BIE 5110/6110
Sprinkle & Trickle Irrigation
Fall Semester 2004 – Exam #1

Include units in all results. Indicate any assumptions that you might make.

Name________________________________

1. Preliminary Design Calculations (25 pts)

   Almonds (deciduous trees, with no cover crop) have been planted in an 80-acre orchard and will be irrigated with a set sprinkler system. The climate can be characterized as “moderate.” The topsoil is 2.7 ft of silty clay loam, and below that are 3.1 ft of clay loam soil. The soil intake rate is 0.5 inch/hr.

   Use an MAD value of 30%. EC_w is 0.47 dS/m and the estimated water application efficiency will be E_a = 85%. There is no effective rain during the peak-use period. For these preliminary calculations, and based on the spacing of the trees, use a sprinkler spacing of 40 ft x 50 ft.

   a) Obtain the values for average W_a, average Z, U_d, U, and EC_e from the tables in Chapter 3 of the textbook.
   b) Calculate the maximum net application depth per irrigation, d_x.
   c) Calculate the maximum irrigation interval, nominal irrigation interval (whole number of days), and the net application depth per irrigation, d_n.
   d) What is the gross depth to apply per irrigation?
   e) What is the irrigation set time, S_{to}, in hours?

2. Economic Pipe Size Selection (25 pts)

   Suppose you applied the economic pipe sizing method. What if you were using the Hazen-Williams equation and based all your calculations on a system capacity of 100 lps, but now you realize a calculation mistake was made, and the system capacity should really be 115 lps.

   A section flow rate, q, (threshold between two adjacent pipe sizes) was 50 lps, but now it needs to be adjusted for the new system capacity of 115 lps.

   What is the new section flow rate for this system capacity?

3. Set Sprinkler Lateral Design (25 pts)

A fixed sprinkler system with buried IPS-PVC (*thermoplastic pipe*) laterals is to be designed. The 304-m long laterals will be a -0.394% (downhill) slope. The nominal sprinkler flow rate is 10 lpm at a pressure of 280 kPa, and the sprinkler spacing on the laterals is 8.0 m. Riser height is 1.0 m. Let the allowable lateral Δh be equal to 20% of h_a.

a) How many sprinklers will operate on the lateral if the first sprinkler is spaced S_e from the lateral inlet?
b) For a dual pipe size lateral, what is the allowable friction loss gradient, J_a?
c) What two adjacent IPS-PVC thermoplastic pipe sizes would you recommend? Specify the nominal diameters in inches according to Table 8.3.
d) What are the respective lengths (x_1 and x_2) of the two pipe sizes? Round the lengths to a multiple of S_e for each size.
e) What is the required lateral inlet pressure head, h_l?
f) What is the pressure at the downstream end of the lateral during operation?
g) Is the mean velocity at the lateral inlet too high?

4. (25 pts) A portable aluminum sprinkler lateral has a nominal diameter of 4 inches and goes downhill at a uniform slope of -0.5%. The inlet flow rate is 260 gpm, the lateral length is 840 ft, and the sprinkler spacing along the lateral is 30 ft. The lateral inlet pressure head is h_l = 30.0 m.

a) What is the location of minimum pressure in the lateral pipe during operation?
b) What is the minimum pressure in the lateral pipe during operation?
c) Is the mean velocity at the lateral inlet too high?

Solutions:

1. Preliminary Design Calculations (25 pts)

a) Obtain the values for average W_a, average Z, U_d, U, and EC_e from the tables in Chapter 3 of the textbook.

- From Table 3.1, W_a range is the same for the topsoil & subsoil. Use W_a = ½(145 + 208) = 176.5 mm/m.
- From Table 3.2, for almonds, Z = ½(0.6 + 1.2) = 0.9 m.
- From Table 3.3, for deciduous orchard w/o cover crop in a "moderate" climate, U_d = 4.8 mm/day, and U = 533 mm/season.
- From Table 3.5, EC_e = 2.0 dS/m for almonds.

b) Calculate the maximum net application depth per irrigation, d_x.

$$d_x = MAD(W_a)(Z) = 0.30(176.5)(0.9) = 47.7 \text{ mm/irrig}$$

c) Calculate the maximum irrigation interval, nominal irrigation interval (whole number of days), and the net application depth per irrigation, d_n.

$$f_x = \frac{d_x}{U_d} = \frac{47.7 \text{ mm/irrig}}{4.8 \text{ mm/day}} = 9.94 \text{ days/irrig}$$

Rounding down, f = 9 days. This is conservative because f_x is nearly 10 days. Then,

$$d_n = (9 \text{ days/irrig})(4.8 \text{ mm/day}) = 43.2 \text{ mm/irrig}$$

d) What is the gross depth to apply per irrigation?

$$LR = \frac{EC_w}{5EC_e - EC_w} = \frac{0.47}{5(2.0)\text{-}0.47} = 0.049$$

LR < 0.1, so,

$$d = \frac{d_n}{E_a} = \frac{43.2 \text{ mm/irrig}}{0.85} = 50.8 \text{ mm/irrig}$$

e) What is the irrigation set time, S_{to}, in hours?

