CHAPTER

18 Microirrigation

Microirrigation is a method for delivering slow, frequent applications of water to the soil using a low-pressure distribution system and special flow-control outlets. Microirrigation is also referred to as drip, subsurface, bubbler, low-flow, low-pressure, or trickle irrigation, and all have similar design and management criteria.

These systems deliver water to individual plants or rows of plants. The outlets are generally spaced at short intervals along small tubing, and unlike surface or sprinkler irrigation, only the soil near the plant is watered. The outlets include emitters, orifices, bubblers, and sprays or microsprinklers with flows ranging from 2 to over 200 L/h.

According to Karmeli & Keller (1975), microirrigation research began in Germany about 1860. In the 1940s it was introduced in England especially for watering and fertilizing plants in greenhouses. With the increased availability of plastic pipe and the development of emitters in Israel in the 1950s, it has since become an important method of irrigation in Australia, Europe, Israel, Japan, Mexico, South Africa, and the United States. According to the "2000 Irrigation Survey" in *Irrigation Journal* (2001) California had 675 000 ha, Florida had 270 000 ha, and the U.S. total was over 3 000 000 ha of microirrigation.

Microirrigation has been accepted mostly in the more arid regions for watering high-value crops, such as fruit and nut trees, grapes and other vine crops, sugar cane, pineapples, strawberries, flowers, melons, vegetables, and landscape plants. Microirrigation has also been successfully used on row crops such as corn, cotton, sorghum, and tomatoes. In Arizona, subsurface systems have been used for cotton, melons, vegetables, and wheat in a crop rotation system for over 10 years (Wuertz, 2001). Special equipment was developed for tillage and field operations without removing or damaging the tubing.

18.1 Advantages and Disadvantages of Microirrigation

With microirrigation only the root zone of the plant is supplied with water, and with proper system management, deep-percolation losses are minimal. Soil evaporation may be lower because only a portion of the surface area is wet. Like solid-set sprinkler systems, labor requirements are lower and the system can be readily automated.

Reduced percolation and evaporation losses result in high efficiencies of water use. Weeds are more easily controlled, especially for the soil area that is not irrigated. Bacteria, fungi, and other pests and diseases that depend on a moist environment are reduced as the above-ground plant parts normally are completely dry; however, harmful soil organisms may be enhanced in the frequently wetted soil. Because soil is kept at a high water level and the water does not contact the plant leaves, use of more saline water may be possible with less stress and damage to the plant, such as leaf burn. Field edge losses and spray evaporation, associated with sprinklers, are reduced with these systems. Low rates of water application at lower pressures are possible, eliminating runoff. With some crops, yields and quality are increased, probably as a result of maintenance of a high temporal soil water level adequate to meet transpiration demands. Experiments have shown crop yield differences varying from little to more than a 50 percent increase compared with other methods of irrigation. Some fertilizers and pesticides may be injected into the system and applied in small quantities, as needed, with the water. With good system design and management, this practice can minimize chemical applications and reduce chemical movement to the ground water supply. Except for acids and chlorine, the system should be operated for sufficient time after injection to assure that chemicals have been flushed from the lines.

The major disadvantages of microirrigation are initial cost and potential clogging of system components, especially emitters, by particulate, biological, and chemical matter. A good filter system is required to remove particulate matter from the water. Chlorine is frequently injected into the water for biological control. Acids are injected to control pH and chemical precipitation, including salt accumulations at the emitter outlets. Special precautions are required for the handling and injection of chemicals (ASAE, 2001c).

Emitters may not be well suited to certain crops and special problems may be caused by salinity. Salt tends to accumulate along the fringes of the wetted surface strip (Figure 18-1). Because these systems normally wet only part of the potential soil-root volume, plant roots may be restricted to the soil volume near each emitter as shown in Figure 18-1. The dry soil area between emitter lateral lines may lead to

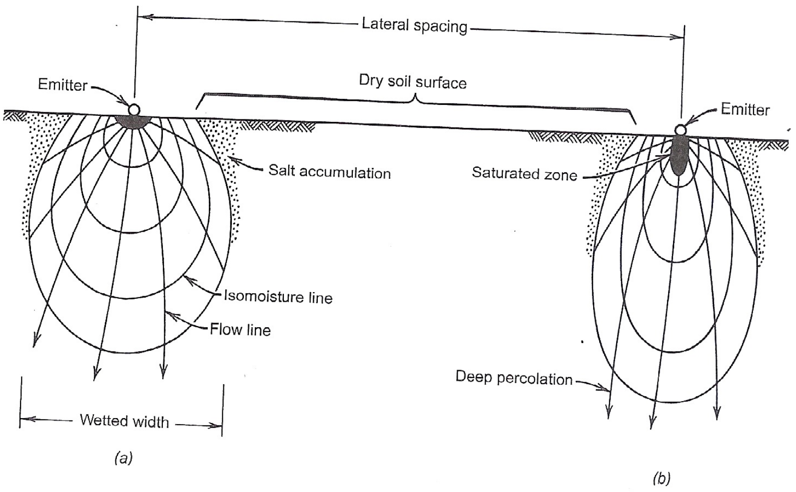

Figure 18–1
Soil-wetting pattern with microirrigation. (a) Medium and heavy soils. (b) Sandy soils. (Adapted from Karmeli & Keller, 1975)

dust formation from tillage operations and subsequent wind erosion. Compared with surface and sprinkler irrigation systems, more highly skilled labor is required to operate and maintain the filtration equipment and other specialized components. Rodents sometimes damage tubing or other plastic components.

18.2 Layout and Components of Microirrigation Systems

System layouts are similar to sprinkler systems (Chapter 17). As with sprinkler systems many arrangements are possible. The layout given in Figure 18-2 shows split-line operation for the upper left quadrant of a 16-ha orchard. The well is located at the center of the larger field. The layout would be similar for the other quadrants. Tree rows are parallel to the laterals. Subunits 1, 2, 3, and 4 of the 4-ha quadrant in Figure 18-2 could be operated independently of each other or in any combination, because each subunit has its own control valve.

