Subsurface drip irrigation saves water, improves crop yields and quality, and facilitates fertilizer application; however, system performance is dependent upon skilled management. Potential disadvantages include salt accumulation near plants, restricted root development, high system costs, and restricted crop rotation. The three primary hydraulic classifications of drip emitters are laminar, turbulent, and pressure compensating. Analysis of Reynolds equation shows the advantage of turbulent flow emitters over laminar flow emitters. Pressure compensating emitters have the best hydraulic performance and generally rely on diaphragms that reduce flow at high pressure. As with sprinkler irrigation laterals, drip irrigation laterals are multi-outlet systems. The hydraulics can be calculated with analytic equations if slope is uniform, or with spreadsheets for any field. Most drip laterals in agriculture are classified as in-line, with emitters manufactured into the tubing. Proper filtration is a key to successful drip irrigation system performance. Sand filters are a necessary pretreatment step when the water source is a pond or stream. The design of lateral length and diameter is evaluated by the emission uniformity, which is a function of number of emitters per plant, minimum and average pressure in the lateral, the emitter exponent, and the manufacturer's coefficient of variation. The most popular drip system is subsurface drip irrigation with dual feed laterals (Fig. 17.1).

Drip Emitters

Drip emitters have small openings that dissipate pressure and discharge a small flow of water in discrete drops or a continuous tiny stream. Emitters are classified as laminar flow, turbulent, orifice, vortex, partially pressure compensating, or pressure compensating. The hydraulic relationship between pressure and flow is a function of the type of emitter. This relationship is given as $q = kh^x$ where q is emitter discharge, h is operating pressure head, k is the emitter discharge coefficient, and x is the emitter discharge exponent. Laminar flow emitters (long path) are long, narrow tubes, and energy is dissipated in the tube. The emitter exponent, x, is 1.0, which indicates that flow is directly proportional to pressure. Another drawback is that tube diameter is narrow and prone to plugging. The tube geometry may be straight (spaghetti tubing) or follow a spiral flow path around a cylindrical core.

Turbulent emitters ($x = 0.57$) dissipate energy in turbulent eddies that form in tortuous paths within the emitter. Orifice emitters dissipate energy in a single orifice; thus, the diameter is extremely small (less than laminar) and these emitters are prone to plugging. The flow varies with the square root of pressure so $x = 0.5$ as with sprinklers. Vortex emitters are similar to orifice emitters except that the water passes through one turbulent eddy before exiting the orifice; the turbulent eddy decreases the emitter exponent x to 0.4. As with orifice emitters, vortex emitters have a narrow orifice and are prone to plugging.

Pressure compensating emitters have virtually no change in flow rate over a range of pressures. These are emitters with diaphragm closing as pressure increases and vice versa. Some emitters with diaphragms "pseudo pressure compensating" may be labeled as pressure compensating, but they are not truly pressure compensating. This mislabeling can cause unexpected nonuniformity if the engineer assumes that the emitters are truly pressure compensating. The engineer will assume that pressure loss along the tubing will not cause a change in flow rate and fail to design a large enough diameter tube to prevent pressure loss. This could cause lawsuits so the design team should check emitters.

Turbulent flow emitters are designed so that vortices are set up in the flow path. One advantage of turbulent flow emitters is that they have a larger diameter flow path because energy is dissipated in turbulent eddies rather than in small diameter tubes or orifices. Thus, they are less likely to plug than laminar flow or orifice emitters. Pressure compensating
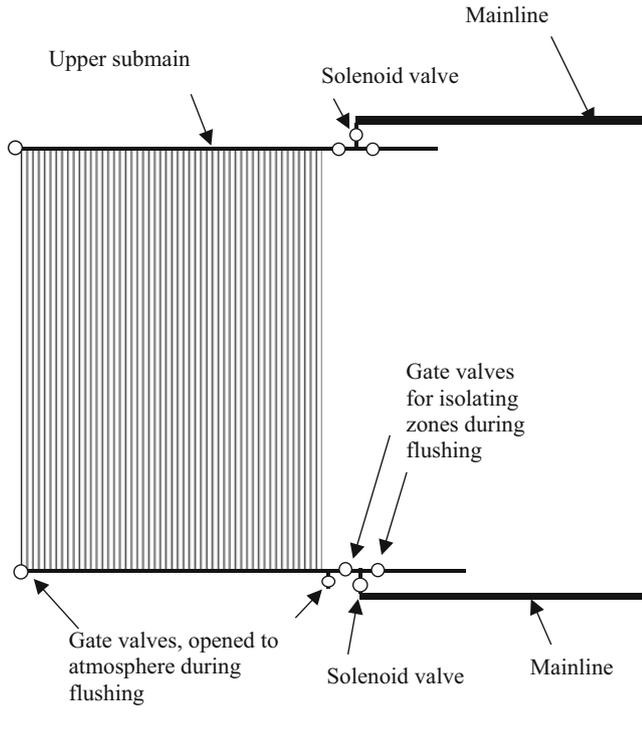
Fig. 17.1 Dual feed subsurface drip irrigation system

emitters with a diaphragm that retracts until pressurization are even less likely to have plugging than normal turbulent emitters. The flushing procedure for the turbulent emitter is the opposite of that for the diaphragm emitter.

Analysis of the Darcy-Weisbach equation shows that x is 1.0 for laminar flow emitters and 0.57 for turbulent flow emitters.

$$h_f = 6.377 fL \left(\frac{q^2}{D^5} \right) \qquad (17.1)$$

The Darcy-Weisbach friction factor is 64/Re for laminar flow. Rearrange Eq. 17.1 substitute 64/Re for f.

$$q^2 = \left(\frac{h_f D^5}{6.377 fL} \right) = \left(\frac{h_f D^5}{\left(\frac{64}{Re} \right) 6.377 L} \right) = \left(\frac{h_f Re D^5}{(64) \; 6.377 L} \right)$$

$$= \left(\frac{h_f \rho V D^6}{(64) \; 6.377 \mu L} \right) = \left(\frac{h_f \rho \left(\frac{q}{A} \right) D^6}{(64) \; 6.377 \mu L} \right)$$

$$q = \left(\frac{h_f \rho D^6}{(64) \; 6.377 \mu L A} \right)$$

$$(17.2)$$

Thus, q is a linear function of pressure drop, h_f (equal to the pressure in the lateral, H), and the emitter exponent, x, is 1.0. The constant k in the emitter flow equation is equal to the rest of the terms on the right side of Eq. 17.2.

$$q = k h_f = k H^1 \qquad (17.3)$$

q varies linearly with viscosity in Eq. 17.2; thus, laminar flow emitters are highly sensitive to viscosity changes because of temperature change. Because water can heat up in drip laterals in the field, especially on the ground surface, this fact can cause major changes in emitter flow rate from one end of the drip lateral to the other.

The Darcy-Weisbach is next used to derive the relationship between flow rate and pressure in a turbulent emitter. The Blasius friction factor for turbulent flow in smooth pipe is

$$f = 0.316 \; Re^{-0.25} \qquad (17.4)$$

Substitute the Blasius friction factor into the Darcy-Weisbach equation.

$$q^2 = \left(\frac{h_f D^5}{6.377 fL} \right) = \left(\frac{h_f D^5}{\left(\frac{0.316}{Re^{0.25}} \right) 6.377 L} \right)$$

$$= \left(\frac{h_f Re^{0.25} D^5}{(0.316) \; 6.377 L} \right) = \left(\frac{h_f \rho^{0.25} \left(\frac{q}{A} \right)^{0.25} D^{5.25}}{(0.316) \; 6.377 \mu^{0.25} L} \right)$$

$$= \left(\frac{h_f \rho^{0.25} q^{0.25} D^{5.25}}{(0.316) \; 6.377 \mu^{0.25} L A^{0.25}} \right)$$

$$q^{1.75} = h_f \left(\frac{\rho^{0.25} D^{5.25}}{(0.316) \; 6.377 \mu^{0.25} L A^{0.25}} \right)$$

$$q = h_f^{1/1.75} \left(\frac{\rho^{0.25} D^{5.25}}{(0.316) \; 6.377 \mu^{0.25} L A^{0.25}} \right)^{1/1.75}$$

$$= h_f^{0.57} \left(\frac{\rho^{0.25} D^{5.25}}{(0.316) \; 6.377 \mu^{0.25} L A^{0.25}} \right)^{0.57}$$

$$(17.5)$$

Equation 17.5 shows that the value of x for turbulent flow emitters is 0.57: $q = k h_f^{0.57}$. Although the theoretical derivation shows that turbulent flow emitters have an emitter exponent equal to 0.57, some turbulent flow emitters have an emitter exponent in the range of 0.5 or less. Flow rate in turbulent emitters is insensitive to viscosity changes, q is proportional to $(\mu^{-0.25})^{0.57} = \mu^{-0.145}$. Because of lower possibility of plugging, less sensitivity to temperature change, and less sensitivity to pressure change, turbulent flow emitters are superior to laminar flow emitters. Figure 17.2
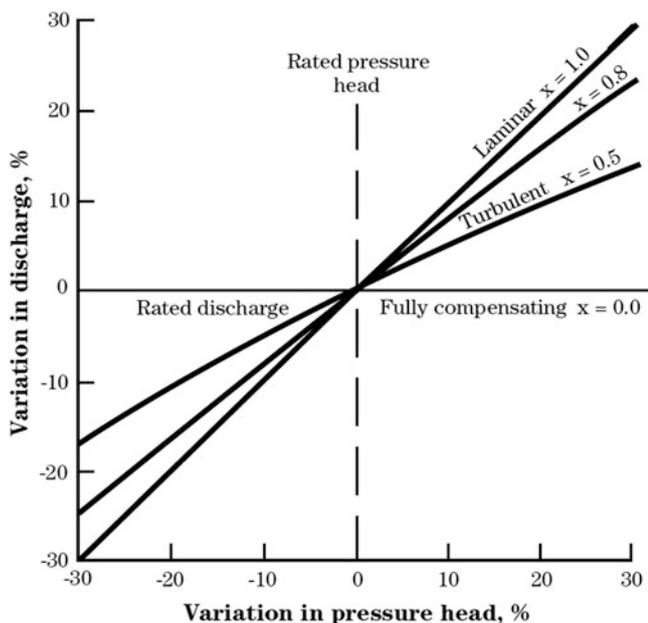
Fig. 17.2 Flow rate versus pressure variations for different emitter exponents (Credit NRCS)

Fig. 17.3 Injection molded inline emitter attached to thick wall polyethylene tubing (Credit NRCS NEH)

shows emitter flow rate vs. pressure variations for several values of x.

