.17
10.00	1.33	.50	67.00	8.89	14.56
11.00	1.46	.59	68.00	9.03	14.95
12.00	1.59	.69	69.00	9.16	15.35
13.00	1.73	.79	70.00	9.29	15.75
14.00	1.86	.90	71.00	9.42	16.16
15.00	1.99	1.02	72.00	9.56	16.57
16.00	2.12	1.14	73.00	9.69	16.98
17.00	2.26	1.27	74.00	9.82	17.41
18.00	2.39	1.40	75.00	9.95	17.83
19.00	2.52	1.54	76.00	10.09	18.26
20.00	2.65	1.69	77.00	10.22	18.69
21.00	2.79	1.84	78.00	10.35	19.13
22.00	2.92	2.00	79.00	10.49	19.58
23.00	3.05	2.16	80.00	10.62	20.02
24.00	3.19	2.33	81.00	10.75	20.48
25.00	3.32	2.51	82.00	10.88	20.93
26.00	3.45	2.69	83.00	11.02	21.39
27.00	3.59	2.87	84.00	11.15	21.86
28.00	3.72	3.06	85.00	11.29	22.33
29.00	3.85	3.26	86.00	11.41	22.80
30.00	3.98	3.46	87.00	11.55	23.28
31.00	4.11	3.67	88.00	11.68	23.77
32.00	4.25	3.89	89.00	11.81	24.26
33.00	4.38	4.11	90.00	11.95	24.75
34.00	4.51	4.33	91.00	12.08	25.25
35.00	4.65	4.56	92.00	12.21	25.75
36.00	4.78	4.79	93.00	12.34	26.25
37.00	4.91	5.03	94.00	12.48	26.77
38.00	5.04	5.28	95.00	12.61	27.28
39.00	5.18	5.53	96.00	12.74	27.80
40.00	5.31	5.78	97.00	12.87	28.32
41.00	5.44	6.04	98.00	13.01	28.85
42.00	5.57	6.31	99.00	13.14	29.38
43.00	5.71	6.58	100.00	13.27	29.92
44.00	5.84	6.86	101.00	13.41	30.46
45.00	5.97	7.14	102.00	13.54	31.01
46.00	6.11	7.42	103.00	13.67	31.56
47.00	6.24	7.72	104.00	13.80	32.11
48.00	6.37	8.01	105.00	13.94	32.67
49.00	6.50	8.31	106.00	14.07	33.23
50.00	6.64	8.62	107.00	14.20	33.80
51.00	6.77	8.93	108.00	14.33	34.37
52.00	6.90	9.24	109.00	14.47	34.95
53.00	7.03	9.57	110.00	14.60	35.53
54.00	7.17	9.89	111.00	14.73	36.12
55.00	7.30	10.22	112.00	14.87	36.70
56.00	7.43	10.56	113.00	15.00	37.30
57.00	7.57	10.90			

Appendix Table 7–5.—Friction loss in trickle irrigation hose, nominal diameter 2 in.

[Inside diameter 2.193 in., discharge increment 1.00 gal/min]

Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft	Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft	Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft
1.00	.08	.00	60.00	5.09	4.10	118.00	10.02	13.79
2.00	.17	.01	61.00	5.18	4.22	119.00	10.10	14.01
3.00	.25	.02	62.00	5.26	4.34	120.00	10.19	14.22
4.00	.34	.04	63.00	5.35	4.47	121.00	10.27	14.43
5.00	.42	.05	64.00	5.43	4.60	122.00	10.36	14.65
6.00	.51	.07	65.00	5.52	4.73	123.00	10.44	14.86
7.00	.59	.09	66.00	5.60	4.86	124.00	10.53	15.03
8.00	.68	.12	67.00	5.69	4.99	125.00	10.61	15.30
9.00	.76	.14	68.00	5.77	5.13	126.00	10.70	15.52
10.00	.85	.17	69.00	5.86	5.26	127.00	10.78	15.75
11.00	.93	.20	70.00	5.94	5.40	128.00	10.87	15.97
12.00	1.02	.24	71.00	6.03	5.54	129.00	10.95	16.20
13.00	1.10	.27	72.00	6.11	5.68	130.00	11.04	16.42
14.00	1.19	.31	73.00	6.20	5.82	131.00	11.12	16.65
15.00	1.27	.35	74.00	6.28	5.96	132.00	11.21	16.83
16.00	1.36	.39	75.00	6.37	6.11	133.00	11.29	17.11
17.00	1.44	.44	76.00	6.45	6.26	134.00	11.38	17.35
18.00	1.53	.48	77.00	6.54	6.40	135.00	11.46	17.58
19.00	1.61	.53	78.00	6.62	6.55	136.00	11.55	17.82
20.00	1.70	.58	79.00	6.71	6.71	137.00	11.63	18.05
21.00	1.78	.63	80.00	6.79	6.86	138.00	11.72	18.29
22.00	1.87	.69	81.00	6.88	7.01	139.00	11.80	18.53
23.00	1.95	.74	82.00	6.96	7.17	140.00	11.89	18.77
24.00	2.04	.80	83.00	7.05	7.33	141.00	11.97	19.01
25.00	2.12	.86	84.00	7.13	7.49	142.00	12.06	19.26
26.00	2.21	.93	85.00	7.22	7.65	143.00	12.14	19.50
27.00	2.29	.99	86.00	7.30	7.81	144.00	12.23	19.75
28.00	2.38	1.05	87.00	7.39	7.97	145.00	12.31	20.00
29.00	2.46	1.12	88.00	7.47	8.14	146.00	12.40	20.25
30.00	2.55	1.19	89.00	7.56	8.31	147.00	12.48	20.50
31.00	2.63	1.26	90.00	7.64	8.47	148.00	12.57	20.75
32.00	2.72	1.34	91.00	7.73	8.64	149.00	12.65	21.01
33.00	2.80	1.41	92.00	7.81	8.82	150.00	12.74	21.26
34.00	2.89	1.49	93.00	7.90	8.99	151.00	12.82	21.52
35.00	2.97	1.57	94.00	7.98	9.16	152.00	12.91	21.78
36.00	3.06	1.65	95.00	8.07	9.34	153.00	12.99	22.04
37.00	3.14	1.73	96.00	8.15	9.52	154.00	13.08	22.30
38.00	3.23	1.81	97.00	8.24	9.69	155.00	13.16	22.56
39.00	3.31	1.90	98.00	8.32	9.88	156.00	13.25	22.82
40.00	3.40	1.99	99.00	8.41	10.06	157.00	13.33	23.09
41.00	3.48	2.08	100.00	8.49	10.24	158.00	13.42	23.35
42.00	3.57	2.17	101.00	8.58	10.43	159.00	13.50	23.62
43.00	3.65	2.26	102.00	8.66	10.61	160.00	13.59	23.89
44.00	3.74	2.36	103.00	8.75	10.80	161.00	13.67	24.16
45.00	3.82	2.45	104.00	8.83	10.99	162.00	13.76	24.43
46.00	3.91	2.55	105.00	8.92	11.18	163.00	13.84	24.70
47.00	3.99	2.65	106.00	9.00	11.37	164.00	13.92	24.98
48.00	4.08	2.75	107.00	9.09	11.57	165.00	14.01	25.26
49.00	4.16	2.85	108.00	9.17	11.76	166.00	14.09	25.53
50.00	4.25	2.96	109.00	9.25	11.96	167.00	14.18	25.81
51.00	4.33	3.06	110.00	9.34	12.16	168.00	14.26	26.09
52.00	4.42	3.17	111.00	9.42	12.36	169.00	14.35	26.37
53.00	4.50	3.28	112.00	9.51	12.56	170.00	14.43	26.65
54.00	4.59	3.39	113.00	9.59	12.76	171.00	14.52	26.94
55.00	4.67	3.51	114.00	9.68	12.96	172.00	14.60	27.22
56.00	4.75	3.62	115.00	9.76	13.17	173.00	14.69	27.51
57.00	4.84	3.74	116.00	9.85	13.38	174.00	14.77	27.80
58.00	4.92	3.86	117.00	9.93	13.58	175.00	14.86	28.09
59.00	5.01	3.98						

Appendix Table 7–6.—Friction loss in trickle irrigation hose, nominal diameter 2.5 in.