As shown in Figures 18-2 and 18-3, the primary components of a microirrigation system are the control head, the main and submain, a manifold, and lateral lines to which the emitters are attached. The control head may consist of the pump, filters, injectors, backflow preventers, pressure gauges and regulators, water meter, flushing valves, air relief valves, and programmable control devices. The manifold is a line to which the laterals are connected. The manifold, submains, and main may be on the surface or buried underground. The manifold is usually flexible pipe if laid on the surface or rigid pipe if buried. The main lines may be any type of pipe, such as polyethylene (PE), polyvinyl chloride (PVC), galvanized steel, or

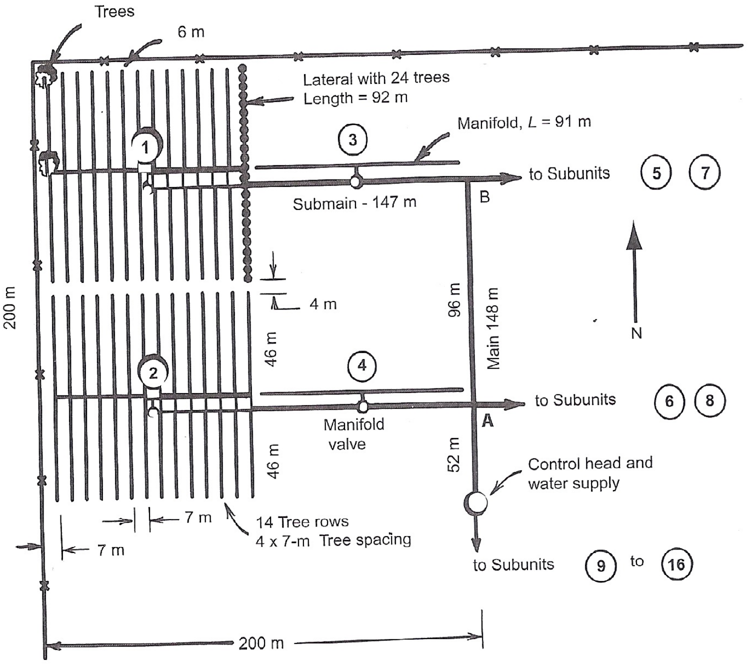

Figure 18–2
Microirrigation system layout for a 4-ha quadrant of a 16-ha orchard with the control head and water supply in the center of a square field.

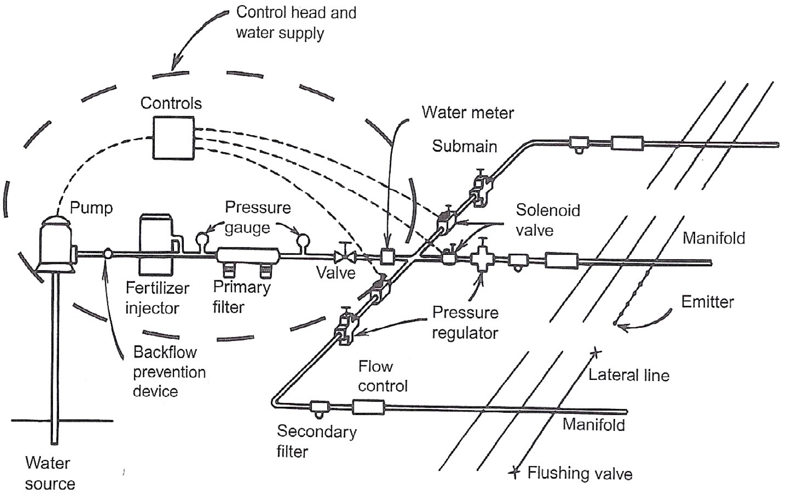

Figure 18–3
Components of a microirrigation system.

aluminum. See Appendix D and ASAE (1998, 2001b) for information on plastic pipe. The lateral lines that have emitters are usually PE or flexible PVC tubing. They generally range from 10 to 32 mm in diameter and have emitters spaced at short intervals appropriate for the crop to be grown. A flushing device at the end of each lateral or a manifold, with an outlet valve, connected to the ends of several laterals is necessary to flush sediment and debris from the laterals. Sometimes secondary filters and pressure regulators are installed at the inlet to each manifold. Valves also may be installed for air and/or vacuum relief.

An efficient filter to prevent emitter clogging is the most important component of the microirrigation system. Particulate removal is more important than for drinking water. Microirrigation systems generally require screen, gravel, or graded sand filters (Evans et al., 2000). Recommendations of the emitter manufacturer should be followed in selecting the filtration system. In the absence of such recommendations, the net opening diameter of the filter should be smaller than one tenth to one fourth of the emitter opening diameter (Evans et al., 2000). For clean ground water, an 80- to 200-mesh filter may be adequate. This filter will remove soil, sand, and debris, but should not be used with high-algae water. For water with high silt and algae contents, a sand filter followed by a screen filter is recommended. A sand separator ahead of the filter may be necessary if the water contains considerable sand. In-line strainers with replaceable screens and cleanout plugs may be adequate with small amounts of sand. These are recommended as a safety precaution should accidents during cleaning or filter damage allow particles or unfiltered water to enter into the system. Filters must be cleaned and serviced regularly. Pressure loss through the filter should be monitored to determine the need for maintenance. (See ASAE, 2000, for details on the testing and performance of media filters.)

Lateral lines may be located along the tree row with several emitters required for each tree as shown in Figure 18-4. Many laterals have multiple emitters, such as the "spaghetti" tubing or "pigtail" lines shown in Figure 18-4c. One or more laterals per row (Figure 18-4a or b) may be provided, depending on the size of the trees. A single line is adequate for small trees. For row crops, a lateral is usually installed for each row.

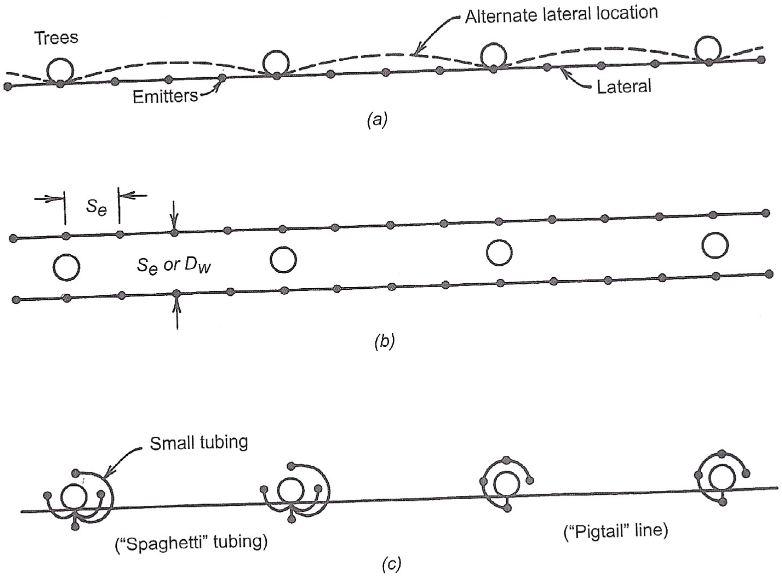

Figure 18–4 Lateral and emitter locations for an orchard or vineyard. (a) Single lateral for each row of plants. (b) Two laterals for each plant row. (c) Multiple outlet layouts.

Many types and designs of emitters are commercially available, some of which are shown in Figure 18-5. The emitter controls the flow from the lateral and reduces the pressure with small openings, long passageways, tortuous passageways, vortex chambers, manual adjustment, or other mechanical devices. Some emitters (Figure 18-5f) may be pressure-compensating by changing the length or by mechanically changing the cross section of passageways or size of orifice, and give a nearly constant discharge over a wide range of pressures. Some are self-cleaning and flush automatically. Porous pipe and tubing may have many small openings as shown in Figure 18-5h to j. The actual size of the opening is much smaller than indicated in the drawing. Some holes are barely visible to the naked eye. The double-tube lateral shown in Figure 18-5j has more openings in the outer channel than in the main flow channel. Such tubes have thin walls and are inexpensive. Tubes may be discarded after the crop is harvested and replaced with new lines. Emitters may be placed on the soil surface, or they may be buried at shallow depths for protection (subsurface drip irrigation, SDI).