Example 17.1 Calculate the flow rate for the following emitters (laminar, turbulent, and pressure compensating) at 50 and 100 kPa pressure (coefficient k for units of LPH and kPa).

$$k = 0.02 \text{ and } x = 1 \quad \text{laminar}$$
$$k = 0.2 \text{ and } x = 0.5 \quad \text{turbulent or orifice}$$
$$k = 2 \text{ and } x = 0 \quad \text{pressure compensating}$$

x = 1	x = 0.5	x = 0
$q = 0.02 (50^1) =$ 1.0 LPH.	$q = 0.2 (50^{0.5}) =$ 1.4 LPH.	$q = 2 (50^0) =$ 2 LPH.
$q = 0.02 (100^1) =$ 2.0 LPH.	$q = 0.2 (100^{0.5}) =$ 2.0 LPH.	$q = 2 * (100^0) =$ 2 LPH.

Drip Tubing

There are primary three types of agricultural drip tubing. Thick wall (45 mil) polyethylene tubing with inline (integral) emitters has emitters manufactured into the tubing wall or injection molded emitters attached to the wall and is used in row crops (Fig. 17.3). Thick wall (45 mil) polyethylene tubing without inline emitters and into which single port emitters are inserted is used in vineyards and landscaping.

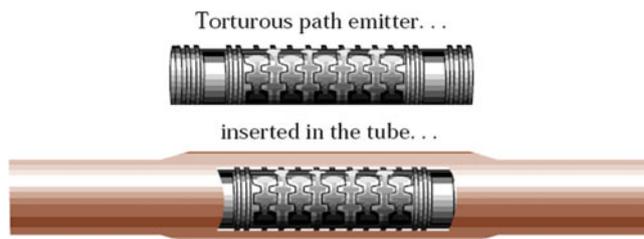Thin wall polyethylene drip tape (lays flat when not pressurized) is sold with a wall thickness ranging from 4 to 15 mil and thicker for larger diameters: a mil is one thousandth of an inch. The thinner wall drip tape, 4–6 mil, is used for one season, cannot be used in soil with rocks or clay, and must be buried. Eight mil tubing may be used for 1–2 years. Fifteen mil drip tape has been shown to last in the field for 15 years when buried and very carefully managed. However, rodents, contact with farm implements, and poor chemical control can dramatically reduce the life span of tubing. Thin wall drip tape has emitter flow rates ranging from 0.5 to 2 LPH and emitter spacing ranging from 10 to 75 cm.

Thick wall tubing (45 mil wall thickness) maintains a cylindrical shape when empty. It can be purchased in many diameters, but typical diameters used in agricultural and landscaping drip laterals are 12, 16, and 22 mm ID. Thick wall inline drip tubing has emitter flow rates ranging from 0.5 to 2 LPH and spacing up to 1.3 m. Common inside diameters of drip tape and thick wall tubing with integral emitters are 13, 16, and 20 mm ID. Some manufacturers also make 22 and 35 mm ID for longer rows.

Subsurface Drip Tape Installation

The most common type of agricultural drip irrigation is subsurface drip irrigation (SDI): drip tape with inline emitters buried approximately 15 cm below the soil surface. Subsurface drip irrigation (SDI) was developed by the USDA Agricultural Research Service in Fresno, California, and adapted to the commercial farm scale by Dr. Howard Wuertz at Sundance Farms in Coolidge, Arizona.

A tape injection unit attached to a tractor automatically installs subsurface drip tape. Spools, holding 1000 to 2000 m rolls of drip tape, feed the roll of tape into atube that trails behind a shank. Tubing is typically installed 0.15 m below the ground surface. With the advent of differential GPS, the location of the tubing is recorded as it is installed; before GPS, the tubing was installed in the center of beds, and the beds were very carefully maintained year after year so that the location of tubing was known. It is important to use high quality and properly maintained tape injection equipment because a small burr or weld in the feeder tube can rip the drip tape, which results in the need for reinstallation.

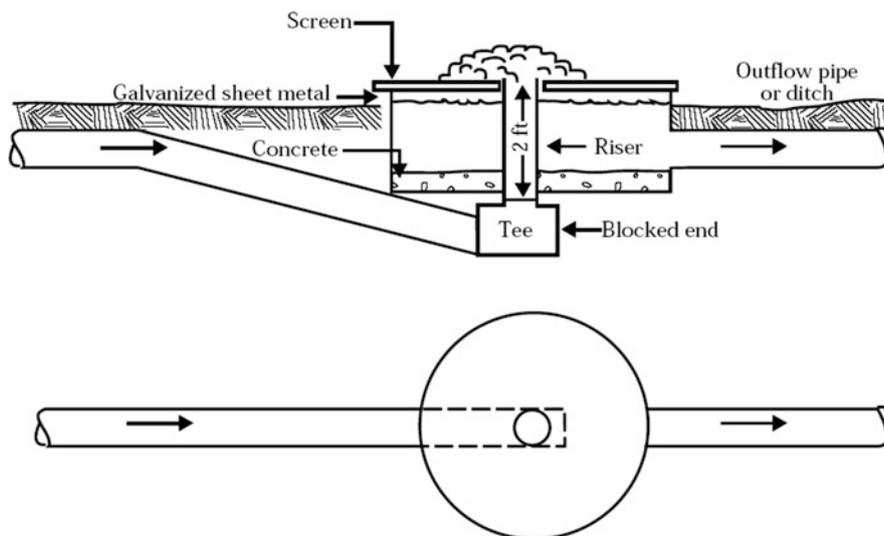**Fig. 17.4** Flat stainless steel screen filter design (Credit NRCS)

Screen

Galvanized sheet metal

Outflow pipe or ditch

Concrete

2 ft

Riser

Tee

Blocked end

Table 17.1 Recommended stainless steel screen and riser pipe diameters for round flat filters (Credit NRCS)

Flow rate		Flow rate	Screen diameter		Riser pipe diameter	
(GPM)	(cfs)	(cms)	(m)	(in)	(m)	(in)
1	450	12.7	42	1.07	8	0.20
2	900	25.5	48	1.22	10	0.25
3	1,350	38.2	60	1.52	12	0.30
4	1,800	51.0	72	1.83	15	0.38
5	2,250	63.7	84	2.13	18	0.46

Filtration

Drip emitters have small openings and are easily plugged; thus, filtration is required to remove suspended sediment and biological materials from irrigation water. There are three primary types of filters used for drip irrigation: sand filters, mesh filters, and disc filters.

Prefiltration: Stainless Steel Screen Filters

If water has a high concentration of algae or sediment, then it will overwhelm and plug sand filters; thus, a prefiltration step, such as a settling pond for sediment or a stainless steel screen filter for algae, must be installed upstream from the filters. Algae can be removed with cylindrical stainless steel screen filters as shown in Fig. 12.30 or with round flat screen filters as shown in Fig. 17.4. Flat screen filters do not require regular cleaning because the water naturally pushes the debris off the edge of the filter. These filters can also be constructed with a linear flow path with water dropping to the filter from one side and pushing debris off the other end.

Recommended screen and riser geometry for round flat filters is listed in Table 17.1.

Prefiltration: Settling Basins

Settling basins can be used as a prefiltration step for waters with high suspended sediment loads. They effectively remove silt or sand but do not remove clay particles because clay particles are small and do not settle. Water flow velocity is low in order to ensure laminar flow with no turbulent eddies. For laminar flow, the settling velocity is determined by Stokes law and can be calculated with the following equation.

$$V_p = 3.43*10^{-5}D^2(SG1) \tag{17.6}$$

where

V_p = settling velocity of particle, m/min,
D = particle diameter, microns,
SG = specific gravity of particle, 2.65 for mineral (soil) particles.

Basins should be long enough so that particles of a given size settle to the bottom of the basin. Settling basin lengths should be approximately 5 times their width in order to prevent short- circuiting (a stream flowing through one side of the settling basin while other zones are stagnant). In order to distribute flow across the basin, a baffle structure may be necessary at the basin inlet. The inlet should be below the surface to prevent contaminants from floating on the water surface. Settling basin depth should be 0.6 m. The surface area of the settling basin is calculated based on the requirement that the velocity remains laminar at an average depth of

0.6 m. A safety factor of 2.0 is incorporated into the design to account for sedimentation and a decrease in depth of the settling basin. If settling basin depth is 0.6 m and side slopes are 2:1, then the water surface area of the settling basin is calculated with the following equation.

$$Area = 0.001 \ F \ \left(\frac{Q}{V_p}\right) = 0.001 \ (2.0) \ \left(\frac{Q}{V_p}\right) \quad (17.7)$$

Where

Area = water surface area, m^2,
F = safety factor,
Q = irrigation system flow rate, LPM
V_p = settling velocity of design particle size, m/min.

The width of the settling basin is a function of the area.

$$W = \sqrt{\frac{Area}{5}}$$

where

W = width of settling basin, m.

The length of the settling basin is a function of the width.

$$L = 5 \ W$$

where

L = length of settling basin, m.