The soil intake rate is given, at 0.5 inch/hr, which equals 12.7 mm/hr. Then, the minimum set time is:

$$(S_{to})_{min} = \frac{50.8 \text{ mm/set}}{12.7 \text{ mm/hr}} = 4.0 \text{ hrs/set}$$

2. Economic Pipe Size Selection (25 pts)

   Note the graph on page 67 of the lecture notes. The lines separating the adjacent pipe sizes do not change because, in this problem, none of the economic parameters have changed. The relationship between Q and q is fixed along the slope of 2:1 on the log-log plot, or 1.852:1 in our case (with Hazen-Williams, as specified).

   We have:

$$Q_s = K\left(q^{-1.852}\right)$$

   Then,

$$\frac{100 = K\left(50^{-1.852}\right)}{115 = K\left(q_{new}{}^{-1.852}\right)}$$

   or,

$$q_{new} = 50\left(\frac{115}{100}\right)^{1/-1.852} = 46.6 \text{ lps}$$

3. Set Sprinkler Lateral Design (25 pts)

   a) How many sprinklers will operate on the lateral if the first sprinkler is spaced S_e from the lateral inlet?

$$\frac{304 \text{ m/lat}}{8 \text{ m/sprink}} = 38 \text{ sprink/lat}$$

   b) For a dual pipe size lateral, what is the allowable friction loss gradient, J_a?

   Since there are more than 30 outlets along the lateral pipe, F = 0.36. The nominal sprinkler pressure head is 280 kPa/9.81 = 28.5 m. Then,

$$J_a = 100\left(\frac{0.20h_a - \Delta h_e}{FL}\right) = 100\left(\frac{0.20(28.5) - (304)(-0.00394)}{(0.36)(304)}\right) = 6.3 \text{ m/100m}$$

   c) What two adjacent IPS-PVC thermoplastic pipe sizes would you recommend? Specify the nominal diameters in inches according to Table 8.3.

The lateral inflow rate is:

$$Q_\ell = (38 \text{ sprink/lat})(10 \text{ lpm/sprink}) = 380 \text{ lpm/lat } (6.33 \text{ lps/lat})$$

With J_a = 6.3 m/100 m, Table 8.3 gives the following two adjacent PVC pipe sizes: 2" and 2½." Note that the respective pipe IDs are 55.7 mm and 67.4 mm.

d) What are the respective lengths (x_1 and x_2) of the two pipe sizes? Round the lengths to a multiple of S_e for each size.

This problem requires a few iterations. Use C = 150 for PVC with Hazen-Williams. Use units of lps and mm. From the lecture notes, we have:

$$\alpha_1 = \frac{1.217(10)^{12}}{100(150)^{1.852}} = 1.135(10)^6$$

$$\alpha_2 = \left[\frac{(10/60)(304)}{8}\right]^{1.852} (67.4)^{-4.87}(0.36)(304) = 4.152(10)^{-6}$$

$$\alpha_3 = \left(67.4^{-4.87} - 55.7^{-4.87}\right)\left(\frac{10/60}{8}\right)^{1.852} = -1.464(10)^{-12}$$

Note that F_1 = 0.36 due to the 38 sprinklers over the length L. F_2 will depend on x_1. Make a table of values, arbitrarily choosing an initial x_1 value of 150 m, and searching for $f(x_1) = 0$:

x_1 (m)	N	F_2	$f(x_1)$
150	19	0.38	-1.10
100	26	0.37	0.19
125	22	0.37	-0.55
112	24	0.37	-0.19
105	25	0.37	0.03

Rounding, let x_1 = 104 m, whereby $x_2 = L – x_1$ = 200 m.

e) What is the required lateral inlet pressure head, h_l?