18.3 Emitter Discharge

In an orifice-type emitter the flow is fully turbulent and the discharge can be determined from the sprinkler nozzle equation (Equation 17.3). The discharge of any emitter may be expressed by the power-curve equation (Karmeli & Keller, 1975)

$$q = Kh^x \qquad \textbf{18.1}$$

where q = emitter discharge (L^3/T),
K = constant for each emitter,

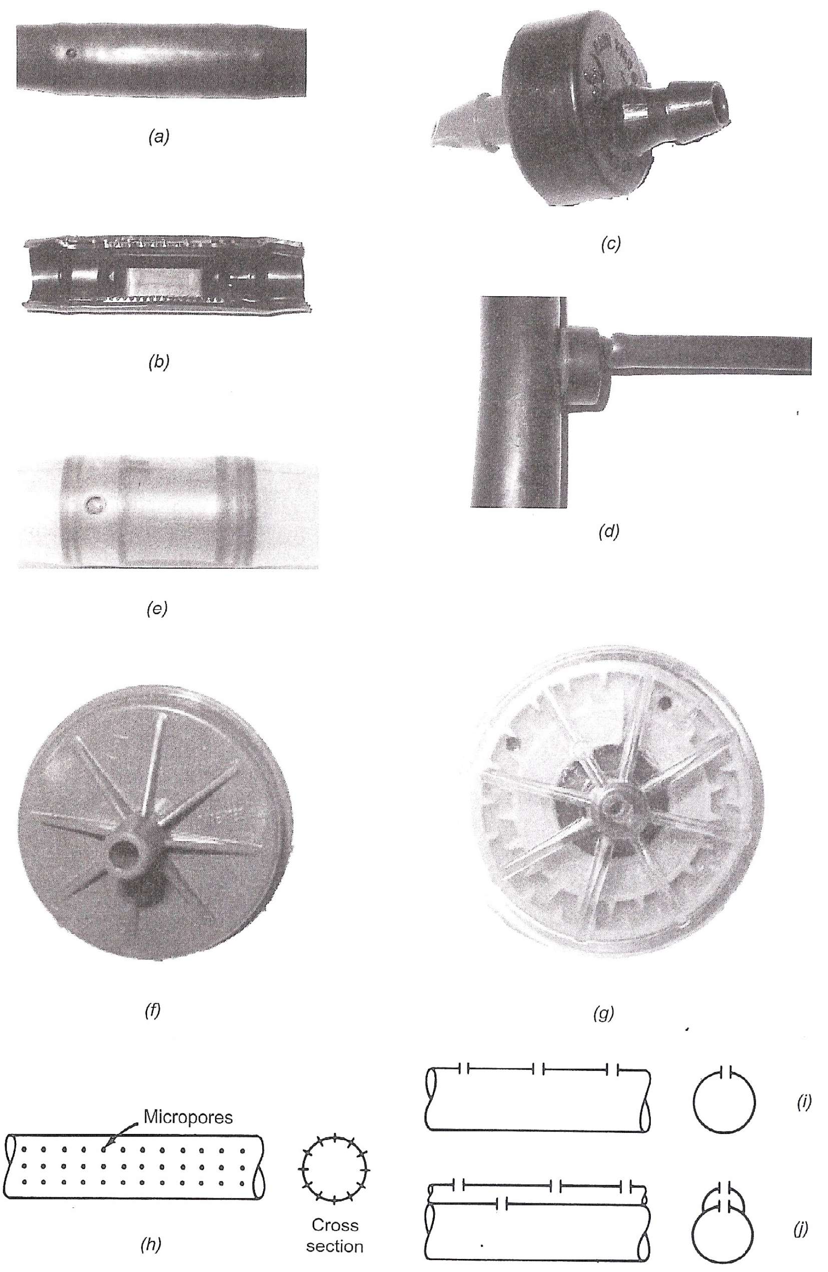

Figure 18–5

Types of microirrigation laterals and emitters. (a) In-line emitter formed in the lateral during production. (b) Cross section of emitter (a). (c) Emitter with barb for attachment. (d) Emitter (c) attached to a lateral and with a small tube attached to deliver water to the desired location. (e) Pre-molded in-line emitter is a transparent tube. (f) Pressure compensating emitter. (g) Emitter (f) with a transparent cap to show the pressure reducing path. (h) Porous tubing. (i) Single-tube lateral. (j) Double-tube lateral.

h = pressure head (L),

x = emitter discharge exponent.

The exponent x and constant K can be determined from a log–log plot of head versus discharge. With x known, K can be determined from Equation 18-1. With fully turbulent flow $x = 0.5$, and in a laminar flow regime $x = 1.0$. In a fully pressure-compensating emitter, K is a constant for a wide range of pressures and $x \approx 0$. Because of the large number of emitters available, it may be more convenient to determine discharge directly from manufacturers' curves. Some examples are shown in Figure 18-6, where K and x are for use in Equation 18.1. Double-tube laterals and porous tubing are typically rated as discharge per length, for example, 3 L/min per 100 m at 70 kPa pressure. Manufacturers' data should be obtained for the actual discharge-versus-pressure rating. Emitter discharge usually varies from about 1 to 30 L/h and pressures range from 15 to 280 kPa. Average diameters of openings for emitters range from 0.0025 to 0.25 mm. Emitters made from thermoplastic materials may vary in discharge depending on the temperature. Thus discharge curves should be corrected for temperature.

18.4 Water Distribution from Emitters

Microirrigation was developed to provide more efficient application of water and to increase yields. An ideal system should provide a uniform discharge from each emitter. Application efficiency depends on the variation of emitter discharge, pressure variation along the lateral, and seepage below the root zone or other losses, such as soil evaporation. Emitter discharge variability is greater than that for sprinkler nozzles because of smaller openings and lower design pressures. Such variability may result from the design of the emitter, materials, and care of manufacture. Solomon (1979) found that the statistical coefficient of variation may range from 0.02 to 0.4. The coefficient of variation (C_v = standard deviation/mean) should be available for emitters and provided by the manufacturer. ASAE (2001a) guidelines for classification of emitter uniformity are shown in Table 18-1.

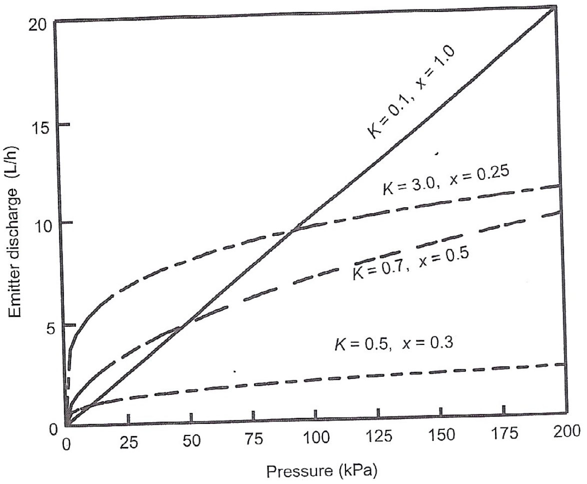

Figure 18–6
Examples of emitter discharges for various values of constant K and exponent x.