Example 17.2 Irrigation system flow rate is 1200 LPM, and the water carries a large volume of silt. What are the required dimensions of the settling basin. Assume that the design particle diameter is 30 microns (0.03 mm)

$$V_p = 3.43*10^{-5}D^2(SG1) = 3.43*10^{-5}\left(30^2\right)(1.65)$$
$$= 0.051 \ m/min$$
$$Area = 0.001 \ F\left(\frac{Q}{V_p}\right) = 0.001 \ (2.0) \ \left(\frac{1,200}{0.051}\right) = 47 \ m^2$$
$$W = \sqrt{\frac{Area}{5}} = \sqrt{\frac{47}{5}} = 3.1 \ m \quad L = 3.1 \ m(5) = 15.5 \ m$$

Prefiltration-Centrifugal Sand Separation

Well water often has a significant fraction of sand. If water has a sand particle concentration in the range between 2 and 20 ppm, a centrifugal sand separator can be installed in the irrigation line to remove sand (Netafim Hydroclone Sand Separators Guide, 2015). The vortex action forces sand to the outside of the tank and sand falls into the sedimentation tank as water is removed from the outlet on top of the cone.

Pressure loss in a sand separator is in the range of 2–5 m. Sand separators are typically followed by an appropriate filter. A screen or disc filter may be used if the sand is removed by the sand separator.

Removal Efficiency

The removal efficiency for any filter or prefiltration step is $(1 - C_{passed})/C_{initial}$ where C_{passed} is the concentration of particles in filter discharge and $C_{initial}$ is the concentration of particles in the filter inlet. Filtration efficiency should be verified before water is injected into a drip irrigation system because filtration failure and clogging can destroy a drip system within a short time and replacement of emitters is the consequence. In addition to an initial performance evaluation, filtration efficiency should be checked regularly.

Filter Mesh Size

Sand, screen, and disc filters are classified based on a mesh size. The filter pores or openings should be approximately ¼ the size of emitter openings. Drip irrigation manufacturers specify a mesh size required for each emitter. For a screen filter, filter mesh size refers to the number of slots per inch (25.4 mm). For example, a 200 mesh filter has 200 slots per linear inch in each direction. Most drip emitter manufacturers recommend mesh sizes between 100 and 200, with 150 and 75 micron openings, respectively. Although sand filters do not have a woven mesh like a screen filter, sand filters can be classified according to mesh size. Silica sand is normally used in sand filters: crushed silica sizes 8, 11, 16, 20, and 30 have screen mesh equivalents of 70, 140, 170, 230, and 400 mesh, respectively (Kansas State University Extension Bulletin).

Filter Selection

Sand filters are required for low quality water (algae or suspended sediment) from a surface water body such as a pond, lake, canal, or stream. Even sand filters, however, may be overloaded by some water sources that are extremely high in sediment or algae. In this case, a prefiltration process is needed. Screen and disc filters have a very small surface area compared to sand filters; thus, they plug rapidly if water has a significant concentration of sediment or organic matter. Screen and disc filters are suitable for municipal water and well water. Screen or disc filters are often placed after sand filters to protect the system if the sand filter fails. If a filter has not been used with a certain water source and system application, then the filter should be tested on-site at the

Fig. 17.5 Sand media filters (Credit Yardney Corp)

expected flow rate. However, even with testing, caution is required because water quality and biological growth rates in canals and streams can fluctuate with temperature, nutrients, or other factors.

Sand Filters

Pressurized tank sand filters (Fig. 17.5) use a pressure differential to force water through the sand media. Particulate matter is caught in the pores between sand particles. The pressure differential across the filter increases as sand becomes clogged with sediment or algae. Once the pressure differential reaches a threshold value, a backflush cycle is triggered. During the backflush cycle, water flow is closed off from the inlet manifold by the backflush valve (Fig. 17.5) and flows upward through the filter from the outlet manifold. The backflush valve directs the discharge to a discharge pipe. Sand filters can be purchased in manual backflush or automatic backflush configurations. An automatic backflush system requires at least two filters installed in parallel because water must pass through one filter in order to backflush the other filter. The backflush flow rate should be set so that a small amount of sand is flushed out of the filter during each backflush cycle. This flow rate fluidizes the sand bed and cleans the bed. Even with proper cleaning, the sand filter media needs to be replaced every two to three years.

During the backflush cycle, pressure in the outlet manifold must be maintained at the pressure recommended by the manufacturer in order to maintain adequate upward flow. The required outlet manifold pressure may be as high as 30 PSI (210 kPa) (Netafim Sand Media Filter Guide, 2015). Thus, a booster pump may be needed during flushing if the required outlet manifold pressure is significantly higher than

normal drip system pressure. If drip tubing has a pressure rating lower than the required backflush pressure, a pressure regulating valve is required downstream from the filter in order to prevent damage to the tubing.

Automatic backflush filters have electronic pressure sensors installed at the inlet and outlet of the sand filter. These sensors monitor the pressure loss through the sand filter, and they trigger a backflush cycle when the pressure differential reaches a threshold set by the operator. The threshold is normally 5–7 PSI (35–42 kPa) greater than the pressure differential with clean sand. Filters can also be set to backflush at set time intervals. Typical backflush intervals are every 2–4 hours and typical backflush cycle times are two minutes; however, this is dependent on water quality. Approximately 30 seconds are required between sequential filter backflushes in order to allow the sand in the filter to settle.

Pressure loss through the sand filter is the sum of losses in the backflush valve, sand media, outlets at the bottom of the sand media, and, if they are installed, secondary screen or disc filters on the discharge side of the filter. Thus, the pressure requirement of the system must include all of the filtration losses, which may be higher than the drip emitter operating pressure.

In selecting sand filters, a rule of thumb is that the maximum flow rate through sand filters should be 18 LPS per square meter of cross-sectional tank area (25 GPM/ft^2). Sand filters should be mounted on a concrete pad that is 0.1 m (4 in.) thick with 0.15×0.15 m (6×6 in.) footings for the legs. The pad dimensions should exceed the filter by 30 cm (1 ft) on all sides.

Example 17.3 Irrigation system flow rate is 300 GPM (1162 LPM). The filter system requires a 30 PSI (210 kPa) discharge manifold pressure. Select a sand filter diameter for a 2 sand filter system. Available alternatives are 24, 30, and 36 in (0.6, 0.75, and 0.9 m) diameter. Assume that the filter has a 1.5 PSI (10 kPa) pressure loss when the sand is clean. The required outlet manifold pressure is 30 PSI (280 kPa). What is the required inlet manifold pressure?

In a 2 filter system, each filter carries half of the flow, 150 GPM (580 LPM). Make an initial estimate based on the 18 LPS/m^2 rule.

$$(580 \text{ LPM}) / (60 \text{ sec /min}) / (18 \text{ LPS/m}^2) = 0.54 \text{ m}^2$$

$$A = \pi D^2/4 \quad D = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4 \ (0.54)}{\pi}} = 0.83 \ m = 33 \ in.$$

The next largest filter size should be selected, the 36 in filter.

Seven PSI should be added to the clean sand pressure loss (8.5 PSI, 59 kPa). If the required outlet manifold pressure is 30 PSI (280 kPa), then the required inlet pressure is 38.5 PSI (340 kPa).

Disc Filters

Disc filters utilize stacks of grooved donut shaped discs that capture sediment between the discs. During filtration, the stack of discs is compressed together, but during the backflush cycle, the stack is loosened as backflush water in the opposite direction through the discs. The backflush water and sediment are discharged from the filter to a discharge pipe.

Screen Filters

Screen filters are commonly used for drip systems that are supplied with relatively clean well water or municipal water. They have low surface area so they plug rapidly if there is significant algae or sediment in the water. The fine mesh can be made of several materials; however, nylon is not suitable for areas with high temperatures because nylon stretches in the heat.

Design of Drip Emitter Spacing, Flow Rate, and Schedule

The first step in the drip irrigation system design process is to make an educated estimate of the emitter spacing along the lateral, the spacing between laterals, the emitter flow rate, and lateral length. Factors that determine the selection of spacing and flow rate include plant spacing, plant rooting characteristics, soil texture, and lateral hydraulics. After a preliminary hydraulic evaluation, it may be necessary to modify the spacings and flow rate. This process continues until the economic cost is minimized and the appropriate design constraints (uniformity and application rate) are met.

Calculation of the soil water holding capacity is generally not required for drip irrigation systems because drip irrigation is a high frequency irrigation system with daily or even more frequent water application.

The gross water application rate (mm/hr) is.

$$(di/dt)_g = \left(\frac{Emitter\ flow\ rate}{area\ per\ emitter}\right) = \left(\frac{q_e}{s_l\ s_d}\right) = \left(\frac{L/hr}{m^2}\right) \tag{17.8}$$

Where

$(di/dt)_g$ = gross water application rate, mm/hr,
s_l = spacing along lateral, m,
s_d = spacing between laterals, m,
q_e = emitter flow rate, L/hr.

The net application rate is the product of the gross application rate and the water application efficiency

$$(di/dt)_a = (di/dt)_g(Eff/100) \tag{17.9}$$

The required number of watering hours per day is the evapotranspiration rate (average for the field, mm/day) divided by the net application rate (average rate over the field area, mm/hr). Divide max $ET_{c\text{-max}}$ (worst case) by the net application rate to find the required hours of application per day in each zone.

$$T_z(hr/day) = \frac{ET_{c-\max}\ (mm/day)}{(di/dt)_a\ (mm/hr)} \tag{17.10}$$

where

T_z = application time per day in each zone, hr/day.

The number of watering periods is the hours of irrigation system operation per day, T_r, divided by T_z. The number of periods must be rounded down to the next smaller whole number.

$$N_p = \frac{T_r}{T_z} \tag{17.11}$$

where

N_p = number of watering periods per day.

In-class Exercise 17.1 Emitters are spaced at 0.25 m along the lateral and 1 m between laterals, and emitter flow rate is 1 LPH. For a daily plant water requirement of 12 mm/day, calculate the application rate and the application time if plants are watered on a daily basis. Assume 90 % efficiency. System is operated for 22 hr/day. Calculate the number of watering periods per day.

Although there may be tens or even hundreds of valves on a large farm, for design purposes in this phase, assume that N_p groups of zones will be watered during the N_p periods. The area of the farm that is watered during each watering period is

$$A_p = \frac{A_f}{N_p} \tag{17.12}$$

where

A_p = area watered during each watering period, ha.
A_f = area of the farm, ha.

The number of emitters per ha is

$$E_d = \left(\frac{10,000 \ m^2}{ha}\right)\left(\frac{1 \ emitter}{s_L \ s_d \ m^2}\right) \qquad (17.13)$$

where

E_d = emitter density, number of emitters per ha.