Calculate h_f using F, as described in the lecture notes:

$$Q_2 = \left(\frac{x_2}{S_e}\right) q_a = \left(\frac{200}{8}\right)(10/60) = 4.17 \text{ lps}$$

$$J_1 = 1.217(10)^{12}\left(\frac{6.33}{150}\right)^{1.852}(67.4)^{-4.87} = 4.30 \text{ m/100m}$$

$$J_2 = 1.217(10)^{12}\left(\frac{4.17}{150}\right)^{1.852}(67.4)^{-4.87} = 1.99 \text{ m/100m}$$

$$J_3 = 1.217(10)^{12}\left(\frac{4.17}{150}\right)^{1.852}(55.7)^{-4.87} = 5.03 \text{ m/100m}$$

where $F_1 = 0.36$ and $F_2 = 0.37$. Then,

$$h_f = \frac{471 - 147 + 372}{100} = 7.0 \text{ m}$$

Finally,

$$h_l = h_a + \frac{5}{8}h_f + \frac{1}{2}\Delta h_e + h_r$$

$$h_l = 28.5 + \frac{5}{8}(7.0) + \frac{1}{2}(-1.2) + 1.0 \cong 33 \text{ m (320 kPa)}$$

f) What is the pressure at the downstream end of the lateral during operation?

$$\begin{aligned} h_{end} &= h_l - h_f - \Delta h_e \\ &= 33 - 7 + 1.2 \\ &\cong 27 \text{ m} \end{aligned}$$

or, $27 - h_r = 27 - 1 = 26$ m head at the last sprinkler.

g) Is the mean velocity at the lateral inlet too high?

$$V = \frac{Q}{A} = \frac{4(6.33 \text{ lps})}{\pi(0.0674 \text{ m})^2(1{,}000 \text{ l/m}^3)} = 1.77 \text{ m/s}$$

Then, $V < 2.0$ m/s, so it is probably all right.

4. (25 pts) Portable aluminum sprinkler lateral.

- From Table 8.1, 4-inch pipe has ID = 3.9” (99.1 mm).
- Q_l = 260 gpm, or 16.4 lps.
- S_e = (30)(0.3048) = 9.14 m.
- N = 840/30 = 28 sprinklers.
- q_a = 16.4/28 = 0.586 lps.
- For aluminum lateral pipe, C = 130.

a) What is the location of minimum pressure in the lateral pipe during operation?

From the lecture notes, page 74:

$$x = \left(\frac{9.14}{0.586}\right)\left[16.4 - 3(10)^{-7}\left(130(0.5)^{0.54}(99.1)^{2.63}\right)\right] = 181\,\text{m}$$

which is x = 595 ft.

b) What is the minimum pressure in the lateral pipe during operation?

- L = 840 ft, or 256 m.
- F_1 = 0.37 for 28 outlets (Table 8.7).
- Outlets beyond x = 181 m: N_2 = (256 – 181)/9.14 ≈ 8.
- F_2 = 0.42 for 8 outlets (Table 8.7).

$$J_1 = 1.217(10)^{12}\left(\frac{16.4}{130}\right)^{1.852}(99.1)^{-4.87} = 5.00\text{ m/100 m}$$

$$J_2 = 1.217(10)^{12}\left(\frac{(8)(0.586)}{130}\right)^{1.852}(99.1)^{-4.87} = 0.49\text{ m/100 m}$$

The friction head loss from inlet to x = 595 ft (181 m) is:

$$\left(h_f\right)_{x=181m} = \frac{J_1F_1L}{100} - \frac{J_2F_2(L-x)}{100}$$

$$\left(h_f\right)_{x=181m} = \frac{(5.00)(0.37)(256)}{100} - \frac{(0.49)(0.42)(75)}{100} = 4.6\text{ m}$$

or, 15 ft of head loss. Note that h_l is given in m, while all other values are given in English units. Finally,

$$
\begin{aligned}
h_{x=181\,m} &= h_l - \left(h_f\right)_{x=181\,m} - \Delta h_e \\
&= 30.0 - 4.6 - 181(-0.005) \\
&\cong 26\text{ m }\ (86\text{ ft, or }37\text{ psi})
\end{aligned}
$$

c) Is the mean velocity at the lateral inlet too high?

$$
V = \frac{Q}{A} = \frac{4(16.4\text{ lps})}{\pi(0.0991\text{ m})^2(1{,}000\text{ l/m}^3)} = 2.1\text{ m/s}
$$

Whereby V > 2.0 m/s, so the entrance velocity in the lateral is higher than what we might nominally allow. This suggests consideration of a larger pipe size.