TABLE 18–1 Recommended Classification of Manufacturer's Coefficient of Variation, C_v

Emitter Type	*C_v Range*	*Classification*
Point source	<0.05	Excellent
	0.05–0.07	Average
	0.07–0.11	Marginal
	0.11–0.15	Poor
	>0.15	Unacceptable
Line source	<0.10	Good
	0.10–0.20	Average
	>0.20	Marginal to unacceptable

Source: ASAE (2001a).

Microirrigation systems must deliver the water required to each plant with minimum losses to obtain high efficiencies. This can be achieved by having a high uniformity of water delivery by each subunit of the system that has a separate control valve. Thus Subunits 1, 2, 3, and 4 in Figure 18-2 should each be designed for a high uniformity. The uniformity varies with pressure, emitter variation, and number of emitters per plant. This is defined by the emission uniformity (ASAE, 2001a).

$$EU = 100\left[1 - 1.27\frac{C_v}{n^{0.5}}\right]\frac{q_{min}}{q_{avg}} \tag{18.2}$$

where EU = emission uniformity (percent),

C_v = manufacturer's coefficient of variation,

n = number of emitters per plant for trees and shrubs or 1 for line sources,

q_{min} = minimum emitter discharge rate for the minimum pressure in the subunit (L^3/T),

q_{avg} = average or design emitter discharge rate for the subunit (L^3/T).

Recommended design values for EU are shown in Table 18-2.

TABLE 18–2 Recommended Ranges of Design Emission Uniformity, *EU*

Emitter Type	*Spacing (m)*	*Topography*	*Slope (%)*	*EU Range (%)*
Point source on perennial crops	>4	Uniform	<2	90–95
		Steep or undulating	>2	85–90
Point source on perennial or semipermanent crops	<4	Uniform	<2	85–90
		Steep or undulating	>2	80–90
Line source on annual or perennial crops	All	Uniform	<2	80–90
		Steep or undulating	>2	70–85

Source: ASAE (2001a).

Example 18.1 Determine the emission uniformity of a system subunit that uses an emitter with $K = 0.3$, $x = 0.57$, $C_v = 0.06$, and two emitters per plant with average pressure of 100 kPa and minimum pressure of 90 kPa.

Solution. Substitute Equation 18.1 into Equation 18.2

$$EU = 100\left[1 - \frac{1.27(0.06)}{2^{0.5}}\right]\frac{0.3(90)^{0.57}}{0.3(100)^{0.57}} = 89 \text{ percent}$$

18.5 Microirrigation System Design

A major difference between microirrigation and other systems is that not all the soil will be irrigated, especially for widely spaced plants. A minimum of 30 percent of the area should be irrigated. For mature trees 75 percent of the area may need to be irrigated, whereas nearly 100 percent of the area is irrigated for closely spaced plants in arid regions.

Emitter spacing and numbers required depends on the wetting pattern and plant spacing. To obtain data on horizontal and vertical water movement, field tests are preferred and should be conducted at several representative locations. If field measurements are not available, estimates may be obtained from Table 18-3 for the maximum horizontal wetted diameter, D_w, from a single emitter. For a line source, the emitter spacing S_e should be less than or equal to 0.8 D_w to overlap the wetting patterns of adjacent emitters along a lateral. For double laterals, a spacing of D_w between laterals will adequately wet the area; however, if emitters are individually spaced, the spacing can be D_w in both directions. If the water is saline, the spacing between laterals should be reduced to S_e. These closer spacings reduce dry areas between emitters where salts might accumulate. The number of emitters required per plant, n, can be obtained from

$$n = \frac{p_w \times \text{area/plant}}{\text{effective area wetted by one emitter}} \tag{18.3}$$

where p_w is the percentage of the total area to be irrigated, "area/plant" is based on the plant spacing, and "effective area wetted by one emitter" depends on the wetted diameter, emitter layout, and water quality.

Example 18.2 For the layout in Figure 18-2 with mature orange trees and one lateral per row, determine the number of the emission devices needed per tree if 40 percent of the area is to be irrigated, salt content of the irrigation water is low, soil is layered, medium density, with coarse texture to a 2-m depth, and emitters will be installed on a "pigtail" as in Figure 18-4c.

Solution. From Table 15-3 determine that the effective rooting depth is 1.5 m; then, from Table 18-3, $D_w = 1.8$ m. The effective wetted area is assumed to be 0.8(1.8 m) × 1.8 m, which is substituted into Equation 18.3.

$$n = \frac{0.40 \times 4 \times 7}{0.8(1.8) \times 1.8} = 4.3, \text{ or round to 5 emitters per tree}$$

Note that if the irrigation water is saline, the effective wetted area is reduced to $0.8(1.8) \times 0.8(1.8)$, which provides overlap of the wetting patterns and reduces salt accumulations within the wetted area.

The evapotranspiration of crops under microirrigation is not well defined because the area is not entirely shaded and it is generally somewhat less than under conventional systems that irrigate the entire area. Local or regional data for measured water use with microirrigation may be available. If local water use data are not available for microirrigation, Keller & Bliesner (1990) suggested the following for average peak transpiration rate for microirrigation design:

$$ET_t = ET_p \times 0.1 \times p^{0.5} \tag{18.4}$$

where ET_t = average peak transpiration of crops under microirrigation (L/T),
ET_p = average peak conventional ET rate for the crop (L/T),
p = percentage total area shaded by the crop.

For example, if a mature orchard shades 70 percent of the area and the average peak conventional *ET* is 7 mm/day, the net microirrigation design rate is 5.9 mm/day ($7 \times 0.1 \times 70^{0.5}$).

The diameter of the laterals and manifolds should be selected to satisfy Equation 18.2 and the appropriate *EU* from Table 18-2. In addition, the velocity should be less than 1.5 m/s to limit friction loss and to prevent pipe damage from water hammer and surge pressures. Water hammer and surge pressures can be reduced by installing slow-acting valves and by controlling the flow when the supply pump is started.

TABLE 18-3

Estimated Maximum Diameter of the Wetted Circle Formed by a Single Emission Outlet Discharging 4 L/h on Various Soils

Soil or Root Depth and Soil Texture	*Homogeneous Soil (m)*	*Varying Layers* *Generally Low Density (m)*	*Varying Layers* *Generally Medium Density (m)*
Depth 0.75 m			
Coarse	0.45	0.75	1.05
Medium	0.90	1.2	1.5
Fine	1.05	1.5	1.8
Depth 1.5 m			
Coarse	0.75	1.4	1.8
Medium	1.2	2.1	2.7
Fine	1.5	2.0	2.4

Source: Adapted from SCS (1984).

The maximum difference in pressure in a subunit usually occurs between the control point at the inlet and the emitter farthest from the inlet. In Figure 18-2 with no slope, the maximum difference in pressure to the farthest emitter is that for one half the lateral length plus one half the manifold length. Where the manifold is connected to the end of each lateral and submain is connected to the end of the manifold, the head loss would be computed for their entire length.