[Inside diameter 2.655 in., discharge increment 2.00 gal/min]

Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft	Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft	Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft
2.00	.12	.00	88.00	5.10	3.26	174.00	10.08	11.09
4.00	.23	.01	90.00	5.21	3.39	176.00	10.20	11.32
6.00	.35	.03	92.00	5.33	3.52	178.00	10.31	11.56
8.00	.46	.05	94.00	5.45	3.66	180.00	10.43	11.79
10.00	.58	.07	96.00	5.56	3.80	182.00	10.54	12.03
12.00	.70	.10	98.00	5.68	3.95	184.00	10.66	12.27
14.00	.81	.13	100.00	5.79	4.09	186.00	10.77	12.51
16.00	.93	.16	102.00	5.91	4.24	188.00	10.89	12.75
18.00	1.04	.19	104.00	6.02	4.39	190.00	11.01	13.00
20.00	1.16	.23	106.00	6.14	4.55	192.00	11.12	13.25
22.00	1.27	.28	108.00	6.26	4.70	194.00	11.24	13.50
24.00	1.39	.32	110.00	6.37	4.86	196.00	11.35	13.75
26.00	1.51	.37	112.00	6.49	5.02	198.00	11.47	14.01
28.00	1.62	.42	114.00	6.60	5.18	200.00	11.59	14.26
30.00	1.74	.48	116.00	6.72	5.34	202.00	11.70	14.52
32.00	1.85	.54	118.00	6.84	5.51	204.00	11.82	14.78
34.00	1.97	.60	120.00	6.95	5.68	206.00	11.93	15.05
36.00	2.09	.66	122.00	7.07	5.85	208.00	12.05	15.31
38.00	2.20	.73	124.00	7.18	6.02	210.00	12.17	15.58
40.00	2.32	.80	126.00	7.30	6.20	212.00	12.28	15.85
42.00	2.43	.87	128.00	7.41	6.38	214.00	12.40	16.12
44.00	2.55	.94	130.00	7.53	6.56	216.00	12.51	16.39
46.00	2.66	1.02	132.00	7.65	6.74	218.00	12.63	16.67
48.00	2.78	1.10	134.00	7.76	6.93	220.00	12.74	16.94
50.00	2.90	1.19	136.00	7.88	7.11	222.00	12.86	17.22
52.00	3.01	1.27	138.00	7.99	7.30	224.00	12.98	17.51
54.00	3.13	1.36	140.00	8.11	7.50	226.00	13.09	17.79
56.00	3.24	1.45	142.00	8.23	7.69	228.00	13.21	18.08
58.00	3.36	1.54	144.00	8.34	7.89	230.00	13.32	18.36
60.00	3.48	1.64	146.00	8.46	8.08	232.00	13.44	18.65
62.00	3.59	1.74	148.00	8.57	8.28	234.00	13.56	18.95
64.00	3.71	1.84	150.00	8.69	8.49	236.00	13.67	19.24
66.00	3.82	1.95	152.00	8.81	8.69	238.00	13.79	19.54
68.00	3.94	2.05	154.00	8.92	8.90	240.00	13.90	19.83
70.00	4.06	2.16	156.00	9.04	9.11	242.00	14.02	20.13
72.00	4.17	2.27	158.00	9.15	9.32	244.00	14.13	20.44
74.00	4.29	2.39	160.00	9.27	9.53	246.00	14.25	20.74
76.00	4.40	2.50	162.00	9.38	9.75	248.00	14.37	21.05
78.00	4.52	2.62	164.00	9.50	9.97	250.00	14.48	21.35
80.00	4.63	2.74	166.00	9.62	10.19	252.00	14.60	21.67
82.00	4.75	2.87	168.00	9.73	10.41	254.00	14.71	21.98
84.00	4.87	2.99	170.00	9.85	10.64	256.00	14.83	22.29
86.00	4.98	3.12	172.00	9.96	10.86	258.00	14.95	22.61

Appendix Table 7-7.—Friction loss in trickle irrigation hose, nominal diameter 3 in.

[Inside diameter 3.284 in., discharge increment 2.00 gal/min]

Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft	Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft	Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft
2.00	.08	.00	110.00	4.16	1.75	218.00	8.25	6.00
4.00	.15	.01	112.00	4.24	1.81	220.00	8.33	6.10
6.00	.23	.01	114.00	4.32	1.87	222.00	8.41	6.20
8.00	.30	.02	116.00	4.39	1.93	224.00	8.48	6.30
10.00	.38	.03	118.00	4.47	1.99	226.00	8.56	6.40
12.00	.45	.03	120.00	4.54	2.05	228.00	8.63	6.50
14.00	.53	.05	122.00	4.62	2.11	230.00	8.71	6.61
16.00	.61	.06	124.00	4.70	2.17	232.00	8.78	6.71
18.00	.68	.07	126.00	4.77	2.24	234.00	8.86	6.82
20.00	.76	.09	128.00	4.85	2.30	236.00	8.94	6.92
22.00	.83	.10	130.00	4.92	2.37	238.00	9.01	7.03
24.00	.91	.12	132.00	5.00	2.43	240.00	9.09	7.14
26.00	.98	.14	134.00	5.07	2.50	242.00	9.16	7.24
28.00	1.06	.15	136.00	5.15	2.56	244.00	9.24	7.35
30.00	1.14	.17	138.00	5.23	2.63	246.00	9.31	7.46
32.00	1.21	.19	140.00	5.30	2.70	248.00	9.39	7.57
34.00	1.29	.22	142.00	5.38	2.77	250.00	9.47	7.68
36.00	1.36	.24	144.00	5.45	2.84	252.00	9.54	7.79
38.00	1.44	.26	146.00	5.53	2.91	254.00	9.62	7.91
40.00	1.51	.29	148.00	5.60	2.99	256.00	9.69	8.02
42.00	1.59	.32	150.00	5.68	3.06	258.00	9.77	8.13
44.00	1.67	.34	152.00	5.76	3.13	260.00	9.84	8.25
46.00	1.74	.37	154.00	5.83	3.21	262.00	9.92	8.36
48.00	1.82	.40	156.00	5.91	3.28	264.00	10.00	8.48
50.00	1.89	.43	158.00	5.98	3.36	266.00	10.07	8.59
52.00	1.97	.46	160.00	6.06	3.44	268.00	10.15	8.71
54.00	2.04	.49	162.00	6.13	3.51	270.00	10.22	8.83
56.00	2.12	.53	164.00	6.21	3.59	272.00	10.30	8.95
58.00	2.20	.56	166.00	6.29	3.67	274.00	10.37	9.07
60.00	2.27	.59	168.00	6.36	3.75	276.00	10.45	9.19
62.00	2.35	.63	170.00	6.44	3.83	278.00	10.53	9.31
64.00	2.42	.67	172.00	6.51	3.91	280.00	10.60	9.43
66.00	2.50	.70	174.00	6.59	4.00	282.00	10.68	9.55
68.00	2.57	.74	176.00	6.66	4.08	284.00	10.75	9.67
70.00	2.65	.78	178.00	6.74	4.16	286.00	10.83	9.80
72.00	2.73	.82	180.00	6.82	4.25	288.00	10.90	9.92
74.00	2.80	.86	182.00	6.89	4.33	290.00	10.98	10.05
76.00	2.88	.90	184.00	6.97	4.42	292.00	11.06	10.17
78.00	2.95	.95	186.00	7.04	4.51	294.00	11.13	10.30
80.00	3.03	.99	188.00	7.12	4.59	296.00	11.21	10.43
82.00	3.10	1.04	190.00	7.19	4.68	298.00	11.28	10.55
84.00	3.18	1.08	192.00	7.27	4.77	300.00	11.36	10.68
86.00	3.25	1.13	194.00	7.35	4.86	302.00	11.43	10.81
88.00	3.33	1.18	196.00	7.42	4.95	304.00	11.51	10.94
90.00	3.41	1.22	198.00	7.50	5.04	306.00	11.59	11.07
92.00	3.48	1.27	200.00	7.57	5.13	308.00	11.66	11.20
94.00	3.56	1.32	202.00	7.65	5.23	310.00	11.74	11.34
96.00	3.63	1.37	204.00	7.72	5.32	312.00	11.81	11.47
98.00	3.71	1.43	206.00	7.80	5.42	314.00	11.89	11.60
100.00	3.79	1.48	208.00	7.88	5.51	316.00	11.96	11.74
102.00	3.86	1.53	210.00	7.95	5.61	318.00	12.04	11.87
104.00	3.94	1.59	212.00	8.03	5.70	320.00	12.12	12.01
106.00	4.01	1.64	214.00	8.10	5.80	322.00	12.19	12.14
108.00	4.09	1.70	216.00	8.18	5.90	324.00	12.27	12.28

Appendix Table 7-8.—Friction loss in trickle irrigation hose, nominal diameter 4 in.

[Inside diameter 4.280 in., discharge increment 5.00 gal/min]

Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft	Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft	Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft
5.00	.11	.00	230.00	5.13	1.85	455.00	10.14	6.35
10.00	.22	.01	235.00	5.24	1.92	460.00	10.25	6.48
15.00	.33	.01	240.00	5.35	2.00	465.00	10.37	6.61
20.00	.45	.02	245.00	5.46	2.07	470.00	10.48	6.74
25.00	.56	.04	250.00	5.57	2.15	475.00	10.59	6.87
30.00	.67	.05	255.00	5.68	2.23	480.00	10.70	7.00
35.00	.78	.06	260.00	5.80	2.31	485.00	10.81	7.13
40.00	.89	.08	265.00	5.91	2.39	490.00	10.92	7.26
45.00	1.00	.10	270.00	6.02	2.47	495.00	11.03	7.40
50.00	1.11	.12	275.00	6.13	2.55	500.00	11.15	7.53
55.00	1.23	.14	280.00	6.24	2.64	505.00	11.26	7.67
60.00	1.34	.17	285.00	6.35	2.72	510.00	11.37	7.81
65.00	1.45	.19	290.00	6.46	2.81	515.00	11.48	7.95
70.00	1.56	.22	295.00	6.58	2.90	520.00	11.59	8.09
75.00	1.67	.25	300.00	6.69	2.99	525.00	11.70	8.23
80.00	1.78	.28	305.00	6.80	3.08	530.00	11.81	8.38
85.00	1.89	.31	310.00	6.91	3.17	535.00	11.93	8.52
90.00	2.01	.34	315.00	7.02	3.26	540.00	12.04	8.66
95.00	2.12	.38	320.00	7.13	3.36	545.00	12.15	8.81
100.00	2.23	.42	325.00	7.24	3.45	550.00	12.26	8.96
105.00	2.34	.45	330.00	7.36	3.55	555.00	12.37	9.11
110.00	2.45	.49	335.00	7.47	3.65	560.00	12.48	9.26
115.00	2.56	.53	340.00	7.58	3.75	565.00	12.59	9.41
120.00	2.67	.58	345.00	7.69	3.85	570.00	12.71	9.56
125.00	2.79	.62	350.00	7.80	3.95	575.00	12.82	9.71
130.00	2.90	.65	355.00	7.91	4.05	580.00	12.93	9.86
135.00	3.01	.71	360.00	8.02	4.16	585.00	13.04	10.02
140.00	3.12	.76	365.00	8.14	4.26	590.00	13.15	10.18
145.00	3.23	.81	370.00	8.25	4.37	595.00	13.26	10.33
150.00	3.34	.86	375.00	8.36	4.47	600.00	13.37	10.49
155.00	3.46	.91	380.00	8.47	4.58	605.00	13.48	10.65
160.00	3.57	.96	385.00	8.58	4.69	610.00	13.60	10.81
165.00	3.68	1.02	390.00	8.69	4.80	615.00	13.71	10.97
170.00	3.79	1.07	395.00	8.81	4.92	620.00	13.82	11.14
175.00	3.90	1.13	400.00	8.92	5.03	625.00	13.93	11.30
180.00	4.01	1.19	405.00	9.03	5.14	630.00	14.04	11.46
185.00	4.12	1.25	410.00	9.14	5.26	635.00	14.16	11.63
190.00	4.24	1.31	415.00	9.25	5.38	640.00	14.27	11.80
195.00	4.35	1.38	420.00	9.36	5.49	645.00	14.38	11.96
200.00	4.46	1.44	425.00	9.47	5.61	650.00	14.49	12.13
205.00	4.57	1.50	430.00	9.58	5.73	655.00	14.60	12.30
210.00	4.68	1.57	435.00	9.70	5.85	660.00	14.71	12.48
215.00	4.79	1.64	440.00	9.81	5.98	665.00	14.82	12.65
220.00	4.90	1.71	445.00	9.92	6.10	670.00	14.94	12.82
225.00	5.02	1.78	450.00	10.03	6.22			

Appendix Table 7-9.—Friction loss in trickle irrigation hose, nominal diameter 6 in.