The required irrigation system flow rate is

$$Q_p = \frac{E_d Q_e A_p}{3,600} \qquad (17.14)$$

where

Q_p = irrigation system flow rate, LPS.

Lateral Design

This chapter includes an Excel workbook that includes the examples in chapters 17 and 18, which focus on dual feed laterals. The workbook in these chapters also does not include local losses due to emitter barbed fittings or inline emitter flow constrictions. The *Chapter 21 Hydroponic irrigation* workbook includes local losses and has far fewer spreadsheets. Thus, it is easier to use for analysis of single feed laterals.

In general, the Darcy-Weisbach equation, with the Blasius or laminar friction factor (64/Re), is used to calculate drip lateral hydraulics. A spreadsheet can be used to calculate pressure and flow distribution along the lateral. The calculation processs begins at the end of the lateral since upstream flow rate and pressure loss are a function of downstream flow rate and pressure. Assume the minimum acceptable pressure at the distal end of the lateral and work backwards to the inlet: flow in each pipe section is the sum of all the downstream emitter flow rates. In this section, the additional pressure loss from barbed drippers inserted into the pipeline is ignored.

$$Q_{n-pipe} = \sum_{n}^{N_e} Q_{n-e} \qquad (17.15)$$

where

Q_{n-pipe} = flow rate in pipe section n,
Q_{n-e} = flow rate in emitter n

The difference in pressure from one emitter to the next is

$$H_n = H_{n+1} + \ h_f + S_e s_l \qquad (17.16)$$

where

H_n = pressure at emitter n, m,
S_e = slope (m/m), negative for inlet higher than distal end,
s_l = distance between emitters,
n = emitter number with n = 1 at the inlet.

One additional constraint on drip lateral design is that sediments must be periodically flushed from laterals. There is disagreement as to the required flushing velocity, but a typical rule of thumb is that flow velocity must be at least 0.5 m/sec (1.5 ft/sec) at the end of laterals in order to keep particles in suspension. The ASAE (EP405) Standard for Microirrigation recommends a velocity of 1 ft/sec (0.33 m/ sec) while others recommend 2 ft/sec (0.67 m/sec). Additional flow velocity may be needed to scour the sides of laterals if a slime begins to develop in tubing.

Example 17.4 Calculate the pressure and emitter flow rate along a 12 mm ID single feed lateral with emitter spacing, s_l = 0.5 m, k = 0.2 (LPH and kPa), x = 0.5, S_e = −0.002 (inlet higher than distal end) and S_e = 0.002 (inlet lower than distal end), and L (length of lateral) = 100 m. Minimum operating pressure is 100 kPa (10.2 m). Because the inlet is higher than distal end, S_e = −0.002. Make two manual calculations and then use the *Single feed lateral* worksheet.

The pressure at the last emitter is 100 kPa.

$$Q_{200} = 0.2(100^{0.5}) = 2.0 \ LPH.$$

Calculate pressure loss in the lateral section before the last emitter.

$$v = \frac{Q}{A} = \left(\frac{2 \ L \ ph}{\pi(6/1000)^2 \ m^2}\right)\left(\frac{m^3}{1,000 \ L}\right)\left(\frac{hr}{3,600 \ sec}\right)$$
$$= 0.0049 \ m/sec$$
$$Re = \frac{vD}{v} = \frac{0.0049 \ (12 \ mm/1,000 \ mm/m)}{1*10^{-6}} = 59$$

Flow is laminar (Re < 2000) so use the laminar flow friction factor equation.

$$f = \frac{64}{Re} = \frac{64}{59} = 1.1$$
$$h_f = 6.377 fL\left[\frac{Q^2}{D^5}\right] = 6.377 \ (1.1) \ (0.5 \ m) \ \left[\frac{2^2}{12^5}\right]$$
$$= 0.000056 \ m$$

Friction loss is 0.000056 m between the last emitter and the next to last emitter. Pressure at the next to last emitter is calculated based on friction loss and elevation difference

between the two emitters. Thus, pressure at the next to last emitter (199) is:

$$H_n = H_{n+1} + h_f + S_e s_l$$
$$= 10.2 \text{ m} + 0.000056 + (-0.002 \text{ m/m})(0.5 \text{ m})$$
$$= 10.19906 \text{ m}/0.102 = 99.99 \text{ kPa}.$$

Pressure is lower in the next to last emitter because friction loss is less than the elevation difference between the last two emitters. Flow from emitter 199 is

$$Q_{199} = 0.2(99.99^{0.5}) = 1.9999 \text{ Lph}$$

Flow in the next to last pipe section of the lateral is the sum of the flows of the last 2 emitters.

$$Q = 2 + 1.9999 = 3.9999.$$

The Blasius equation for friction factor is used once the Reynolds number rises above 2000. Calculations are made in the *Single feed lateral* worksheet (Fig. 17.6). Ignore the information in the upper right corner of the worksheet.

Average flow rate in the downslope lateral is 2.105 LPH, and average pressure is 11.33 m. Figure 17.7 shows the pressure vs. flow distribution for the upslope ($S_e = 0.002$) lateral. Average flow rate in the upslope lateral is 2.124 LPH, and average pressure is 11.55 m.

The *Flushing* worksheet evaluates the flushing process. In order to maintain minimum scouring velocity, flow rate and pressure were specified at the end of the downslope lateral as 264 LPH (0.5 m/sec in 12 mm tubing) and 1.0 m, respectively. This results in an inlet flow rate of 544 LPH and inlet pressure of 12.4 m (Fig. 17.8).

Drip irrigation lateral hydraulics can also be calculated with analytic equations that use the Christensen's factor.

$$h_{ac} = h_f F \tag{17.17}$$

where

h_{ac} = actual pressure loss in the pipeline
h_f = friction loss in fully flowing pipe
F = Christensen's friction factor.

Christensen's friction factor for drip irrigation laterals is

$$F = \frac{1}{m+1} + \frac{1}{2N} + \frac{(m-1)^{0.5}}{6N^2} \tag{17.18}$$

where

N = number of outlets
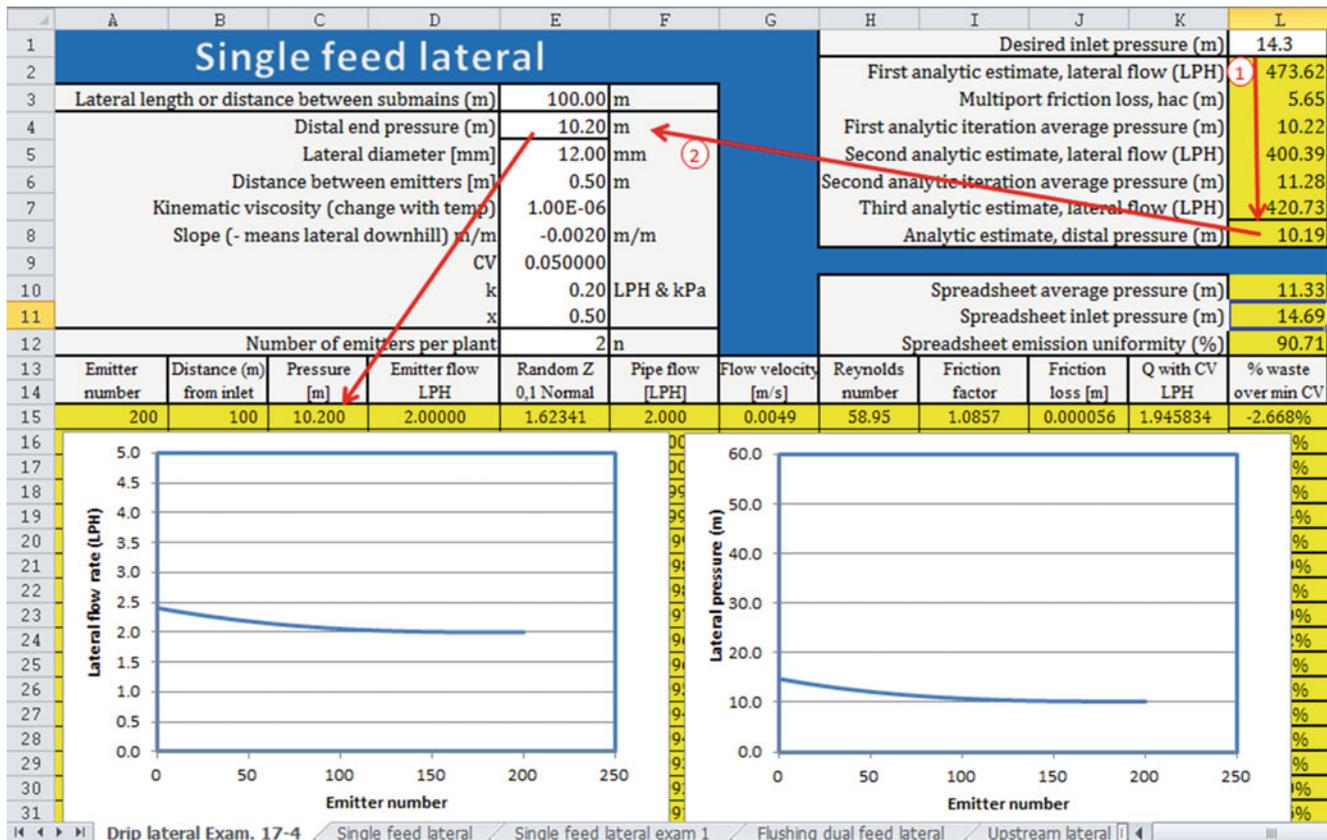m = exponent in Darcy-Weisbach equation, (2).

