

**BIE 5110/6110**  
**Sprinkle & Trickle Irrigation**  
**Fall Semester 2004 – Final Exam**

*Include units in all results. Indicate any assumptions that you might make.  
Don't show more than three significant digits in any of the results.*

Name \_\_\_\_\_

1. (35 pts) A mature citrus orchard will be drip-irrigated (drip emitters) using a single lateral per row of trees in a 132-ha field area. Other information:

- Tree spacing is 6.0 x 6.0 m.
- Peak daily ET is  $U_d = 5.1$  mm/day.
- Seasonal water requirement:  $U = 660$  mm.
- Effective rain, peak-use period: 1.5 mm/day (average, w/ 90% probability)
- Residual soil water in the spring: assume zero.
- Soil water holding capacity is 175 mm/m (medium texture).
- Irrigation water quality:  $EC_w = 0.89$  dS/m.
- Root zone depth is 1.5 m.
- Shaded area is 78%.
- Emitter equation:

$$q = 0.28P^{0.481}$$

for q in lph; and P in kPa.

- Nominal emitter flow rate:  $q_a = 3.85$  lph.
- Manufacturer's emitter coefficient of variation: 0.0487.
- Average wetted width at 3.85 lph:  $w = 2.01$  m.
- Outlets per emitter: one.
- Use an MAD of 20%.

**What you need to do:**

1. Select an appropriate emitter spacing,  $S_e$ .
2. Determine the number of emitters per tree,  $N_p$ .
3. Calculate percent wetted area,  $P_w$ .
4. Calculate maximum net depth to apply per irrigation,  $d_x$ .
5. Calculate the average peak daily "transpiration" rate,  $T_d$ .
6. Calculate the maximum irrigation interval,  $f_x$ . If  $f_x \geq 1$  day, use  $f' = 1$  day.
7. Calculate the net depth per irrigation,  $d_n$ .
8. Select a reasonable target EU value.
9. Determine  $(EC_e)_{max}$ .
10. Determine the transmission ratio,  $T_r$ .

11. Calculate the leaching requirement,  $LR_t$ .
12. Calculate the gross depth to apply per irrigation,  $d$ .
13. Calculate the gross volume of water per tree per day,  $G$ .
14. Calculate  $h_a$ , corresponding to  $q_a = 3.85$  lph, in m of water head.
15. Calculate the water application time,  $T_a$ .
16. Select the number of stations,  $N_s$ .
17. Determine the minimum number of emitters per tree,  $N_p'$ .
18. Calculate the system coefficient of variation,  $v_s$ .
19. Calculate the minimum allowable emitter flow rate,  $q_n$ .
20. Calculate the allowable subunit pressure head variation,  $\Delta H_s$ .
21. Calculate the system capacity,  $Q_s$ .
22. Calculate the total gross seasonal depth to apply,  $D_g$ .
23. Calculate the gross seasonal volume of irrigation water,  $V_s$ .
24. Calculate the required number of operating hours per season,  $O_t$ .

2. (30 pts) A rectangular field of strawberries will be trickle irrigated. The laterals are 380-m long in the direction of the 17.8-mm inside diameter PE laterals. Nominal emitter flow rate is 2.75 lph at a pressure head of 11.5 m. The emitters are in-line, without any barbs, spaced at 0.4 m along the lateral hose, which lies along a uniform ground slope of 0.761%. The strawberries are spaced at 0.5 m in the field rows. The emitter exponent is  $x = 0.544$ , and the system flow rate is 8.05 lps.

**What you need to do:**

1. Determine the optimal manifold location.
2. Determine the location of the minimum downhill lateral pressure.
3. Calculate the required lateral inlet pressure head,  $H_l$ .
4. Calculate the minimum uphill lateral pressure head,  $(H_n')_{\text{uphill}}$ .
5. Do your work neatly for full credit on this problem.

3. (35 pts) A trickle irrigation system with a manifold inflow rate of 8.4 lps has an allowable subunit pressure head variation of  $\Delta H_s = 4.72$  m. The calculated pressure variation along the lateral pipes is  $\Delta H_l = 2.44$  m, and the total length of the manifold will be 290 m. There is a uniform ground slope of 1.73% in the manifold direction. The following PVC pipe sizes are available:

Size (inches)	I.D. (inches)
1.5	1.610
2.0	2.067
2.5	2.469
3.0	3.068
4.0	4.000
6.0	6.000

### What you need to do:

1. Design the manifold, using up to four different pipe diameters.
2. Use the attached friction loss curves for the six available pipe sizes.
3. Determine appropriate manifold pipe sizes and lengths.
4. Do not allow the maximum velocity in each pipe size to exceed 2.0 m/s.
5. Do your work neatly for full credit on this problem.