For minimum cost, Karmeli & Keller (1975) recommended that on a level area, 55 percent of the allowable head loss should be allocated to the lateral and 45 percent to the manifold. As in sprinkler laterals, allowable head loss should be adjusted for elevation differences along the lateral and along the manifold, unless pressure-compensating devices are used.

The friction loss for mains and submains can be computed from the Hazen-Williams or the Darcy-Weisbach equations. The Hazen-Williams equation as used for sprinkler design (Equation 17.4) is

$$H_f = 1.21 \times 10^{10} \frac{L}{D^{4.87}} \left(\frac{Q}{C}\right)^{1.852} \qquad \textbf{18.5}$$

where H_f = head loss in the pipe (m),
L = pipe length (m),
D = actual i.d. (inside diameter) of the pipe (mm),
Q = flow rate in the pipe (L/s),
C = Hazen-Williams roughness coefficient.

Equation 18.5 applies for continuous lengths of pipe. For smooth plastic pipe, $C = 150$. The same F factor for pipes with multiple outlets in Table 17-5 is valid for microirrigation laterals. Also, Equations 17.5, 17.6, and 17.7 can be applied to microirrigation laterals and are repeated below with $h_f = F \times H_f$.

$$H_a = H_d + 0.26h_f + \frac{S_o L_L}{2} \qquad \textbf{18.6}$$

$$H_o = H_a + 0.74h_f + \frac{S_o L_L}{2} \qquad \textbf{18.7}$$

Solving Equation 18.6 for H_d yields

$$H_d = H_a - 0.26h_f - \frac{S_o L_L}{2} \qquad \textbf{18.8}$$

where H_a = average pressure in the lateral (L),
H_d = pressure at the distal end of the lateral (L),
S_o = slope of the lateral (positive uphill),

L_L = lateral length (L),
H_o = inlet pressure of the lateral (L).

For in-line emitters (Figures 18-5a and 18-5b), on-line emitters (Figure 18-5d), and other connectors, the head loss should be increased. Such losses may be expressed as equivalent length of pipe. This increase in length L_e can be estimated as follows (Karmeli & Keller, 1975),

(1) L_e = 1.0 to 3.0 m for each in-line emitter (Figure 18-5a),
(2) L_e = 0.1 to 0.6 m for each on-line emitter (emitter attached by insert through pipe wall, Figure 18-5d),
(3) L_e = 0.3 to 1.0 m for a solvent-welded T-connector.

The design process for a subunit requires determination of the peak *ET*, water required per plant, emitter selection, design operating pressure, minimum emitter discharge in the subunit, average emitter discharge in the subunit, and the emission uniformity, *EU*, of the subunit. Determining the average and minimum emitter discharges in a subunit requires calculating the average pressure in each lateral in the subunit. The process is usually started at the farthest lateral of the subunit having the lowest pressure because of distance from the water source and highest elevation. The design pressure and emitter discharge for the farthest lateral is based on the average emitter flow needed to meet ET. The pressure at the inlet to the next lateral upstream is determined from the pressure at the inlet to the first lateral and the friction loss in the manifold to the next lateral. A spreadsheet can be set to iterate for the average emitter pressure and emitter discharge in the lateral. The procedure continues until the average pressure and emitter discharge are calculated for all the laterals in the subunit.

If *EU* is too low, the options are to (1) choose another emitter with a smaller discharge exponent, manufacturing coefficient of variation, or both; (2) increase the number of emitters per plant; (3) redesign the system with a higher h_{avg}, which may require selecting a different emitter; or (4) reduce the design *EU* (SCS, 1984). If *EU* is high, the system may be overdesigned and more costly than necessary. Pipe sizes may also be changed to change *EU*.

Example 18.3

Design a microirrigation system for the orchard layout shown in Figure 18-2, assuming mature orange trees. The field is level with trees spaced 4-m apart in rows on a 7-m spacing and a manifold in the center of 92-m long laterals. Assume the maximum time for irrigation is 22 hours/day, 40 percent of the area is to be irrigated, and average peak transpiration rate corrected for shaded area is 5.9 mm/day. Subunits 1 and 2 are irrigated together every 2 days; Subunits 3 and 4 are irrigated on the alternate days. In addition, each quarter of the field has similar subunits irrigated every other day. Determine the emitter discharge, the required discharge for each subunit, and the total pumping head and flow rate to irrigate the field.

Solution.

(1) Use a spreadsheet to perform the calculations. From Table 18-2 the minimum *EU* is 90 percent. The volume of water required per tree per day is

$$\text{Volume} = \frac{5.9\,(\text{mm/day}) \times 4\,(\text{m}) \times 7\,(\text{m}) \times 1000\,(\text{L/m}^3)}{1000\,(\text{mm/m}) \times 90/100} = 184\ \text{L/day}$$

(2) Since each tree is irrigated every other day, 2 × 184 = 368 L must be delivered at each irrigation to each tree to meet the average peak transpiration. (*Note:* If the irrigation water contained sufficient salts, extra water would be required for leaching (Chapter 15; Keller & Bliesner, 1990; Clark et al., 2005)). From Example 18.2, five emitters are used per tree and each emitter must deliver 368/5 = 73.6 L in 22 h or 73.6/22 = 3.35 L/h is the required emitter flow rate.

(3) Determine if the soil has sufficient capacity to store the water applied. From Example 18.2, the rooting depth of oranges is 1.5 m and the expected wetted diameter is 1.8 m. From Table 15.4, *MAD* for Group 3 with 6 mm/day is 0.45. From Table 15-2 for a sandy loam soil, the available water is 12 percent on a volumetric basis. The potential wetted soil volume from five emitters is $5 \times \pi \times (1.8/2)^2 \times 1.5 = 19.1\ \text{m}^3$. The maximum change in water content from an irrigation is soil volume × available water × *MAD* or $19.1 \times 0.12 \times 0.45 = 1.0\ \text{m}^3$ or 1000 L, which is very adequate compared to the 368 L to be applied. Although it appears that fewer emitters might be used, this is not recommended because sufficient soil must be wetted for the trees to develop an adequate root system for stability and for water and nutrient uptake.

(4) An emitter is selected with $K = 0.151$, $x = 0.63$ for q in L/hour, h in kPa, and a coefficient of variation of 0.05. *Note:* This information should be available from the manufacturer; if not, it can be obtained by testing several emitters.

(5) Substituting into Equation 18.1, $h = (3.35/0.151)^{1/0.63} = 137.0$ kPa or 13.96 m. This is the average operating pressure of the lateral with the lowest pressure, usually the farthest lateral.