[Inside diameter 6.301 in., discharge increment 5.00 gal/min]

Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft	Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft	Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft
5.00	.05	.00	275.00	2.83	.40	545.00	5.61	1.37
10.00	.10	.00	280.00	2.88	.41	550.00	5.66	1.39
15.00	.15	.00	285.00	2.93	.43	555.00	5.71	1.42
20.00	.21	.00	290.00	2.98	.44	560.00	5.76	1.44
25.00	.26	.01	295.00	3.03	.45	565.00	5.81	1.46
30.00	.31	.01	300.00	3.09	.47	570.00	5.86	1.49
35.00	.36	.01	305.00	3.14	.48	575.00	5.91	1.51
40.00	.41	.01	310.00	3.19	.49	580.00	5.97	1.53
45.00	.46	.02	315.00	3.24	.51	585.00	6.02	1.56
50.00	.51	.02	320.00	3.29	.52	590.00	6.07	1.58
55.00	.57	.02	325.00	3.34	.54	595.00	6.12	1.61
60.00	.62	.03	330.00	3.39	.55	600.00	6.17	1.63
65.00	.67	.03	335.00	3.45	.57	605.00	6.22	1.65
70.00	.72	.03	340.00	3.50	.58	610.00	6.27	1.68
75.00	.77	.04	345.00	3.55	.60	615.00	6.33	1.70
80.00	.82	.04	350.00	3.60	.62	620.00	6.38	1.73
85.00	.87	.05	355.00	3.65	.63	625.00	6.43	1.76
90.00	.93	.05	360.00	3.70	.65	630.00	6.48	1.78
95.00	.98	.06	365.00	3.75	.66	635.00	6.53	1.81
100.00	1.03	.07	370.00	3.81	.68	640.00	6.58	1.83
105.00	1.08	.07	375.00	3.86	.70	645.00	6.63	1.86
110.00	1.13	.08	380.00	3.91	.71	650.00	6.69	1.88
115.00	1.18	.08	385.00	3.96	.73	655.00	6.74	1.91
120.00	1.23	.09	390.00	4.01	.75	660.00	6.79	1.94
125.00	1.29	.10	395.00	4.06	.77	665.00	6.84	1.96
130.00	1.34	.10	400.00	4.11	.78	670.00	6.89	1.99
135.00	1.39	.11	405.00	4.17	.80	675.00	6.94	2.02
140.00	1.44	.12	410.00	4.22	.82	680.00	6.99	2.05
145.00	1.49	.13	415.00	4.27	.84	685.00	7.05	2.07
150.00	1.54	.13	420.00	4.32	.86	690.00	7.10	2.10
155.00	1.59	.14	425.00	4.37	.87	695.00	7.15	2.13
160.00	1.65	.15	430.00	4.42	.89	700.00	7.20	2.16
165.00	1.70	.16	435.00	4.47	.91	705.00	7.25	2.18
170.00	1.75	.17	440.00	4.53	.93	710.00	7.30	2.21
175.00	1.80	.18	445.00	4.58	.95	715.00	7.35	2.24
180.00	1.85	.19	450.00	4.63	.97	720.00	7.41	2.27
185.00	1.90	.20	455.00	4.68	.99	725.00	7.46	2.30
190.00	1.95	.21	460.00	4.73	1.01	730.00	7.51	2.33
195.00	2.01	.22	465.00	4.78	1.03	735.00	7.56	2.36
200.00	2.06	.23	470.00	4.83	1.05	740.00	7.61	2.38
205.00	2.11	.24	475.00	4.89	1.07	745.00	7.66	2.41
210.00	2.16	.25	480.00	4.94	1.09	750.00	7.71	2.44
215.00	2.21	.26	485.00	4.99	1.11	755.00	7.77	2.47
220.00	2.26	.27	490.00	5.04	1.13	760.00	7.82	2.50
225.00	2.31	.28	495.00	5.09	1.15	765.00	7.87	2.53
230.00	2.37	.29	500.00	5.14	1.17	770.00	7.92	2.56
235.00	2.42	.30	505.00	5.19	1.19	775.00	7.97	2.59
240.00	2.47	.31	510.00	5.25	1.21	780.00	8.02	2.62
245.00	2.52	.32	515.00	5.30	1.24	785.00	8.07	2.65
250.00	2.57	.34	520.00	5.35	1.26	790.00	8.13	2.68
255.00	2.62	.35	525.00	5.40	1.28	795.00	8.18	2.72
260.00	2.67	.36	530.00	5.45	1.30	800.00	8.23	2.75
265.00	2.73	.37	535.00	5.50	1.32	805.00	8.28	2.78
270.00	2.78	.39	540.00	5.55	1.35	810.00	8.33	2.81

Appendix Table 7–10.—Friction loss in trickle irrigation hose, nominal diameter 8 in.

[Inside diameter 8.205 in., discharge increment 10.00 gal/min]

Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft	Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft	Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft
10.00	.06	.00	550.00	3.34	.39	1090.00	6.61	1.35
20.00	.12	.00	560.00	3.40	.40	1100.00	6.67	1.37
30.00	.18	.00	570.00	3.46	.42	1110.00	6.73	1.40
40.00	.24	.00	580.00	3.52	.43	1120.00	6.79	1.42
50.00	.30	.01	590.00	3.58	.44	1130.00	6.85	1.44
60.00	.36	.01	600.00	3.64	.46	1140.00	6.91	1.47
70.00	.42	.01	610.00	3.70	.47	1150.00	6.98	1.49
80.00	.49	.01	620.00	3.76	.49	1160.00	7.04	1.51
90.00	.55	.02	630.00	3.82	.50	1170.00	7.10	1.53
100.00	.61	.02	640.00	3.88	.51	1180.00	7.16	1.56
110.00	.67	.02	650.00	3.94	.53	1190.00	7.22	1.58
120.00	.73	.03	660.00	4.00	.54	1200.00	7.28	1.60
130.00	.79	.03	670.00	4.06	.56	1210.00	7.33	1.64
140.00	.85	.03	680.00	4.12	.57	1220.00	7.39	1.66
150.00	.91	.04	690.00	4.19	.59	1230.00	7.45	1.68
160.00	.97	.04	700.00	4.25	.61	1240.00	7.51	1.71
170.00	1.03	.05	710.00	4.31	.62	1250.00	7.58	1.73
180.00	1.09	.05	720.00	4.37	.64	1260.00	7.64	1.76
190.00	1.15	.06	730.00	4.43	.65	1270.00	7.70	1.78
200.00	1.21	.06	740.00	4.49	.67	1280.00	7.76	1.81
210.00	1.27	.07	750.00	4.55	.69	1290.00	7.82	1.83
220.00	1.33	.08	760.00	4.61	.70	1300.00	7.88	1.86
230.00	1.40	.08	770.00	4.67	.72	1310.00	7.95	1.89
240.00	1.46	.09	780.00	4.73	.74	1320.00	8.01	1.91
250.00	1.52	.09	790.00	4.79	.75	1330.00	8.07	1.94
260.00	1.58	.10	800.00	4.85	.77	1340.00	8.13	1.97
270.00	1.64	.11	810.00	4.91	.79	1350.00	8.19	1.99
280.00	1.70	.12	820.00	4.97	.81	1360.00	8.25	2.02
290.00	1.76	.12	830.00	5.03	.82	1370.00	8.31	2.05
300.00	1.82	.13	840.00	5.10	.84	1380.00	8.37	2.07
310.00	1.88	.14	850.00	5.16	.86	1390.00	8.43	2.10
320.00	1.94	.15	860.00	5.22	.88	1400.00	8.49	2.13
330.00	2.00	.16	870.00	5.28	.90	1410.00	8.55	2.16
340.00	2.06	.16	880.00	5.34	.92	1420.00	8.61	2.18
350.00	2.12	.17	890.00	5.40	.93	1430.00	8.67	2.21
360.00	2.18	.18	900.00	5.46	.95	1440.00	8.73	2.24
370.00	2.24	.19	910.00	5.52	.97	1450.00	8.80	2.27
380.00	2.30	.20	920.00	5.58	.99	1460.00	8.86	2.30
390.00	2.37	.21	930.00	5.64	1.01	1470.00	8.92	2.33
400.00	2.43	.22	940.00	5.70	1.03	1480.00	8.98	2.36
410.00	2.49	.23	950.00	5.76	1.05	1490.00	9.04	2.38
420.00	2.55	.24	960.00	5.82	1.07	1500.00	9.10	2.41
430.00	2.61	.25	970.00	5.88	1.09	1510.00	9.16	2.44
440.00	2.67	.26	980.00	5.94	1.11	1520.00	9.22	2.47
450.00	2.73	.27	990.00	6.00	1.13	1530.00	9.28	2.50
460.00	2.79	.28	1000.00	6.07	1.15	1540.00	9.34	2.53
470.00	2.85	.29	1010.00	6.13	1.18	1550.00	9.40	2.56
480.00	2.91	.31	1020.00	6.19	1.20	1560.00	9.46	2.59
490.00	2.97	.32	1030.00	6.25	1.22	1570.00	9.52	2.62
500.00	3.03	.33	1040.00	6.31	1.24	1580.00	9.58	2.65
510.00	3.09	.34	1050.00	6.37	1.26	1590.00	9.64	2.68
520.00	3.15	.35	1060.00	6.43	1.28	1600.00	9.70	2.71
530.00	3.21	.37	1070.00	6.49	1.31	1610.00	9.77	2.75
540.00	3.28	.38	1080.00	6.55	1.33	1620.00	9.83	2.78