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### Solutions:

#### 1. Trickle Design Calculations

1. Select an appropriate emitter spacing,  $S_e$ .

$$S'_e = 0.8w = 0.8(2.01) = 1.61 \text{ m}$$

2. Determine the number of emitters per tree,  $N_p$ .

$$N_p = \frac{S_p}{S_e} = \frac{6.0}{1.61} = 3.73$$

3. Calculate percent wetted area,  $P_w$ .

$$P_w = 100 \left( \frac{N_p S_e w}{S_p S_r P_d} \right) = 100 \left( \frac{(3.73)(1.61)(2.01)}{(6.0)(6.0)(0.78)} \right) = 43.0\%$$

which is within acceptable limits.

4. Calculate maximum net depth to apply per irrigation,  $d_x$ .

Table 3.2:  $Z_{avg}$  (for citrus) =  $\frac{1}{2}(0.9 + 1.5) = 1.2 \text{ m}$ .

$$d_x = \frac{MAD}{100} \frac{P_w}{100} W_a Z = (0.2)(0.43)(175)(1.2) = 18.1 \text{ mm}$$

5. Calculate the average peak daily "transpiration" rate,  $T_d$ .

$$T_d = 0.1 U_d \sqrt{P_d} = 0.1(5.1)\sqrt{78} = 4.50 \text{ mm/day}$$

6. Calculate the maximum irrigation interval,  $f_x$ . If  $f_x \geq 1 \text{ day}$ , use  $f' = 1 \text{ day}$ .

$$f_x = \frac{d_x}{T_d} = \frac{18.1}{4.50} = 4.0 \text{ days}$$

Then, let  $f' = 1$  day (for design).

7. Calculate the net depth per irrigation,  $d_n$ .

$$d_n = T_d f' = (4.5)(1) = 4.5 \text{ mm/day}$$

8. Select a reasonable target EU value.

Table 20.3: “point-source” water applicators with  $N_p > 3$  gives recommended EU range of 90 to 95%. Choose EU = 92%.

9. Determine  $(EC_e)_{\max}$ .

From Table 19.2, for a citrus (e.g. orange) crop,  $(EC_e)_{\max} = 8$  dS/m.

10. Determine the transmission ratio,  $T_r$ .

From Table 19.3, for a “deep-rooted” ( $Z > 1.5$  m) crop and a “medium-textured” soil:  $T_r = 1.00$ .

11. Calculate the leaching requirement,  $LR_t$ .

$$LR_t = \frac{EC_w}{2(EC_e)_{\max}} = \frac{0.89}{2(8)} = 0.056$$

12. Calculate the gross depth to apply per irrigation,  $d$ .

For  $LR_t < 0.1$ , the following equation is applied:

$$d = 100 \left( \frac{d_n T_r}{EU} \right) = 100 \left( \frac{(4.50)(1.00)}{92\%} \right) = 4.89 \text{ mm/day}$$

13. Calculate the gross volume of water per tree per day,  $G$ .

$$G = \frac{d}{f'} S_p S_r = \frac{4.89}{1} (6.0)(6.0) = 176 \text{ liter/day/tree}$$

14. Calculate  $h_a$ , corresponding to  $q_a = 3.85$  lph, in m of water head.

Apply the given emitter equation, and use 9.81 kPa/m:

$$h_a = \left( \frac{1}{9.81} \right) \left( \frac{3.85}{0.28} \right)^{1/0.481} = 23.7 \text{ m}$$

15. Calculate the water application time,  $T_a$ .

$$T_a = \frac{G}{N_p q_a} = \frac{176}{(3.73)(3.85)} = 12.3 \text{ hrs/day}$$

16. Select the number of stations,  $N_s$ .

Two stations would require  $2(12.3) = 24.6$  hrs/day. Thus, there can be only one station ( $N_s = 1$ ) in this design.