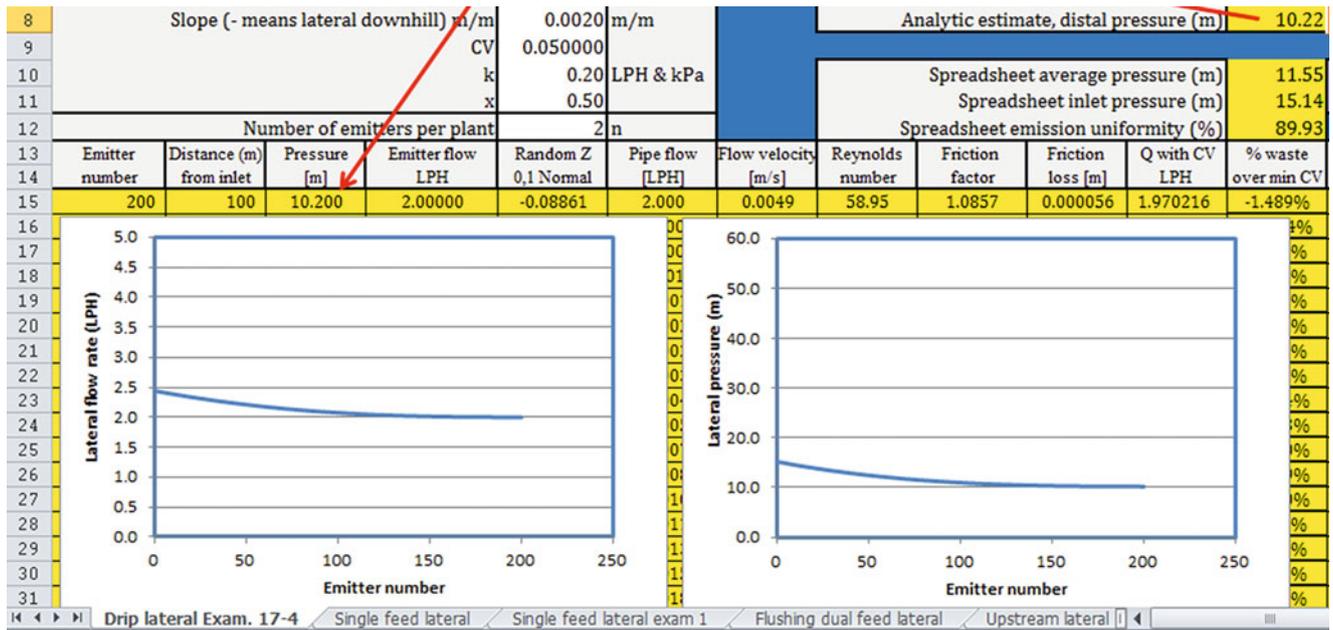Fig. 17.6 Emitter flow rate and pressure for downhill lateral

Slope (- means lateral downhill) m/m	0.0020 m/m			Analytic estimate, distal pressure (m)		10.22
CV	0.050000					
k	0.20 LPH & kPa			Spreadsheet average pressure (m)		11.55
x	0.50			Spreadsheet inlet pressure (m)		15.14
Number of emitters per plant	2 n			Spreadsheet emission uniformity (%)		89.93

Emitter number	Distance (m) from inlet	Pressure [m]	Emitter flow LPH	Random Z 0,1 Normal	Pipe flow [LPH]	Flow velocity [m/s]	Reynolds number	Friction factor	Friction loss [m]	Q with CV LPH	% waste over min CV
200	100	10.200	2.00000	-0.08861	2.000	0.0049	58.95	1.0857	0.000056	1.970216	-1.489%

Fig. 17.7 Emitter flow rate and pressure for uphill lateral

Single feed lateral

		Desired inlet pressure (m)	20
Lateral length or distance between submains (m)	120.00 m	First analytic estimate, lateral flow (LPH)	1680.34
Distal end pressure (m)	2.00 m	Multiport friction loss, hac (m)	62.17
Lateral diameter [mm]	12.00 mm	First analytic iteration average pressure (m)	-26.01
Distance between emitters [m]	0.20 m	Second analytic estimate, lateral flow (LPH)	#NUM!
Kinematic viscosity (change with temp)	1.00E-06	Second analytic iteration average pressure (m)	#NUM!
Slope (- means lateral downhill) m/m	0.0000 m/m	Third analytic estimate, lateral flow (LPH)	#NUM!
CV	0.050000	Analytic estimate, distal pressure (m)	#NUM!
k	0.20 LPH & kPa	Spreadsheet average pressure (m)	16.88
x	0.50	Spreadsheet inlet pressure (m)	28.87
Number of emitters per plant	2 This is n	Spreadsheet emission uniformity (%)	75.14

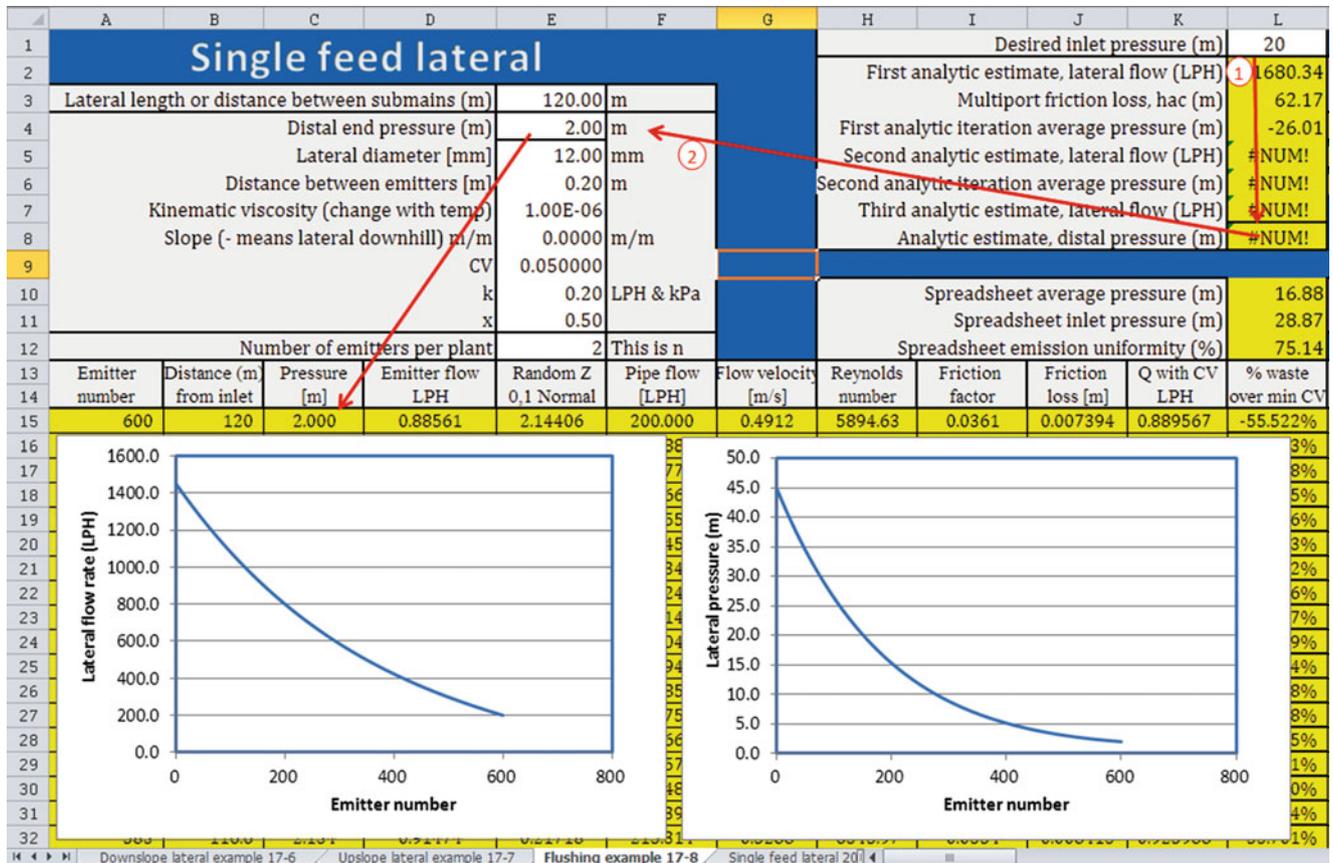| Emitter number	Distance (m) from inlet	Pressure [m]	Emitter flow LPH	Random Z 0,1 Normal	Pipe flow [LPH]	Flow velocity [m/s]	Reynolds number	Friction factor	Friction loss [m]	Q with CV LPH	% waste over min CV
600	120	2.000	0.88561	2.14406	200.000	0.4912	5894.63	0.0361	0.007394	0.889567	-55.522%

Fig. 17.8 Flushing lateral hydraulics for downslope lateral with 0.5 m/sec velocity

With pressure compensating emitters, all emitters have the same flow rate, and the lateral flow rate is the sum of all of the emitter flow rates; thus, the only design parameter is that the last emitter (lowest pressure emitter on a slope) on the lateral must operate at or above the minimum acceptable pressure. However, if emitters are not pressure compensating, then the flow rate for the lateral should be calculated based on the average pressure in the lateral. Pressures in laterals can be computed with Eqs. 17.19, 17.20, 17.21, and 17.22.

$$H_a = H_d + \frac{h_{ac}}{3.852} + \frac{S_e\ L}{2} \qquad (17.19)$$

$$H_o = H_a + 0.74\ h_{ac} + \frac{S_eL}{2} \qquad (17.20)$$

$$H_d = H_a - 0.26\ h_{ac} - \frac{S_eL}{2} \qquad (17.21)$$

$$H_0 = H_d +\ h_{ac} + S_eL \qquad (17.22)$$

where

H_a = average pressure in lateral, m,
H_o = pressure at inlet, m,
H_d = pressure at distal end, m,
S_e = slope (m/m), negative for inlet higher than distal end,
L = lateral length, m.

If the design is based on the pressure at the distal end as the minimum acceptable pressure, then Eq. 17.17 can be used directly to find the average pressure. A few iterations are necessary since h_{ac} is a function of H_a. If the design is based on a known inlet pressure, H_0, then Eq. 17.18 is rearranged and solved for H_a after some iteration. If the design is based on H_a, then H_o and H_d are calculated directly (no iteration) with Eqs. 17.18 and 17.19.