(6) For 12 trees per half-lateral, $F = 0.36$ from Table 17-5. Calculate h_f from Equation 18.5. The discharge in the first lateral is $3.35 \times 5 \times 12 = 201$ L/h or 0.056 L/s. A T-connection at each tree connects the pigtail to the lateral and has an equivalent length of 2 m of pipe. Assume an initial lateral inside diameter of 15.8 mm. The equivalent lateral length is $46 + 12 \times 2 = 70$ m.

$$h_f = 0.36 \times 1.21 \times 10^{10} \times \frac{70}{15.8^{4.87}}\left(\frac{0.056}{150}\right)^{1.852} = 0.20\ \text{m}$$

(7) Calculate the pressure at the distal end of the first lateral from Equation 18.8.

$$H_d = 13.96 - 0.26 \times 0.20 - 0 \times 46/2 = 13.91\ \text{m}$$

(8) The discharge of the last emitter for this case is q_{min}.

$$q_{min} = 0.151(13.91 \times 9.81)^{0.63} = 3.34\ \text{L/h}$$

(9) Calculate the inlet pressure for the first lateral using Equation 18.7.

$$H_o = 13.96 + 0.74 \times 0.20 + 0 \times 46/2 = 14.11\ \text{m}$$

(10) Calculate the head loss in the section of manifold between laterals 1 and 2 using Equation 18.5. The manifold is 26.6 mm in diameter, the equivalent

length for the fitting is 0.5 m so the manifold length is taken as 7.5 m, and the discharge in the manifold is $0.056 \times 2 = 0.11$ L/s because of the flow to the other half lateral.

$$H_f = 1.21 \times 10^{10} \times \frac{7.5}{26.6^{4.87}}\left(\frac{0.11}{150}\right)^{1.852} = 0.02 \text{ m}$$

(11) The pressure at the inlet to lateral 2 is $0.02 + 14.11 = 14.13$ m.

(12) Calculate the average pressure in lateral 2 from Equation 18.7. Because the discharge in lateral 2 is not yet known, the value for h_f for lateral 1 is assumed. Iterate until the values for h_f and emitter discharge converge. (The spreadsheet can perform the iterations.) In this case the head loss in the manifold is very small and one iteration is sufficient.

$$H_a = 14.13 - 0.74 \times 0.20 - 0 \times 46/2 = 13.98 \text{ m}$$

$$q = 0.151 \times (13.98 \times 9.81)^{0.63} = 3.35 \text{ L/s}$$

$$h_f = 0.36 \times 1.21 \times 10^{10} \times \frac{70}{15.8^{4.87}}\left(\frac{3.35 \times 12 \times 5/3600}{150}\right)^{1.852} = 0.20 \text{ m}$$

$$H_a = 14.13 - 0.74 \times 0.20 - 0 \times 46/2 = 13.98 \text{ m}$$

The average lateral pressures match and the lateral discharge is 3.35 L/h.

(13) Calculate the total discharge in lateral 2:

$$Q = 3.35 \times 12 \times 5 = 201 \text{ L/h or } 0.056 \text{ L/s}$$

(14) The discharge in the manifold between laterals 2 and 3 is

$$Q = 0.11 + 0.056 \times 2 = 0.22 \text{ L/s}$$

(15) Repeating the process from Step 8 for the laterals produces the following table. The solution is obtained by iterating in the spreadsheet until the values for average emitter flow and h_f in each row are within prescribed tolerances.

Lateral No.	***Lateral Inlet Head (m)***	***Average Lateral Head, H_a (m)***	***Average Emitter Flow (L/h)***	***Total Flow in Lateral (L/s)***	***Head Loss in Lateral, h_f (m)***	***Flow in Manifold (L/s)***	***Manifold. Head Loss, H_f (m)***	***Manifold Velocity (m/s)***
1	14.11	13.96	3.35	0.056	0.20	0.11	0.02	0.20
2	14.13	13.98	3.35	0.056	0.20	0.22	0.06	0.40
3	14.19	14.04	3.36	0.056	0.20	0.34	0.13	0.60
4	14.31	14.17	3.38	0.056	0.20	0.45	0.22	0.81
5	14.53	14.38	3.41	0.057	0.20	0.56	0.33	1.01
6	14.87	14.71	3.46	0.058	0.21	0.68	0.47	1.22
7	15.34	15.18	3.53	0.059	0.22	0.80	0.64	1.43

Note: Manifold velocity does not exceed 1.5 m/s; however, adding another lateral would increase the velocity beyond the limit and the manifold diameter would need to be increased.

(16) Determine the average emitter discharge for the seven laterals, then calculate *EU* for Subunit 1 from Equation 18.2. *Note*: If the field was not level, the average emitter discharge would need to be calculated for both uphill and downhill half-laterals to calculate *EU* for Subunit 1.

$$q_{avg} = (3.35 + \ldots + 3.53)/7 = 3.41$$

$$EU = 100\left[1 - \frac{1.27(0.05)}{5^{0.5}}\right]\frac{3.34}{3.41} = 95.2 \text{ percent}$$

This is greater than 90 percent determined as acceptable in Step 1, so, the subunit design is acceptable.

(17) Compute the friction loss in each main and submain from Equation 18.5 by determining the diameter that keeps the velocity below 1.5 m/s and the pressure loss within reasonable limits. Assume PVC for the manifold and mains.

Line	Q (L/s)	Pipe i.d.[a] (mm)	Velocity (m/s)	Pipe Length (m)	H_f (m)
Submain, Subunit 1 to B	1.59	52.5	0.73	147	1.64
Main, B to A	3.18	62.7	1.03	96	1.63
Main, A to control head	6.36	77.9	1.34	52	1.11

[a] Inside diameters of Schedule 40 PVC pipe.

(18) The total head required at the outlet from the control head is the pressure required at the inlet to the manifold from Step 15 plus the friction loss in the submain and main lines from Step 17. Assume the head loss through the valve for Subunit 1, obtained from a manufacturer's table, is 1.2 m.

$$15.3 + 1.2 + 1.6 + 1.6 + 1.1 = 20.8 \text{ or use } 21\,\text{m}$$

To irrigate half of the field, the pump must deliver 12.7 L/s (2 × 6.36). The total head requirement for the pump is 21 m plus allowances for pumping lift, pump wear, pump losses, and losses through filters, pressure regulators, valves, and other devices.

18.6 Subsurface Drip Irrigation

Subsurface drip irrigation (SDI) laterals and pipelines in the cropped area are buried. The laterals are placed to deliver water within the plant root zone. Both tubing and tapes are used for SDI laterals. Tubing has thicker walls similar to polyethylene pipe and can be buried deeper. Tapes have thin walls and are less expensive than tubing, but are not as durable and may collapse from soil compaction and traffic. Thicker walled tapes are available and have been successfully used for several years. Thin-walled tapes are used when laterals are replaced after one or two seasons. Pressure-compensating emitters are available with both tubing and tapes.

Evans et al. (2000) indicate the following advantages for properly designed and managed SDI systems: (1) yield may increase; (2) field access is not limited by the irrigation system; (3) limited wetting of the soil surface reduces weed growth and better weed control with minimal chemical application and reduced incidences of diseases; (4) system efficiently and effectively applies labeled chemicals for disease and pest control; (5) reduced handling and exposure of workers to chemicals; (6) permanent beds, minimum tillage, and multiple cropping systems are possible with special equipment; and (7) water and emitter temperature extremes are buffered by the soil, which minimizes the associated flow rate changes.