Appendix Table 7-11.—Friction loss in trickle irrigation hose, nominal diameter 10 in.

[Inside diameter 10.226 in., discharge increment 10.00 gal/min]

Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft	Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft	Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft	Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft
10.00	.04	.00	600.00	2.34	.16	1190.00	4.65	.55	1780.00	6.95	1.14
20.00	.08	.00	610.00	2.38	.16	1200.00	4.69	.56	1790.00	6.99	1.15
30.00	.12	.00	620.00	2.42	.17	1210.00	4.72	.57	1800.00	7.03	1.16
40.00	.16	.00	630.00	2.46	.17	1220.00	4.76	.57	1810.00	7.07	1.18
50.00	.20	.00	640.00	2.50	.18	1230.00	4.80	.58	1820.00	7.11	1.19
60.00	.23	.00	650.00	2.54	.18	1240.00	4.84	.59	1830.00	7.15	1.20
70.00	.27	.00	660.00	2.58	.19	1250.00	4.88	.60	1840.00	7.19	1.21
80.00	.31	.00	670.00	2.62	.19	1260.00	4.92	.61	1850.00	7.22	1.22
90.00	.35	.01	680.00	2.66	.20	1270.00	4.96	.62	1860.00	7.26	1.24
100.00	.39	.01	690.00	2.69	.20	1280.00	5.00	.63	1870.00	7.30	1.25
110.00	.43	.01	700.00	2.73	.21	1290.00	5.04	.64	1880.00	7.34	1.26
120.00	.47	.01	710.00	2.77	.22	1300.00	5.08	.64	1890.00	7.38	1.27
130.00	.51	.01	720.00	2.81	.22	1310.00	5.12	.65	1900.00	7.42	1.28
140.00	.55	.01	730.00	2.85	.23	1320.00	5.15	.66	1910.00	7.46	1.30
150.00	.59	.01	740.00	2.89	.23	1330.00	5.19	.67	1920.00	7.50	1.31
160.00	.62	.01	750.00	2.93	.24	1340.00	5.23	.68	1930.00	7.54	1.32
170.00	.66	.02	760.00	2.97	.24	1350.00	5.27	.69	1940.00	7.58	1.33
180.00	.70	.02	770.00	3.01	.25	1360.00	5.31	.70	1950.00	7.61	1.35
190.00	.74	.02	780.00	3.05	.26	1370.00	5.35	.71	1960.00	7.65	1.36
200.00	.78	.02	790.00	3.09	.26	1380.00	5.39	.72	1970.00	7.69	1.37
210.00	.82	.02	800.00	3.12	.27	1390.00	5.43	.73	1980.00	7.73	1.38
220.00	.86	.03	810.00	3.16	.27	1400.00	5.47	.74	1990.00	7.77	1.40
230.00	.90	.03	820.00	3.20	.28	1410.00	5.51	.75	2000.00	7.81	1.41
240.00	.94	.03	830.00	3.24	.29	1420.00	5.55	.76	2010.00	7.85	1.42
250.00	.98	.03	840.00	3.28	.29	1430.00	5.58	.77	2020.00	7.89	1.44
260.00	1.02	.04	850.00	3.32	.30	1440.00	5.62	.78	2030.00	7.93	1.45
270.00	1.05	.04	860.00	3.36	.30	1450.00	5.66	.79	2040.00	7.97	1.46
280.00	1.09	.04	870.00	3.40	.31	1460.00	5.70	.80	2050.00	8.01	1.47
290.00	1.13	.04	880.00	3.44	.32	1470.00	5.74	.81	2060.00	8.04	1.49
300.00	1.17	.05	890.00	3.48	.32	1480.00	5.78	.82	2070.00	8.08	1.50
310.00	1.21	.05	900.00	3.51	.33	1490.00	5.82	.83	2080.00	8.12	1.51
320.00	1.25	.05	910.00	3.55	.34	1500.00	5.86	.84	2090.00	8.16	1.53
330.00	1.29	.05	920.00	3.59	.34	1510.00	5.90	.85	2100.00	8.20	1.54
340.00	1.33	.06	930.00	3.63	.35	1520.00	5.94	.86	2110.00	8.24	1.55
350.00	1.37	.06	940.00	3.67	.36	1530.00	5.97	.87	2120.00	8.28	1.57
360.00	1.41	.06	950.00	3.71	.36	1540.00	6.01	.88	2130.00	8.32	1.58
370.00	1.44	.07	960.00	3.75	.37	1550.00	6.05	.89	2140.00	8.36	1.59
380.00	1.48	.07	970.00	3.79	.38	1560.00	6.09	.90	2150.00	8.40	1.61
390.00	1.52	.07	980.00	3.83	.39	1570.00	6.13	.91	2160.00	8.43	1.62
400.00	1.56	.08	990.00	3.87	.39	1580.00	6.17	.92	2170.00	8.47	1.64
410.00	1.60	.08	1000.00	3.90	.40	1590.00	6.21	.93	2180.00	8.51	1.65
420.00	1.64	.08	1010.00	3.94	.41	1600.00	6.25	.94	2190.00	8.55	1.66
430.00	1.68	.09	1020.00	3.98	.41	1610.00	6.29	.95	2200.00	8.59	1.68
440.00	1.72	.09	1030.00	4.02	.42	1620.00	6.33	.96	2210.00	8.63	1.69
450.00	1.76	.09	1040.00	4.06	.43	1630.00	6.37	.97	2220.00	8.67	1.71
460.00	1.80	.10	1050.00	4.10	.44	1640.00	6.40	.98	2230.00	8.71	1.72
470.00	1.84	.10	1060.00	4.14	.44	1650.00	6.44	.99	2240.00	8.75	1.73
480.00	1.87	.11	1070.00	4.18	.45	1660.00	6.48	1.00	2250.00	8.79	1.75
490.00	1.91	.11	1080.00	4.22	.46	1670.00	6.52	1.02	2260.00	8.83	1.76
500.00	1.95	.11	1090.00	4.26	.47	1680.00	6.56	1.03	2270.00	8.86	1.78
510.00	1.99	.12	1100.00	4.30	.48	1690.00	6.60	1.04	2280.00	8.90	1.79
520.00	2.03	.12	1110.00	4.33	.48	1700.00	6.64	1.05	2290.00	8.94	1.80
530.00	2.07	.13	1120.00	4.37	.49	1710.00	6.68	1.06	2300.00	8.98	1.82
540.00	2.11	.13	1130.00	4.41	.50	1720.00	6.72	1.07	2310.00	9.02	1.83
550.00	2.15	.14	1140.00	4.45	.51	1730.00	6.76	1.08	2320.00	9.06	1.85
560.00	2.19	.14	1150.00	4.49	.52	1740.00	6.79	1.09	2330.00	9.10	1.86
570.00	2.23	.14	1160.00	4.53	.52	1750.00	6.83	1.11	2340.00	9.14	1.88
580.00	2.26	.15	1170.00	4.57	.53	1760.00	6.87	1.12	2350.00	9.18	1.89
590.00	2.30	.15	1180.00	4.61	.54	1770.00	6.91	1.13			