Example 17.5 Repeat Example 17.4 with Eqs. 17.19, 17.20, 17.21, 17.22, and Christensen's F.
Calculate the Christensen's F for the Darcy-Weisbach equation with 200 emitters.

$$F = \frac{1}{m+1} + \frac{1}{2N} + \frac{(m-1)^{0.5}}{6N^2}$$

$$= \frac{1}{2+1} + \frac{1}{2\ (200)} + \frac{(2-1)^{0.5}}{6\ (200^2)} = 0.338$$

Make an initial guess for lateral flow rate is based on the flow from the last emitter.

$$0.2(100\ kPa)^{0.5} = 2\ LPH.$$

There are 2 emitters per m and the length of tubing is 100 m. Thus, there are 200 emitters and the total flow rate per lateral is (2 LPH/emitter) (200 emitters) = 400 LPH.
Calculate friction loss in fully flowing pipe

$$v = \frac{Q}{A} = \left(\frac{400\ L\,ph}{\pi(6/1000)^2 m^2}\right)\left(\frac{m^3}{1,000\ L}\right)\left(\frac{hr}{3,600\ sec}\right)$$

$$= 0.98\ m/sec$$

$$Re = \frac{vD}{v} = \frac{0.98\ (12\ mm)/(1,000\ mm/m)}{1*10^{-6}} = 11,800$$

$$f = \frac{0.316}{Re^{1/4}} = \frac{0.316}{11,800^{1/4}} = 0.0303$$

$$h_f = 6.377 fL\left[\frac{Q^2}{D^5}\right]$$

$$= 6.377\ (0.0303)\ (100\ m)\left[\frac{(400\ LPH)^2}{(12\ mm)^5}\right] = 12.4\ m$$

$$h_{ac} = h_f F =\ (12.4\ m)(0.338) = 4.2\ m.$$

Pressure (m) at the distal end is known

$$H_d,\ is\ 100\ kPa(0.102) = 10.2\ m$$

Calculate average pressure in the lateral ($S_e = -0.002$)

$$H_a = H_d + \frac{h_{ac}}{3.852} + \frac{S_eL}{2}$$

$$= 10.2 + \frac{4.2}{3.852} + \frac{-0.002\ (100\ m)}{2}$$

$$= 10.2 + 1.09 - 0.1 = 11.19\ m$$

Second iteration
Find average emitter flow rate and lateral flow rate

$$0.2(11.19\ m/0.102\ m/kPa)^{0.5} = 2.095\ LPH$$
$$\rightarrow 2.095\ LPH/emitter(200\ emitters) = 419\ LPH$$

Calculate friction loss in fully flowing pipe.

$$v = \frac{Q}{A} = \left(\frac{419\ L\,ph}{\pi(6/1000)^2\ m^2}\right)\left(\frac{m^3}{1,000\ L}\right)\left(\frac{hr}{3,600\ sec}\right)$$

$$= 1.03\ m/sec$$

$$Re = \frac{vD}{v} = \frac{1.03*12/1,000}{1*10^{-6}} = 12,360$$

$$f = \frac{0.316}{Re^{1/4}} = \frac{0.316}{12,360^{1/4}} = 0.03$$

$$h_f = 6.377 fL\left[\frac{Q^2}{D^5}\right] = (6.377)(0.03)(100\ m)\left[\frac{419^2}{12^5}\right] = 13.5\ m$$

The Christensen's F for the Darcy-Weisbach equation with 200 emitters is 0.338.

$$h_{ac} = h_f F = (13.5\ m)(0.338) = 4.6\ m.$$

Third iteration

Calculate average pressure in the lateral

$$H_a = H_d + \frac{h_{ac}}{3.852} + \frac{S_e\ L}{2}$$

$$= 10.2 + \frac{4.6}{3.852} + \frac{(-0.002)(100\ m)}{2}$$

$$= 10.2 + 1.19 - 0.1 = 11.29\ m$$

Recalculate lateral flow rate based on average pressure of 11.29 m

Average emitter flow rate = $0.2*(11.29\ m/0.102\ m/kPa)^{0.5}$
$$= 2.10\ LPH$$

Calculate inlet pressure

$$H_0 = H_d +\ \ h_{ac} + S_e L$$
$$= 10.2\ m + 4.6\ m + (-0.002)(100\ m) = 14.6\ m.$$

The inlet pressure calculated with the analytic solution (14.6 m) is the same as the inlet pressure calculated with the spreadsheet (14.69 m) in Example 17.5. Average flow rate along the lateral at the average pressure is $Q_a = 0.2\ H_a^{0.5} = 0.2\ (11.29/0.102)^{0.5} = 2.104$ LPH, which is the same as the average flow rate calculated with the spreadsheet, 2.105 LPH.

Calculate for upslope (inlet is lower than distal end)
Use same initial guess for lateral flow rate = (2 LPH/emitter) (200 emitters) and h_{ac} = 4.2 m.

Calculate average pressure in the lateral (S_e = 0.002)

$$H_a = H_d + \frac{h_{ac}}{3.852} + \frac{S_e\ L}{2}$$

$$= 10.2\ m + \frac{4.2\ m}{3.852} + \frac{(+0.002)(100\ m)}{2}$$

$$= 10.2 + 1.09 + 0.1 = 11.39\ m$$

Calculate again with average pressure.
Find average emitter flow rate and lateral flow rate

$0.2(11.39/0.102)^{0.5} = 2.11 \rightarrow 2.11$ LPH/emitter*200 emitters
$= 422$ LPH422 LPH $\rightarrow h_{ac} = h_f F = 13.7*0.338 = 4.6$ m.

Calculate average pressure in the lateral

$$H_a = H_d + \frac{h_{ac}}{3.852} + \frac{S_e\ L}{2}$$

$$= 10.2\ m + \frac{4.6\ m}{3.852} + \frac{(0.002)(100\ m)}{2}$$

$$= 10.2 + 1.19 + 0.1 = 11.49\ m$$

Average emitter flow rate = $0.2\ (11.49\ /\ 0.102)^{0.5} = 2.12$ LPH

$$H_o = H_d + h_{ac} + S_e\ \ L = 10.2 + 4.6 - (0.002)(100\ m)$$
$$= 10.2 + 4.6 + 0.2 = 15.0\ m$$

Again, the inlet pressure calculated with the analytic solution (15.0 m) is the same as the inlet pressure calculated with the spreadsheet (15.14 m) in Example 17.5. Average flow rate along the lateral at the average pressure is $Q_a = 0.2\ H_a^{0.5} = 0.2 * (11.49/0.102)^{0.5} = 2.122$ LPH, which is the same as the average flow rate calculated with the spreadsheet, 2.124 LPH.

A similar iteration method is used in the spreadsheet that enables the user to input a distal end pressure based on an upstream pressure (cells L1:L8), but the results are slightly different from these calculations.

The uniformity along a drip irrigation lateral is typically quantified with the emission uniformity equation:

$$U_e = 100\left[1 - \left(\frac{1.27}{\sqrt{n}}\right)C_v\right]\frac{q_{min}}{q_{average}} \qquad (17.23)$$

where

U_e = emission uniformity
n = number of emitters per plant
C_v = manufacturers coefficient of variation
q_{min} = minimum emitter discharge based on lateral hydraulic calculation
q_{ave} = average emitter discharge based on lateral hydraulic calculation.

For new systems, the coefficient of variation that is used in the emission uniformity equation is the number reported by the factory whereas older systems would develop a higher coefficient of variation.

Example 17.6 Calculate the emission uniformity for Example 17.4 (downslope and upslope). Assume that the coefficient of variation is 0.05 or 5 % and that there are 2 emitters per plant.

Downslope uniformity

$$q_{ave} = 0.2\ H_a^{0.5} = 0.2(11.29/0.102)^{0.5} = 2.104\ LPH$$
$$q_{min} = 0.2(100)^{0.5} = 2\ LPH$$

$$U_e = 100\left[1 - \left(\frac{1.27}{\sqrt{2}}\right)0.05\right]\frac{2}{2.104} = 91\ \%$$

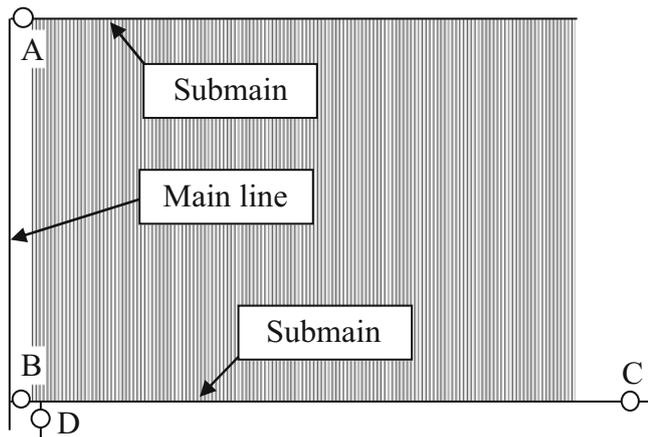This is the same uniformity that is calculated in the worksheet (Fig. 17.6).

Fig. 17.9 Dual feed laterals with flushing

Upslope uniformity

$$q_{ave} = 0.2 \ H_a^{0.5} = 0.2(11.49/0.102)^{0.5} = 2.122 \ \text{LPH}$$
$$q_{min} = 0.2(100)^{0.5} = 2 \ \text{LPH}$$

$$U_e = 100\left[1 - \left(\frac{1.27}{\sqrt{2}}\right)0.05\right]\frac{2}{2.122} = 90 \ \%$$

When drip laterals are fed from both ends (Fig. 17.9) plugging is reduced, and flushing can be automated. Another advantage is that if a break in the drip lateral occurs, water enters the break from both ends, and dirt is not washed into the section of tube that is downstream from the break (the problem with single feed laterals). During irrigation, valves A and B are open and valves C and D are closed. During flushing, valves A, C, and D are open and valve B is closed. Submain diameters should be large enough to maintain a sufficient flushing flow velocity in the laterals. Use gate valves (lower pressure loss) for valves C and D in order to minimize backpressure during flushing.