The disadvantages of SDI systems include (1) initial cost may be high; (2) emitters may be plugged by roots or chemical precipitates; (3) potential rodent or insect damage may occur; (4) salts may accumulate above the laterals, which may interfere with root development; (5) upward movement of water is low in coarse-textured soils; (6) vehicular traffic or roots may pinch the tubing; and (7) management is crucial and somewhat less is known about SDI than other irrigation systems.

The design requirements for SDI systems are similar to those for other microirrigation systems. Special attention must be given to water filtration and treatment, proper location of check and vacuum relief valves, and flushing of the laterals. Because the laterals are buried, it is more difficult to see plugged outlets and to repair plugged emitters or damaged tubing. Check and vacuum relief valves are necessary to prevent negative pressures from developing in the laterals. Negative pressures may cause soil particles to be pulled into the laterals and increase plugging. Emitter outlets should face up so that debris along the bottom of the lateral is less likely to flow into the emitter. Because the ends of the laterals are buried, it is desirable to install a manifold at the downstream end of the laterals for flushing, if laterals are closely spaced. This extra manifold also tends to balance the flow in the laterals and supplies water to both ends of plugged or broken laterals.

The depth of SDI laterals is a balance between avoiding damage by traffic or tillage equipment and the water distribution to the active root zone. It is generally recommended that laterals be installed as shallow as possible with minimal surface wetting because most of the biological activity, air movement, and rooting occurs in the shallow soil layers. With annual and shallow rooted crops, the lateral depth may need to be shallow to wet the soil surface for germination and crop growth. Soil surface wetting (surfacing) is minimized if the laterals are placed deeper, which minimizes evaporation and potential weed growth. Laterals are generally installed at shallower depths in coarse-textured soils and deeper in fine-textured soils. SDI laterals are typically installed at 0.025 to 0.075 m for shallow-rooted crops, at 0.3 to 0.5 m for crops such as cotton, potatoes, sugar beets, and maize, and at 0.15- to 0.2-m depths for many vegetable crops. Emitters may be spaced 0.2 to 1.5 m apart along the lateral depending on the crop and soil characteristics. If a line source is needed, the emitters should be spaced sufficiently close to overlap wetting patterns. Field testing of soil water movement is recommended to determine emitter spacing.

Salinity requires special attention in semiarid and arid regions, because salts tend to reach high concentrations above the lateral and are leached if rainfall occurs. The leached salts will move into the active root zone and may severely affect plant growth. One management solution is to turn on the irrigation system, which will continue to move the salts downward through the soil past the root zone.

Example 18.4 Design a subsurface drip irrigation system for a subunit that is one eighth (100 rows) of the 400-m square field in Figure 18-2. Assume cotton is grown in Arizona with 1-m row spacings and the soil is fine with varying layers of generally low density to 1 m. The field slope is 0.002 down from north to south with no cross slope and laterals run on the slope. Assume the laterals are 15.8 mm in diameter with emitters molded onto the exterior of the pipe with Hazen-Williams C = 140 and will be buried 0.3 m below the soil surface. The laterals are to be supplied from manifolds at both ends to allow occasional flushing of the laterals. Assume minimum *EU* and application efficiency are 90 percent.

Solution. The procedure is similar to Example 18.3.

(1) Use a spreadsheet to perform the calculations. From Figure 15-1, read that the peak *ET* is 10 mm/day and the rooting depth is 1.8 m; however, in this case the rooting depth is limited by the soil to 1 m.

(2) Assume the initial design will use an emitter discharging 2 L/h emitter with $K = 0.5$ and $x = 0.3$ for q in L/h and h in kPa. Field measurements show the average wetted diameter for this emitter is 0.75 m. Select a 0.5-m emitter spacing to ensure the wetted diameters overlap.

(3) Assume a 1-day irrigation frequency. The actual frequency can be changed with a corresponding change in duration. Select a lateral length of 190 m to allow roadways at each end of the subunit. Because water is being supplied from a manifold at both ends, the design will be based on a 95-m half-lateral length with water flowing uphill. The volume of water per half-lateral is

$$d = \frac{10\ \text{mm/day} \times 95\ \text{m} \times 1\ \text{m} \times 1000\ \text{L/m}^3}{1000\ \text{mm/m} \times 0.90} = 1056\ \text{L/day}$$

(4) Substituting into Equation 18.1, $h = (2.0/0.5)^{1/0.3} = 101.6$ kPa or 10.36 m. This is the average operating pressure in the lateral.

(5) With 380 emitters per lateral discharging 2 L/h, the irrigation time is $1056\ \text{L/day}/(2\ \text{L/h} \times 190) = 2.8\ \text{h/day}$. If the field is divided into 8 subunits, the total irrigation time is $2.8 \times 8 = 22.4$ h/day. If the irrigator wants more time for maintenance or repairs, a different layout would be needed.

(6) Calculate the head loss in the half-lateral from Equation 18.5. From Table 17-5, the F value for 190 emitters per lateral is 0.35. The discharge is $2 \times 190 = 380$ L/h or 0.106 L/s.

$$h_f = 0.35 \times 1.21 \times 10^{10} \frac{95}{15.8^{4.87}} \left(\frac{0.106}{140}\right)^{1.852} = 0.97\ \text{m}$$

(7) Calculate the pressure at the distal end of the farthest lateral from Equation 18.8

$$H_d = 10.36 - 0.26 \times 0.97 - 0.002 \times 95/2 = 10.01\ \text{m}$$

(8) The discharge for the last emitter for this lateral is q_{min}.

$$q_{min} = 0.5(10.01 \times 9.81)^{0.3} = 1.98\ \text{L/h}$$

(9) Calculate the inlet pressure for the first lateral using Equation 18.7

$$H_o = 10.36 + 0.74 \times 0.97 + 0.002 \times 95/2 = 11.17\ \text{m}$$

(10) Calculate the head loss in the section of the manifold between laterals 1 and 2 using Equation 18.5. The manifold is 62.71 mm (60 mm nominal) diameter, the connection has no head loss, and the flow in the manifold is 0.211 L/s.

$$H_f = 1.21 \times 10^{10} \times \frac{1}{62.71^{4.87}}\left(\frac{0.106}{150}\right)^{1.852} = 0.00003 \text{ m}$$

(11) The pressure at the inlet to lateral 2 is 11.17 + 0.00003 = 11.17 m.

(12) Calculate the average pressure in lateral 2 from Equation 18.7. Because the discharge in lateral 2 is not known, the value for h_f for lateral 1 is assumed. Iterate until the values for h_f and emitter discharge converge. (The spreadsheet can perform the iterations.) Here the head loss in the manifold is very small and one iteration is sufficient.

$$H_a = 11.17 - 0.74 \times 0.97 - 0.002 \times 95/2 = 10.36 \text{ m}$$

$$q = 0.5(10.36 \times 9.81)^{0.3} = 2.0 \text{ L/h}$$

$$Q_{lateral} = 2.0 \times 190/3600 = 0.106 \text{ L/s}$$

$$h_f = 0.35 \times 1.21 \times 10^{10} \times \frac{95}{15.8^{4.87}}\left(\frac{0.106}{140}\right)^{1.852} = 0.97 \text{ m}$$

$$H_a = 11.17 - 0.74 \times 0.97 - 0.002 \times 95/2 = 10.36 \text{ m}$$

The average pressures match and the average emitter discharge is 2.00 L/h.