Appendix Table 7-12.—Friction loss in trickle irrigation hose, nominal diameter 12 in.

[Inside diameter 12.128 in., discharge increment 20.00 gal/min]

Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft	Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft	Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft
20.00	.06	.00	1160.00	3.22	.23	2300.00	6.39	.80
40.00	.11	.00	1180.00	3.28	.24	2320.00	6.44	.81
60.00	.17	.00	1200.00	3.33	.25	2340.00	6.50	.82
80.00	.22	.00	1220.00	3.39	.25	2360.00	6.55	.84
100.00	.28	.00	1240.00	3.44	.26	2380.00	6.61	.85
120.00	.33	.00	1260.00	3.50	.27	2400.00	6.66	.86
140.00	.39	.01	1280.00	3.55	.28	2420.00	6.72	.88
160.00	.44	.01	1300.00	3.61	.28	2440.00	6.77	.89
180.00	.50	.01	1320.00	3.66	.29	2460.00	6.83	.90
200.00	.56	.01	1340.00	3.72	.30	2480.00	6.88	.92
220.00	.61	.01	1360.00	3.78	.31	2500.00	6.94	.93
240.00	.67	.01	1380.00	3.83	.32	2520.00	7.00	.94
260.00	.72	.02	1400.00	3.89	.32	2540.00	7.05	.96
280.00	.78	.02	1420.00	3.94	.33	2560.00	7.11	.97
300.00	.83	.02	1440.00	4.00	.34	2580.00	7.16	.98
320.00	.89	.02	1460.00	4.05	.35	2600.00	7.22	1.00
340.00	.94	.03	1480.00	4.11	.36	2620.00	7.27	1.01
360.00	1.00	.03	1500.00	4.16	.37	2640.00	7.33	1.03
380.00	1.05	.03	1520.00	4.22	.38	2660.00	7.39	1.04
400.00	1.11	.03	1540.00	4.28	.39	2680.00	7.44	1.06
420.00	1.17	.04	1560.00	4.33	.39	2700.00	7.50	1.07
440.00	1.22	.04	1580.00	4.39	.40	2720.00	7.55	1.08
460.00	1.28	.04	1600.00	4.44	.41	2740.00	7.61	1.10
480.00	1.33	.05	1620.00	4.50	.42	2760.00	7.66	1.11
500.00	1.39	.05	1640.00	4.55	.43	2780.00	7.72	1.13
520.00	1.44	.05	1660.00	4.61	.44	2800.00	7.77	1.14
540.00	1.50	.06	1680.00	4.66	.45	2820.00	7.83	1.16
560.00	1.55	.06	1700.00	4.72	.46	2840.00	7.89	1.17
580.00	1.61	.07	1720.00	4.78	.47	2860.00	7.94	1.19
600.00	1.67	.07	1740.00	4.83	.48	2880.00	8.00	1.20
620.00	1.72	.07	1760.00	4.89	.49	2900.00	8.05	1.22
640.00	1.78	.08	1780.00	4.94	.50	2920.00	8.11	1.23
660.00	1.83	.08	1800.00	5.00	.51	2940.00	8.16	1.25
680.00	1.89	.09	1820.00	5.05	.52	2960.00	8.22	1.27
700.00	1.94	.09	1840.00	5.11	.53	2980.00	8.27	1.28
720.00	2.00	.10	1860.00	5.16	.54	3000.00	8.33	1.30
740.00	2.05	.10	1880.00	5.22	.55	3020.00	8.38	1.31
760.00	2.11	.11	1900.00	5.27	.56	3040.00	8.44	1.33
780.00	2.17	.11	1920.00	5.33	.58	3060.00	8.50	1.34
800.00	2.22	.12	1940.00	5.39	.59	3080.00	8.55	1.36
820.00	2.28	.12	1960.00	5.44	.60	3100.00	8.61	1.38
840.00	2.33	.13	1980.00	5.50	.61	3120.00	8.66	1.39
860.00	2.39	.13	2000.00	5.55	.62	3140.00	8.72	1.41
880.00	2.44	.14	2020.00	5.61	.63	3160.00	8.77	1.43
900.00	2.50	.15	2040.00	5.66	.64	3180.00	8.83	1.44
920.00	2.55	.15	2060.00	5.72	.65	3200.00	8.88	1.46
940.00	2.61	.16	2080.00	5.77	.67	3220.00	8.94	1.48
960.00	2.67	.16	2100.00	5.83	.68	3240.00	8.99	1.49
980.00	2.72	.17	2120.00	5.89	.69	3260.00	9.05	1.51
1000.00	2.78	.18	2140.00	5.94	.70	3280.00	9.11	1.53
1020.00	2.83	.18	2160.00	6.00	.71	3300.00	9.16	1.54
1040.00	2.89	.19	2180.00	6.05	.72	3320.00	9.22	1.56
1060.00	2.94	.20	2200.00	6.11	.74	3340.00	9.27	1.58
1080.00	3.00	.20	2220.00	6.16	.75	3360.00	9.33	1.60
1100.00	3.05	.21	2240.00	6.22	.76	3380.00	9.38	1.61
1120.00	3.11	.22	2260.00	6.27	.77	3400.00	9.44	1.63
1140.00	3.16	.22	2280.00	6.33	.79	3420.00	9.49	1.65

Appendix Table 7-13.—Friction loss in plastic irrigation pipe, nominal diameter 15 in.