For modeling a dual feed lateral laid on a slope, the point of zero flow is not midway between the submains. The zero flow point in the lateral will be closer to the lower submain. For a more accurate simulation, the water flowing into the lateral from the lower submain (lateral upslope direction) is modeled separately from the water flowing into the lateral from the upper submain (lateral downslope direction). The midpoint is shifted until the point of zero flow has the same distal end pressure in each lateral.

Example 17.7 Design the emitter spacing, lateral lengths and lateral diameter for a subsurface drip irrigation system on a 32 ha row crop farm. Use dual feed laterals. The rows are in the N-S direction so the laterals must also be N-S. Rows are 1 m apart, and there should be one lateral per row. Farm size is 32 ha with 820 m (N-S) × 400 m (E-W) boundaries. The farmer already has dirt access roads every

205 m in the E-W direction for field access. Roads are 5 m wide. There is a 0.2 % slope in N-S direction with North as the high elevation. The system efficiency is 90 %. The maximum daily plant water requirement (ET_{c-max}) in the middle of summer is 10 mm/day. Soil is a loam (medium texture). Assume that the system will operate for 22 hours per day during peak ET, leaving 2 hours for repairs, etc. Emitters are turbulent flow with x = 0.5 and K = 0.2 for units of kPa and LPH (2 LPH emitters). Minimum acceptable design pressure is 100 kPa. Manufacturer's CV = 0.05. Calculate emission uniformity of the lateral.

Emitter wetted diameter for a 2 LPH emitter is 0.7 m in a medium textured soil. In order to create a line source along the drip lateral, select a 0.5 m emitter spacing along the lateral.

Calculate the gross application rate

$$(di/dt)_g = \left(\frac{2 \ LPH}{(0.5 \ m)(1 \ m)}\right) = 4 \ mm/hr$$

Calculate the net application rate

$$(di/dt)_a = (4 \ mm/hr)(90 \ \%/100 \ \%) = 3.6 \ mm/hr$$

Calculate the required hours of application per day in each zone.

$$T_z = \frac{ET_{c-max}}{(di/dt)_a} = \frac{10 \ mm/day}{3.6 \ mm/hr} = 2.78 \ hr/day$$

Calculate the number of watering periods.

$$N_p = \frac{T_r}{T_z} = \frac{22}{2.78} = 7.91 \ periods$$

Normally, the number of periods would be rounded down. However, 7.91 is close to 8 so round up to 8 periods.

Calculate the area that is watered during each period (subtract the road area).

$$A_f = (820 - (4 \ road)(5 \ m/road)(400 \ m)/(10{,}000 \ m^2/ha)$$
$$= 32 \ ha.$$

$$A_p = \frac{A_f}{N_p} = \frac{32 \ ha}{8} = 4 \ ha$$

Calculate number of emitters per ha

$$E_d = \left(\frac{10{,}000 \ m^2}{ha}\right)\left(\frac{1 \ emitter}{s_L * s_d \ m^2}\right)$$
$$= \left(\frac{10{,}000 \ m^2}{ha}\right)\left(\frac{1 \ emitter}{(0.5 \ m)(1 \ m)}\right)$$
$$= 20{,}000 \ emitters/ha$$

The required irrigation system flow rate is

$$Q_p = \frac{E_d Q_e A_p}{3,600}$$

$$= \frac{(20,000 \ emitters/ha)(2 \ LPH/emitter)(4 \ ha)}{3,600 \ sec/hr}$$

$$= 44.4 \ LPS$$

The next step is to select a lateral length. The laterals must run in the N-S direction, and the length of the field in the N-S direction is 800 m. Because the farmer already has E-W roads every 200 m, use 200 m long dual feed laterals. The hydraulic calculation for a 200 m long dual feed lateral during irrigation is the nearly the same as designing two 100 m long single feed laterals in the upslope and downslope direction. However, during the flushing cycle, water must travel the entire distance between submains, 200 m. Use 16 mm ID tubing to maintain uniform flow distribution during irrigation and to provide a large enough diameter to flush the 200 m laterals. During flushing, the required flow rate at the distal end of a 16 mm ID lateral is $Q = vA = v \pi r^2 = (0.5 \ m/sec)(\pi)(0.008)^2 (1000 \ LPS/(m^3/sec)) = 0.074$

$LPS = 361 \ LPH$. The 361 LPH flushing flow rate was added spreadsheet at the distal end of the lateral (Fig. 17.10). The required lateral inlet flushing pressure is 16.2 m.

The next step is to model the dual feed system during irrigation (Fig. 17.11). The irrigation parameters are entered into both the *Upper lateral* and *Lower lateral* worksheets, and a VBA program (*Make calcs* button) makes the hydraulic calculations. The pressure difference between the two ends of the lateral is specified in cell N2. The program adds 13 emitters are added to the downslope lateral. The average pressure in the lateral is the weighted average of the average pressures in the upslope and downslope lateral sections: $H_{a\text{-upslope}} = 10.55$ m; $H_{a\text{-downslope}} = 10.46$ m. The same numbers are also seen in the spreadsheet analysis (Fig. 17.11).

$$H_{a-average} = \frac{187 \ (H_{a-upslope}) + 213 \ (H_{a-downslope})}{400}$$

$$= \frac{187 \ (10.55 \ m) + 213 \ (10.46 \ m)}{2} = 10.50 \ m$$

$$q_{ave} = 0.2 \ H_a^{0.5} = 0.2(10.50 \ m/0.102)^{0.5} = 2.029 \ LPH$$

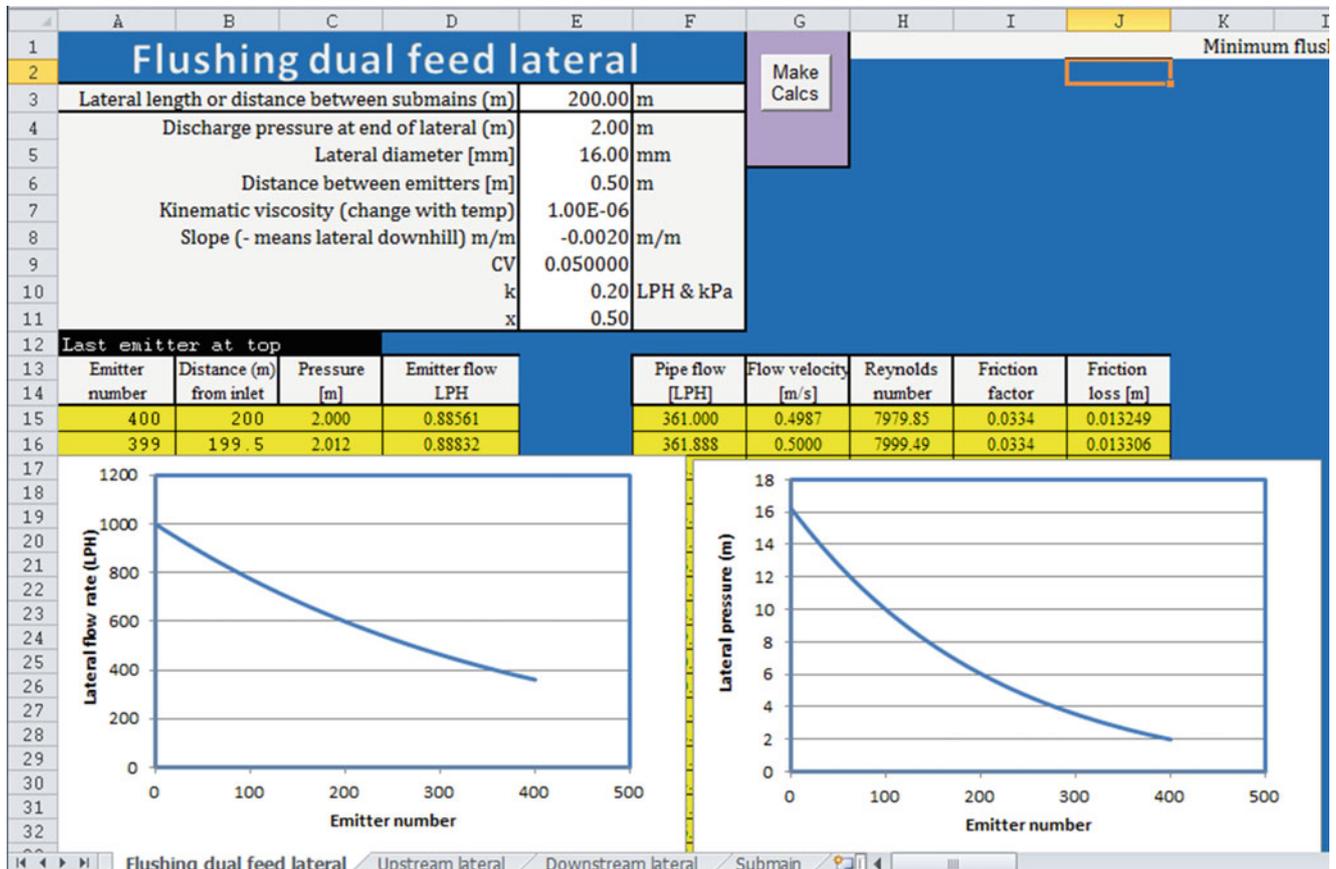**Fig. 17.10** Lateral flow rate and pressure during flushing cycle for 16 mm tubing with 2 LPH emitters at 0.5 m spacing