17. Determine the minimum number of emitters per tree,  $N_p'$ .

Here is a new equation for  $N_p'$ :

$$N_p' = 2 \left[ \text{trunc} \left( 1 + \frac{S_p + w - 2S_e}{2S_e} \right) \right] + 1$$

In this problem,

$$\begin{aligned} N_p' &= 2 \left[ \text{trunc} \left( 1 + \frac{6.0 + 2.01 - 2(1.61)}{2(1.61)} \right) \right] + 1 \\ &= 2 [\text{trunc}(2.49)] + 1 \\ &= 5 \text{ emitters} \end{aligned}$$

Note that  $N_p'$  must be an integer value.

18. Calculate the system coefficient of variation,  $v_s$ .

$$v_s = \frac{v}{\sqrt{N_p'}} = \frac{0.0487}{\sqrt{5}} = 0.022$$

19. Calculate the minimum allowable emitter flow rate,  $q_n$ .

$$q_n = \frac{q_a EU}{100(1 - 1.27v_s)} = \frac{(3.85)(92)}{100(1 - 1.27(0.022))} = 3.64 \text{ lph}$$

which corresponds to a head of:

$$h_n = \left( \frac{1}{9.81} \right) \left( \frac{3.64}{0.28} \right)^{1/0.481} = 21.1 \text{ m}$$

20. Calculate the allowable subunit pressure head variation,  $\Delta H_s$ .

$$\Delta H_s = 2.5(h_a - h_n) = 2.5(23.7 - 21.1) = 6.50 \text{ m}$$

21. Calculate the system capacity,  $Q_s$ .

$$Q_s = 2.78 \frac{AN_p q_a}{N_s S_p S_r} = 2.78 \frac{(132)(3.73)(3.85)}{(1)(6.0)(6.0)} = 146 \text{ lps}$$

22. Calculate the total gross seasonal depth to apply,  $D_g$ .

Assume a  $T_R$  value of 1.00 (Table 19.4). Then,  $E_s = EU = 92\%$ . Seasonal effective rain is assumed to be zero because the value is not given. Residual soil moisture is given to be zero. Thus,

$$D_n = U(0.1\sqrt{P_d}) = 660(0.1\sqrt{78}) = 583 \text{ mm}$$

Then, gross seasonal depth is:

$$D_g = \frac{100D_n}{E_s(1-LR_t)} = \frac{100(583)}{92(1-0.056)} = 671 \text{ mm}$$

23. Calculate the gross seasonal volume of irrigation water,  $V_s$ .

$$V_s = \frac{D_g A}{1000} = \frac{(671)(132)}{1000} = 88.6 \text{ ha-m}$$

24. Calculate the required number of operating hours per season,  $O_t$ .

$$O_t = 2778 \frac{V_s}{Q_s} = 2778 \left( \frac{88.6}{146} \right) \approx 1,690 \text{ hrs/season}$$

## 2. Optimal Manifold Location

Number of emitters for the pair of laterals:

$$\frac{380 \text{ m}}{0.4 \text{ m/emitter}} = 950 \text{ emitters}$$

Total nominal discharge for the pair of laterals:

$$Q_{\text{pair}} = \frac{(950 \text{ emitters})(2.75 \text{ lph/emitter})}{3600 \text{ s/hr}} = 0.726 \text{ lps}$$

Friction loss gradient (Eq. 8.7a):

$$J = 7.83(10)^7 \frac{(0.726)^{1.75}}{(17.8)^{4.75}} = 51.4 \text{ m/100 m}$$

Note that this is a high value for  $J$ , and is beyond the values given in Table 8.2. The multiple-outlet factor,  $F$ , is 0.36 for 950 outlets. Take  $f_e = 0$  since the emitters are in-line.

Friction loss for the pair of laterals:

$$(h_f)_{\text{pair}} = \frac{(51.4)(0.36)(380)}{100} = 70.3 \text{ m}$$

which is equal to about 100 psi.