[Inside diameter 14.554 in., discharge increment 50.00 gal/min]

Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft	Flow (Q) gal/min	Flow (v) ft/s	Friction loss (J) ft/100 ft
50.00	.10	.00	2650.00	5.11	.43
100.00	.19	.00	2700.00	5.21	.44
150.00	.29	.00	2750.00	5.30	.46
200.00	.39	.00	2800.00	5.40	.47
250.00	.48	.01	2850.00	5.49	.49
300.00	.58	.01	2900.00	5.59	.51
350.00	.67	.01	2950.00	5.69	.52
400.00	.77	.01	3000.00	5.78	.54
450.00	.87	.02	3050.00	5.88	.55
500.00	.96	.02	3100.00	5.98	.57
550.00	1.06	.03	3150.00	6.07	.59
600.00	1.16	.03	3200.00	6.17	.61
650.00	1.25	.03	3250.00	6.27	.62
700.00	1.35	.04	3300.00	6.36	.64
750.00	1.45	.04	3350.00	6.46	.66
800.00	1.54	.05	3400.00	6.55	.68
850.00	1.64	.05	3450.00	6.65	.69
900.00	1.74	.06	3500.00	6.75	.71
950.00	1.83	.07	3550.00	6.84	.73
1000.00	1.93	.07	3600.00	6.94	.75
1050.00	2.02	.08	3650.00	7.04	.77
1100.00	2.12	.08	3700.00	7.13	.79
1150.00	2.22	.09	3750.00	7.23	.81
1200.00	2.31	.10	3800.00	7.33	.83
1250.00	2.41	.11	3850.00	7.42	.85
1300.00	2.51	.12	3900.00	7.52	.87
1350.00	2.60	.13	3950.00	7.61	.89
1400.00	2.70	.13	4000.00	7.71	.91
1450.00	2.80	.14	4050.00	7.81	.93
1500.00	2.89	.15	4100.00	7.90	.95
1550.00	2.99	.16	4150.00	8.00	.97
1600.00	3.08	.17	4200.00	8.10	.99
1650.00	3.18	.18	4250.00	8.19	1.02
1700.00	3.28	.19	4300.00	8.29	1.04
1750.00	3.37	.20	4350.00	8.39	1.06
1800.00	3.47	.21	4400.00	8.48	1.08
1850.00	3.57	.22	4450.00	8.58	1.11
1900.00	3.66	.23	4500.00	8.68	1.13
1950.00	3.76	.25	4550.00	8.77	1.15
2000.00	3.86	.26	4600.00	8.87	1.17
2050.00	3.95	.27	4650.00	8.96	1.20
2100.00	4.05	.28	4700.00	9.06	1.22
2150.00	4.14	.29	4750.00	9.16	1.25
2200.00	4.24	.31	4800.00	9.25	1.27
2250.00	4.34	.32	4850.00	9.35	1.29
2300.00	4.43	.33	4900.00	9.45	1.32
2350.00	4.53	.34	4950.00	9.54	1.34
2400.00	4.63	.36	5000.00	9.64	1.37
2450.00	4.72	.37	5050.00	9.74	1.39
2500.00	4.82	.39	5100.00	9.83	1.42
2550.00	4.92	.40	5150.00	9.93	1.44
2600.00	5.01	.41			

Appendix C—Equations

7-1 $$P_w = \frac{eS_eS_w}{S_pS_r} \times 100$$

7-2 $$P_w = \frac{eS_e'(S_e' + S_w)}{2(S_pS_r)} \times 100$$

7-3 $$P_w = \frac{e[A_s + (½S_e' \times PS)]}{(S_pS_r)} \times 100$$

7-4 $$F_{mn} = (M_{ad})(WHC)(RZD)(P_w)$$

7-5 $$T_d = u_d[P_s + 0.15(1.0 - P_s)]$$

7-6 $$F_n = T_dI_f$$

7-7 $$EU = 100(1.0 - \frac{1.27}{\sqrt{e}}v)\frac{q_n}{q_a}$$

7-8a $$F_g = \frac{F_nT_r}{EU}$$

7-8b $$F_g = \frac{F_n}{EU(1.0 - LR_t)}$$

7-9 $$F_{(gp/d)} = 0.623\frac{S_pS_rF_g}{I_f}$$

7-10 $$F_{(an)} = (U - R_e - W_s)[P_s + 0.15(1.0 - P_s)]$$

7-11 $$E_s = EU$$

7-12 $$E_s = \frac{EU}{T_R(1.0 - LR_t)}$$

7-13 $$F_{sg} = \frac{F_{an}}{E_s(1.0 - LR_t)}$$

7-14 $$V_i = \frac{F_{an}A}{12(1.0 - LR_t)E_s/100}$$

7-15 $$Y = \frac{EC_w - \min EC_e}{\max EC_e - \min EC_e} \times 100$$

7-16 $$LR_t = \frac{L_n}{F_n} = \frac{L_N}{F_{an}} = \frac{EC_w}{EC_{dw}}$$

7-17 $$LR_t = \frac{EC_w}{2(\max EC_e)}$$

7-18 $$v = \frac{S}{\bar{q}} = \frac{\sqrt{q_1^2 + q_2^2 \ldots + q_n^2 - n(\bar{q})^2}/\sqrt{n - 1}}{\bar{q}}$$