(13) Calculate the total discharge in lateral 2 = 2.00 × 190 = 380 L/h or 0.106 L/s.

(14) The discharge in the manifold between laterals 2 and 3 is 0.106 + 0.106 = 0.212 L/s.

(15) Repeating the process from Step 8 produces a table in the spreadsheet of these values for each lateral. Assuming 100 laterals, the velocity nears the limit in the 60-mm manifold so the manifold is increased to a 100-mm nominal diameter at lateral 40. The following table shows the calculations for a few selected laterals.

Lateral No.	Lateral Inlet Head (m)	Average Lateral Head, H_a (m)	Average Emitter Flow (L/h)	Total Flow in Lateral (L/s)	Head Loss in Lateral, h_f (m)	Flow in Manifold (L/s)	Manifold Head Loss, H_f (m)	Manifold Velocity (m/s)
1	11.17	10.36	2.000	0.106	0.97	0.106	0.00003	0.03
2	11.17	10.36	2.000	0.106	0.97	0.212	0.00011	0.07
39	11.52	10.69	2.019	0.107	0.99	4.14	0.0277	1.34
40	11.55	10.72	2.021	0.107	0.99	4.24	0.0027	0.52[a]
99	11.98	11.14	2.044	0.108	1.01	10.57	0.0145	1.29
100	11.99	11.15	2.045	0.108	1.01	10.68	0.0148	1.30

[a] Manifold diameter increased.

(16) *The average emitter discharge in the 100 laterals is 2.0202 L/h. The emission uniformity is*

$$EU = 100\left[1 - \frac{1.27 \times 0.05}{1^{0.5}}\right]\frac{1.98}{2.0202} = 91.8 \text{ percent}$$

This is greater than the desired 90 percent and the design is accepted.

If a design is not acceptable because *EU* is too low, redesign options include (1) increasing pressure, which increases the flow rate; (2) shortening the laterals; (3) selecting emitters that have more pressure compensation; (4) increasing lateral diameter; and (5) re-evaluating emitter wetting pattern to determine if emitter spacing can be increased.

18.7 Microirrigation of Landscape Plants

Landscape plantings, which are often arranged in small groups or as individual plants, are well suited to microirrigation. Water can be supplied to meet the needs of each plant. Simple systems may be connected to a valve on a house and consist of a backflow preventer, a small filter, a pressure regulator, and a lateral with the emitters. Complex systems must be designed for large areas such as parks and golf courses, around large structures, or along highways. In designing these systems, care must be taken to have plants with similar water requirements on the same control valve. Plants in greenhouses and nurseries also are easily irrigated with microirrigation systems since water and nutrients can be delivered to individual plants. Backflow prevention devices are required to prevent contamination of the water supply.

18.8 Microirrigation and the Environment

A properly designed and managed microirrigation system has several environmental advantages compared to surface and sprinkler systems. Because only the soil near plants is irrigated, smaller amounts of chemicals are applied and can be applied where they are most beneficial. Many plants are more tolerant of salinity when the soil water content is maintained at a high level with microirrigation, thus minimum leaching is required and less water and chemicals are carried below the root zone. Disposal of flush water from filters and the lateral lines can be an environmental problem, particularly if the water contains chemicals.

Internet Resources

General reference sites for equipment and information
- www.clemson.edu. Key search term: irrigation
- www.irrigation-mart.com
- www.irrigation.org
- www.wcc.nrcs.usda.gov/nrcsirrig/

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PROBLEMS

18.1 Determine the emission uniformity for emitters with $K = 0.4$ and $x = 0.6$ for q in L/h and p in kPa if the manufacturer's coefficient of variation is 0.1. There are four emitters per plant, average operating pressure is 80 kPa, and the minimum pressure is 70 kPa. What is the emission uniformity if there are two emitters per plant? What is the emission uniformity with 4 emitters per plant, an average operating pressure is 110 kPa, and the minimum pressure is 100 kPa?

18.2 If the conventional peak *ET* of an orchard is 7.5 mm/day and 65 percent of the area is shaded by trees, determine the design *ET* rate, volume of water required per tree per day, and application rate in L/h per tree for a microirrigation system. Assume *EU* = 92 percent, a tree spacing of 3 × 6 m, 20 h/day operation, and irrigation interval of 2 days.

18.3 For the orchard in Problem 18.2, determine the number of emitters required per tree. Assume a coarse-textured soil of low density, a 1.5-m root zone, and 40 percent of the area is to be irrigated.

18.4 Determine the friction loss in the 15.8-mm-diameter lateral if 72 in-line emitters are uniformly spaced 1m apart along a line as in Figure 18-4a. Assume the average emitter discharge is 3.6 L/h and the equivalent pipe length for an emitter is 2 m.

18.5 Develop a spreadsheet for calculating *EU* for Subunit 1 in Example 18.3.

18.6 For the data in Example 18.3, determine *EU* for Subunit 2 by adding to the spreadsheet in Problem 18.5.

18.7 Determine *EU* for Subunit 1 of Example 18.3 if the field has a 1 percent slope uphill from the water supply and no cross slope.

18.8 From the data in Example 18.3, redesign the delivery system for laterals with 48 trees. Assume the manifolds remain 91 m long.

18.9 Design a microirrigation system for 10 rows of forty 20-L pots in a nursery. Assume the rows have a 1-m spacing and the pots a 0.5-m spacing in the row, and water is available at 15 m head. The pots are to receive 0.2 L of water twice a day.

18.10 Develop a spreadsheet to perform the calculations for Example 18.4.

18.11 Complete the design of Example 18.4 to determine the pipe diameter, head, and flow rate required at the outlet of the control head. Assume the flow rate in the manifold at the other end of the laterals is equal to the flow rate calculated for the manifold in the example.

18.12 Use the spreadsheet from Problem 18.10 to determine *EU* for the subunit in Example 18.4 if the emitter spacing is changed to 0.6 m. Can the field be irrigated in one day with this design? Explain your answer.

18.13 Use the spreadsheet from Problem 18.10 to determine *EU* for Example 18.4 if C_v is 0.07. What is the *EU* for Example 18.4 if the exponent x is changed to 0.4? What is *EU* in Example 18.4 if the lateral slope is 0.01? Explain why *EU* changes.

18.14 Use the spreadsheet from Problem 18.10 to design one subunit of a SDI system for a 600-m square level field. Assume a row spacing of 0.8 m, peak *ET* is 7 mm/day, $K = 0.55$ and $x = 0.3$ in Equation 18.1 for q in L/h and h in kPa, and the operating time is a maximum of 22 hours/day.

Soil and Water Conservation Engineering

FIFTH EDITION

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