Elevation change for the pair of laterals:

$$(\Delta h_e)_{\text{pair}} = (0.00761)(380) = 2.89 \text{ m}$$

Ratio of elevation change to friction loss for the pair of laterals:

$$\left( \frac{\Delta h_e}{h_f} \right)_{\text{pair}} = \frac{2.89}{70.3} = 0.041$$

Plot the above value (0.041) on the ordinate of the dimensionless friction loss graph (Fig. 8.2) at  $x/L = 1.0$ , then draw a straight line from the origin to this point. Slide the dimensionless curve for the downhill portion of the laterals until it is tangent to

the line, then trace it. Slide the curves up further so that the uphill curve passes through the plotted point. Determine the intersection of the two curves:

$$x/L \approx 0.52$$

Then, the downhill portion of the pair of laterals will have a length of:

$$L_d = (380)(0.52) \approx 198 \text{ m}$$

The uphill portion of the pair of laterals will have a length of:

$$L_u = 380 - 198 = 182 \text{ m}$$

Graphically, the location of minimum pressure in the downhill lateral would be:

$$L_{\min} = 0.1(380) = 38 \text{ m}$$

as measured from the end of the downhill lateral, or  $198 - 38 = 160 \text{ m}$  from the manifold location.

The required lateral inlet head is:

$$\alpha = \frac{3}{4} \left[ (0.52)^{3.75} + (1 - 0.52)^{3.75} \right] = 0.112$$

and,

$$h_l = h_a + \alpha (h_f)_{\text{pair}} + \left( \frac{x}{L} - 0.5 \right) (\Delta h_e)_{\text{pair}}$$

$$h_l = 11.5 + 0.112(70.3) + (0.52 - 0.5)(2.89) = 19.5 \text{ m}$$

which is 191 kPa, or 28 psi.

The minimum pressure head in the uphill lateral is:

Friction loss gradient (Eq. 8.7a):

$$J = 7.83(10)^7 \frac{\left( \frac{(182)(2.75)}{(0.4)(3600)} \right)^{1.75}}{(17.8)^{4.75}} = 14.2 \text{ m/100 m}$$

Friction loss:



$$(h_f)_{up} = \frac{(14.2)(0.36)(182)}{100} = 9.30 \text{ m}$$

Minimum pressure head:

$$\begin{aligned} (h_n')_{up} &= h_a - (h_f)_{up} - (\Delta h_e)_{up} \\ &= 19.5 - 9.30 - (182)(0.00761) \\ &= 8.81 \text{ m} \end{aligned}$$

### 3. Manifold Design

The elevation change over the manifold length is:

$$\Delta E_m = (290)(0.0173) = 5.02 \text{ m}$$

The allowable head variation in the manifold is:

$$(\Delta h_m)_a = 4.72 - 2.44 = 2.28 \text{ m}$$

The sum of elevation change and allowable head variation is:  $5.02 + 2.28 = 7.30 \text{ m}$ .

Draw a line from the origin to (8.4, 5.02). Draw a parallel line from (0.0, 2.28) to (8.4, 7.30). These two lines define the band within which the friction loss curves should be contained.

Look at the six friction loss curves on the attached graph. The smallest four sizes are too small to fit within the band. The largest (6 inches) is too large because the friction loss curve goes outside the band. Start with the 4-inch pipe size, but not at the point (8.4, 7.30); start at (8.4, 5.02) such that the curve can fit within the band. Trace the curve for the 4-inch pipe on the graph.

Entrance velocity would be:

$$V_{4\text{-inch}} = \frac{4Q}{\pi D^2} = \frac{4(0.0084)}{\pi \left[ \left( \frac{4}{12} \right) (0.3048) \right]^2} = 1.04 \text{ m/s}$$

which is within acceptable limits.

Note that the 4-inch pipe could be used for the whole length of the manifold and still accommodate the allowable pressure head variation. But part of the manifold

should be 3-inch pipe, thereby reducing the head variation further, and also decreasing the pipe cost.

Trace the 3-inch friction loss curve on the graph, making it tangent to the lower line (ground slope line). This curve intersects the 4-inch curve at a flow rate of about 3.45 lps. The entrance velocity to the 3-inch pipe would be:

$$V_{3\text{-inch}} = \frac{4Q}{\pi D^2} = \frac{4(0.00345)}{\pi \left[ \left( \frac{3.068}{12} \right) (0.3048) \right]^2} = 0.72 \text{ m/s}$$

which is also within acceptable limits.

Then, use two pipe diameters (4- and 3-inch) with the following lengths of pipe in the manifold:

$$L_{3\text{-inch}} = 290 \left( \frac{3.45}{8.4} \right) = 119 \text{ m}$$

$$L_{4\text{-inch}} = 290 - 119 = 171 \text{ m}$$

where, of course, the upstream end has the 4-inch pipe. These lengths could be rounded as necessary to accommodate the lateral spacing.