7-19 $$v_s = \frac{v}{\sqrt{e'}}$$

7-20 $$q = k_dh^x$$

7-21 $$x = \frac{\log(q_1/q_2)}{\log(h_1/h_2)}$$

7-22 $$l_c = \frac{hgd^4\pi}{98.6q\nu}$$

7-23 $$q = 187ac_q\sqrt{2gh}$$

7-24 $$q = 187ac_q\sqrt{2g(h - h^1)}$$

7-25 $$h^1 = \frac{h}{1 + m^2}$$

7-26 $$q = 187ac_q\sqrt{2g}\, h^{0.4}$$

7-27 $$q = 187ac_q\sqrt{2g}\, h^x$$

7-28 $$q = 187ac_q\sqrt{2g}(h/m')^{0.7}$$

7-29 $$q = 187ac_q\sqrt{2gh/m'}$$

7-30 $$T_a = \frac{F_{(gp/d)}}{eq_a}$$

7-31 $$h_a = (\frac{q_a}{k_d})^{1/x}$$

7-32 $$EU = 100\ q_n'/q_a'$$

7-33a $$EU = 100(1.0 - 1.27\frac{v}{\sqrt{e'}})\frac{q_n}{q_a}$$

7-33b $$EU = 100(1.0 - 1.27v_s)\frac{q_n}{q_a}$$

7-34 $$\triangle H_s = 2.5(h_a - h_n)$$

7-35a $$Q_s = 726\frac{A}{N}\frac{eq_a}{S_pS_r}$$

7-35b $$Q_s = 726\frac{A}{N}\frac{q_a}{S_eS_l}$$

7-36 $$Q_s = 726\frac{A}{N}\frac{e}{S_p}q_a$$

7–37 $Q_t = 5{,}430 \frac{V_i}{Q_s}$

7–38 $q_n = q_a (\frac{h_n}{h_a})^x$

7–39 $h_n = (H_m - \triangle H_m - \triangle h)$

7–40 $F_n = 1.604 \frac{EU}{100} \frac{eq_a}{S_p S_r}$

7–41 $q_f = \frac{F_r A}{HF_c H_r}$

7–42 $C_t = \frac{F_r A}{F_c}$

7–43 $q_c = \frac{0.006CQ_s}{csg}$

7–44 $J = \frac{h_f 100}{L} = 1{,}050 \frac{(\frac{Q}{C})^{1.85}}{D^{4.87}}$

7–45 $N_R = 3{,}214 \frac{Q}{D}$

7–46 $h_f = f \frac{L}{D} \frac{v^2}{2g}$

7–47a $f = \frac{64}{N_R}$

7–47b $\frac{1}{\sqrt{f}} = 0.80 + 2.0 \log (N_R \sqrt{f})$

7–48 $f = 0.32\ N_R^{-0.25}$

7–49a $J = \frac{h_f 100}{L} = 0.133 \frac{Q^{1.75}}{D^{4.75}}$

7–49b $J = \frac{h_f 100}{L} = 0.100 \frac{Q^{1.83}}{D^{4.83}}$

7–50 $h_e = K_f \frac{V^2}{2g}$

7–51a $l' = l(\frac{S_e + f_e}{S_e})$

7–51b $J' = J(\frac{S_e + f_e}{S_e})$

7–52 $h_f = J'FL/100$

7–53 $\frac{h_{fx}}{L/100} = J'F(\frac{x}{L})^{2.75}$

7–54 $PW(r) = [\frac{(1 + r)^n - (1 + i)^n}{(1 + r) - (1 + i)}] \times [\frac{1}{(1 + i)^n}]$

7–55 $EAE(r) = [\frac{(1 + r)^n - (1 + i)^n}{(1 + r) - (1 + i)}] \times [\frac{i}{(1 + i)^n - 1}]$

7–56 $CRF = \frac{i(1 + i)^n}{(1 + i)^n - 1}$

7–57 $C_{whp} = \frac{(Q_t)(P_{uc})[EAE(r)]}{(E_p)(BHP/P_u)}$

7–58 $A_f = \frac{0.001C_{whp}}{(CRF)(P_c)}$

7–59 $Q_s' = A_f Q_s$

7–60 $(H_{fe})_m = \sum_1^m h_f \pm \triangle El$

7–61 $L_s = \frac{\triangle H}{J_s - J_l} \times 100$

7–62 $q_l = \frac{l}{S_e} \frac{q_a}{60} = \frac{n_e q_a}{60}$

7–63a $h_l = h_a + 0.75h_{fp}[z^{3.75} + (1 - z)^{3.75}] - \frac{\triangle El}{2}(2z - 1)$

7–63b $h_l = h_a + 0.75h_{fp}\ (0.5)^{2.75} = h_a + 0.11h_{fp}$

7–63c $h_l = h_a + \frac{3h_f}{4} + \frac{\triangle El}{2}$

7–64a $h_c = h_a - (\frac{h_f}{4} + \frac{\triangle El}{2})$

7–64b $h_c = h_l - (h_f + \triangle El)$

7–65a $(h_f)_b \cong (h_f)_a(\frac{l_b}{l_a})^{2.75}$

7–65b $l_b \cong l_a(\frac{(h_f)_b}{(h_f)_a})^{1/2.75}$

7–66 $\triangle h = \frac{J'F}{10}\frac{L}{100}(\frac{\triangle h}{L/100})'$

7–67 $Y = (S/J')^{1/1.75}$

7–68 $S' = SY - J'F(Y)^{2.75}$

7–69 $\frac{S - S'}{J'F} = (x/L)^{2.75} - (1 - x/L)^{2.75}$

7–70 $\triangle h = \frac{L}{100}[J'F(x/L)^{2.75} + S' - S(x/L)]$

7–71a $\triangle h_c = S'(L/100)$

7–71b $\triangle h_c = S^{1.57}(J')^{-0.57}(1 - F)L/100$

7–72 $\triangle h = \frac{L}{100}(J'F + S' - S)$

7–73 $(\triangle H_m)_a = \triangle H_s - \triangle h'$

7–74 $L_p = [(n_r)_p - 1]S_r$

7–75 $L_m = (n_r - 1/2)S_r$

7–76a $H_m = h_l + \triangle H'_m$

7–76b $H_m = h_a + \triangle h' + \triangle H'_m$

7–77 $Q'_s = A_f q_m$

7–78 $L_d = \frac{q_d - q_{d-1}}{q_m} L_m$

7–79a $k = (L_m/q_m)(0.1 \text{ gpm/ft})$

7–79b $k = (S_l/q_l)(0.1 \text{ gpm/ft})$

7–80 $H_f = k(H_{fg})$

7–81a $\triangle H_m = H_f$

7–81b $\triangle H_m = H_f + S(L_m/100)$

7–81c $\triangle H_m = H_f - [S(0.1 - \frac{0.36}{c})\frac{L_m}{100}]$

7–82a $Q''_s = \frac{H_f}{(\triangle H_m)_a} Q'_s$

7–82b $Q''_s = \frac{H_f}{(\triangle H_m)_a - S(L_m/100)}$

7–82c $Q''_s = \frac{H_f}{(\triangle H_m)_a + [S(1.0 - \frac{0.36}{c})L_m/100]}$

7–83 $S_f = \frac{(q_l)_c}{(q_l)_a} = \frac{(n_p)_c}{(n_p)_a}$

7–84 $H_f = JFF_s(L_m/100) = JF'(L_m/100)$

7–85 $J = J_x(\frac{q_m}{q_x})^{1.8}$

7–86 $j = \frac{(\triangle H_m)_a}{L_m/100}$

7–87 $j' = \frac{(\triangle H_m)_a}{k}$

7–88 $S' = \frac{SL_m}{100k} = \frac{Sq_m}{10} = \frac{\triangle El}{k}$

7–89 $(H_f)_2 = \frac{L_2}{L_1}\frac{(F_s)_2}{(F_s)_1}(\frac{q_2}{q_1})^{1.8}(H_f)_1$

7–90 $F'_{aw} = \frac{1.604eq'_aT_a}{A_w}$

7–91 $F'_a = \frac{1.604eq'_aT_a}{S_p \times S_r}$

7–92 $F'_{(gp/d)} = \frac{eq'_aT_a}{I_f}$

7–93 $EU'_m = 100\, q'_n/q'_a$

7–94a $ERF = \frac{\text{average MLIP} + (1.5 \text{ minimum MLIP})}{2.5(\text{average MLIP})}$

7–94b $ERF = (\frac{\text{minimum MLIP}}{\text{average MLIP}})^x$

7–95 $EU' = (ERF)(EU'_m)$

7–96 $F_n = (F'_n - R'_e)[\frac{P_s}{100} + 0.15(1.0 - \frac{P_s}{100})]$

7–97a $PE_{lq} = \frac{EU'}{T_r(1.0 - LR_t)}$

7–97b $PE_{lq} = EU'$

7–98 $E_{lq} = \frac{100G}{F'_{(gp/d)}}$