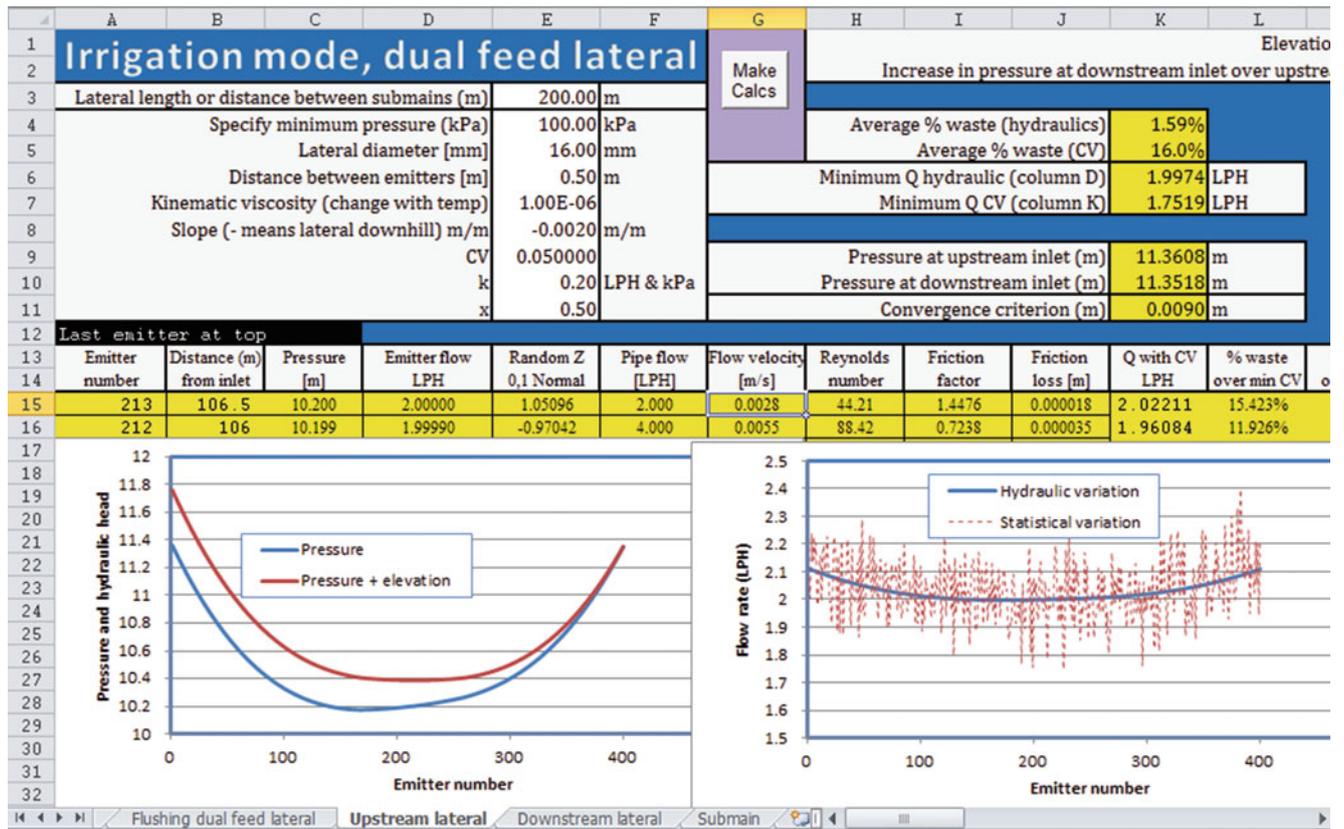|	A	B	C	D	E	F	G	H	I	J	K	L
1	Irrigation mode, dual feed lateral				200.00	m	Make Calcs					Elevatio
2								Increase in pressure at downstream inlet over upstre				
3	Lateral length or distance between submains (m)				200.00	m						
4	Specify minimum pressure (kPa)				100.00	kPa		Average % waste (hydraulics)			1.59%	
5	Lateral diameter [mm]				16.00	mm		Average % waste (CV)			16.0%	
6	Distance between emitters [m]				0.50	m		Minimum Q hydraulic (column D)			1.9974	LPH
7	Kinematic viscosity (change with temp)				1.00E-06			Minimum Q CV (column K)			1.7519	LPH
8	Slope (- means lateral downhill) m/m				-0.0020	m/m						
9	CV				0.050000			Pressure at upstream inlet (m)			11.3608	m
10	k				0.20	LPH & kPa		Pressure at downstream inlet (m)			11.3518	m
11	x				0.50			Convergence criterion (m)			0.0090	m
12	Last emitter at top											
13	Emitter number	Distance (m) from inlet	Pressure [m]	Emitter flow LPH	Random Z 0,1 Normal	Pipe flow [LPH]	Flow velocity [m/s]	Reynolds number	Friction factor	Friction loss [m]	Q with CV LPH	% waste over min CV
15	213	106.5	10.200	2.00000	1.05096	2.000	0.0028	44.21	1.4476	0.000018	2.02211	15.423%
16	212	106	10.199	1.99990	-0.97042	4.000	0.0055	88.42	0.7238	0.000035	1.96084	11.926%

Fig. 17.11 Flow variation in dual feed irrigation lateral

Minimum pressure is 10.174 m (Fig. 17.11)

$$q_{min} = 0.2(10.17/0.102)^{0.5} = 1.997 \text{ LPH}$$

$$U_e = 100\left[1 - \left(\frac{1.27}{\sqrt{2}}\right)0.05\right]\frac{1.997}{2.029} = 94 \%$$

Connecting Drip Irrigation Laterals to PVC Submains

Subsurface drip irrigation laterals are typically placed 0.15 m below the ground surface, and submains are deeper. Polyethylene tubing tends to kink when it is bent so it is difficult to connect directly to the submain and bend the polyethylene tubing without kinking. Black flexible PVC pipe (1/2 in., 13 mm) does not kink when it is bent. It can be glued into a saddle that is glued to the top of the PVC submain (Fig. 17.12). Use of saddles or grommets and drilling holes into the submain rather than using Tees saves money – large Tees are expensive. The black flexible PVC can be connected to the drip lateral with a PVC to drip lateral connector.
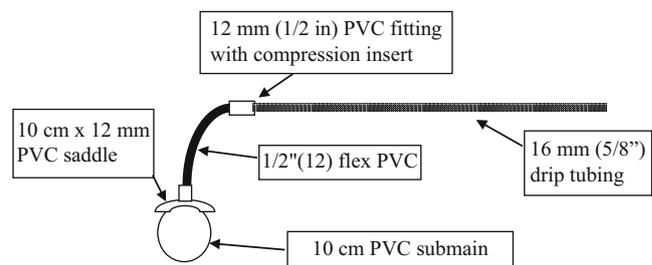

Fig. 17.12 Connection of subsurface drip irrigation lateral to PVC submain

Questions

1. How many 4 ft (1.22 m) diameter sand filters are needed for a 260 ha (640 ac) drip irrigated farm? Crop ET is 11 mm/day. Irrigation efficiency is 90 %.
2. Design particle size for a settling basin is 25 microns. Irrigation system flow rate is 1000 GPM. What are the dimensions of the settling basin?

3. Calculate head loss and emission uniformity in a 120 m length of 18 mm ID tubing. $x = 0.57$ and $k = 0.15$. Inlet pressure is 200 kPa. Emitters are spaced at 0.2 m. The crop is carrots. Determine if the design is acceptable based on a criteria of 90 % emission uniformity. Use the analytic solution method and check your answer with the *Single feed lateral* spreadsheet. The manufacturer's coefficient of variation is 0.07 or 7 %, and there are 2 emitters per plant. There is no slope.

4. Calculate head loss and emission uniformity in an 80 m length of 18 mm ID tubing. $x = 0.57$ and $k = 0.15$. Inlet pressure is 50 kPa. Emitters are spaced at 0.2 m. The crop is carrots. Determine if the design is acceptable based on a criteria of 90 % emission uniformity. Use the analytic solution method and check your answer with the *Single feed lateral* spreadsheet. The manufacturer's coefficient of variation is 0.07 or 7 %, and there are 2 emitters per plant. There is no slope.

5. Calculate head loss and emission uniformity in a 120 m length of 18 mm ID tubing. $x = 0.57$ and $k = 0.15$. Inlet pressure is 200 kPa. Emitters are spaced at 0.2 m. The crop is carrots. Determine if the design is acceptable based on a criteria of 90 % emission uniformity. Just use the *Single feed lateral* spreadsheet for the calculation. The manufacturer's coefficient of variation is 0.07 or 7 %, and there are 2 emitters per plant. Slope is 5 % downhill.

6. For the parameters in question 3, calculate the inflow rate and pressure needed to flush the 120 m length tube. Make the calculations in the worksheet. Discuss whether flushing is viable for this system.

7. For the parameters in question 5, calculate the inflow rate and pressure needed to flush the 120 m length tube. Make the calculations in the worksheet. Discuss whether flushing is viable for this system.

8. Emitters are spaced at 1 m along the plant row and 1 m between plant rows, and emitter flow rate is 2 lph. For a daily plant water requirement of 12 mm/day, calculate the application rate and the application time if plants are watered on a daily basis. Application efficiency is 85 %.

9. Two submains are 200 m apart and supply a dual feed lateral. Tubing diameter is 12 mm ID. $x = 0.5$ and $k = 0.2$. Inlet pressure is 100 kPa. Emitters are spaced at 0.5 m. There is no slope. Use the *upper lateral* worksheet to plot the hydraulic and flow variation. Make sure to press the Make calcs button.

10. Two submains are 200 m apart and supply a dual feed lateral. Tubing diameter is 12 mm ID. $x = 0.5$ and $k = 0.2$. Inlet pressure is 100 kPa. Emitters are spaced at 0.5 m. There is 1 % slope. Use the *upper lateral* worksheet to plot the hydraulic and flow variation. There is no pressure difference between the uphill and downhill inlets. Explain the difference between the red and blue lines in the pressure graph. Which line is the hydraulic head?

11. Design a dual feed lateral with a 1 % slope, and 240 m distance between submains. Determine the emission uniformity.

References

Netafim (2015) AGF sand media filters: operation, installation, and maintenance guide. Netafim USA, Fresno. http://www.netafimusa.com/files/literature/agriculture/filters/A048-AGF-Manual.pdf

Netafim (2015) Hydrocyclone sand separators: operation, installation, and maintenance guide. Netafim USA, Fresno. http://www.netafimusa.com/files/literature/agriculture/filters/hydrman-hydrocyclone-manual.pdf

ASAE Engineering Practice: ASAE EP405 – Design, Installation, and Performance of Trickle Irrigation Systems (1993) American Society of Agricultural Engineers, St. Joseph