BIE 5110/6110
Sprinkle & Trickle Irrigation
Fall Semester, 2004

Assignment #5 (100 pts)
Minor Losses & Pumps
Due: 13 Oct 04

Given:

- A rectangular field to be sprinkler irrigated
- There will be four laterals, two on each side of the mainline
- All of the periodic-move laterals will move in the same direction
- At the beginning of an irrigation, two laterals are at the upstream end of the mainline (first hydrant) and the other two are at the mid-point of the mainline
- The nominal hydrant diameter, and the inside diameter, is 4 inches
- Each lateral irrigates ¼ of the field area, and each is 600 ft in length
- Required lateral inlet pressure head is P_l = 44 psi
- The mainline will be 5-inch aluminum (see Table 8.4), with hydrant values spaced at S_l = 30 ft along the 1,320-ft length of the mainline
- The first hydrant is located 30 ft from the beginning of the mainline, and the last hydrant is 1,320 ft from the beginning of the mainline
- The sprinkler system will operate 12 hrs/day, and the irrigation interval during the peak-use period is 7 days
- The gross depth to apply per irrigation is 1.9 inches
- The mainline slopes downhill at a uniform slope of 0.18%
- See the table in Chapter 8 for the roughness height of aluminum pipe
- See Table 11.1 for minor loss coefficients, K_r

Required:

- What is the field area, in acres?
- What is the system capacity, in gpm?
- Will the velocity in the mainline acceptable, or too high?
- Use the Darcy-Weisbach equation for pipe friction loss
- Make a graph of required (minimum) pressure at the upstream end of the mainline as a function of lateral position, such that the minimum lateral inlet pressure (for each lateral position) is exactly 44 psi
- This means that one pair of laterals will have exactly 44 psi inlet pressure, while the other pair will have a slightly higher inlet pressure, and this will be the case for each lateral position
- Note that there will be 1,320/(2*30) = 22 different positions lateral for each pair of laterals
- On the graph, you can call the lateral positions “1,” “2,” “3,” … “21,” and “22.”
- Make note of any assumptions and of references which you use to obtain data

Solution:

1. Field Area:

The field is given to be rectangular. Note that there are 43,560 ft^2/acre. The irrigated area is the length of the mainline (1,320 ft) multiplied by twice the length of one lateral (2 x 600 ft):

$$\frac{(1{,}320)(1{,}200)}{43{,}560} = 36.4 \text{ acres}$$

2. System Capacity:

Use Eq. 5.4 and the given data:

$$Q_s = 453\frac{Ad}{fT} = 453\frac{(36.4)(1.9)}{(7)(12)} = 373 \text{ gpm}$$

3. Velocity Checks:

Table 8.4: 5-inch aluminum pipe has an inside diameter of 4.900 inches (0.408 ft). Note that the maximum recommended velocity, in general, for sprinkler systems is 5 to 7 fps.

3(a). Full system capacity in the mainline:

$$V_{Q_s} = \frac{Q_s}{A} = \frac{4(373 \text{ gpm})}{\pi(60 \text{ s/min})(7.481 \text{ gal/ft}^3)(0.408 \text{ ft})^2} = 6.36 \text{ fps}$$

3(b). Half system capacity in the mainline:

$$V_{Q_s/2} = \frac{Q_s}{2A} = \frac{2(373 \text{ gpm})}{\pi(60 \text{ s/min})(7.481 \text{ gal/ft}^3)(0.408 \text{ ft})^2} = 3.18 \text{ fps}$$

3(c). Half system capacity through a hydrant valve:

$$V_{hydrant} = \frac{Q_s}{2A} = \frac{2(373 \text{ gpm})}{\pi(60 \text{ s/min})(7.481 \text{ gal/ft}^3)(0.333 \text{ ft})^2} = 4.77 \text{ fps}$$

All of the above velocities are below 7 fps, so they are found to be acceptable.

4. Reynolds Numbers and Darcy-Weisbach f:

The Reynolds number for a circular pipe is defined as:

$$R_e = \frac{VD}{\nu} = \frac{4Q}{\pi D \nu}$$

Assume a water temperature of 10°C. From the table on page 126 of the lecture notes (or from any other reference), the kinematic viscosity at this temperature is ν = $1.306(10)^{-6}$ m^2/s.

4(a). Full system capacity in the mainline:

$$\left(R_e\right)_{Q_s} = \frac{4(373\ \text{gpm})(0.3048\ \text{m/ft})^2}{\pi(448.86\ \text{gpm/cfs})(0.408\ \text{ft})(1.306\text{E-6 m}^2\text{/s})} \approx 184{,}000$$

4(b). Half system capacity in the mainline:

$$\left(R_e\right)_{Q_s/2} = \frac{2(373\ \text{gpm})(0.3048\ \text{m/ft})^2}{\pi(448.86\ \text{gpm/cfs})(0.408\ \text{ft})(1.306\text{E-6 m}^2\text{/s})} \approx 92{,}000$$

From the table on page 138 (Chapter 8) of the textbook, the roughness height of aluminum pipe (with couplers as an equivalent length of pipe) is 0.005 ft. Then, from the Swamee-Jain equation:

$$f_{Q_s} = 0.0213$$

and,

$$f_{Q_s/2} = 0.0225$$

5. Velocity Heads:

There are three different velocity heads to be considered, based on the three velocities given in 3(a) – 3(c) above. These are:

5(a). Full system capacity in the mainline:

$$\frac{V_{Q_s}^2}{2g} = \frac{(6.36\ \text{fps})^2}{2(32.2\ \text{ft/s}^2)} = 0.628\ \text{ft}$$

5(b). Half system capacity in the mainline:

$$\frac{V_{Q_s/2}^2}{2g} = \frac{(3.18\text{ fps})^2}{2(32.2\text{ ft/s}^2)} = 0.157\text{ ft}$$

5(c). Half system capacity through a hydrant valve:

$$\frac{V_{hydrant}^2}{2g} = \frac{(4.77\text{ fps})^2}{2(32.2\text{ ft/s}^2)} = 0.353\text{ ft}$$

6. Minor Loss Coefficients:

From Table 11.2 for a 4-inch aluminum hydrant valve:

Flow Path	**K_r**
Past closed hydrant	0.5
Past open hydrant	0.6
Through open hydrant	7.5

7. Calculating Hydraulic Losses:

At the start of an irrigation, one pair of laterals is at the first hydrant (#1), which is 30 ft from the beginning of the mainline. The second pair of laterals is at a distance of 660 ft from the first pair, at hydrant #23. At each subsequent set, the laterals move S_l = 30 ft down the mainline.

The second set will find the first pair of laterals at hydrant #2, and the second pair at hydrant #24. Finally, the last set of the irrigation will have the first pair at hydrant #22, and the second pair at hydrant #44 (the last one on the mainline).

The minimum pressure head required in the mainline pipe at a open hydrant is the required lateral inlet pressure head of (44 psi)(2.31 ft/psi) = 102 ft, plus the head loss through the hydrant valve, which is:

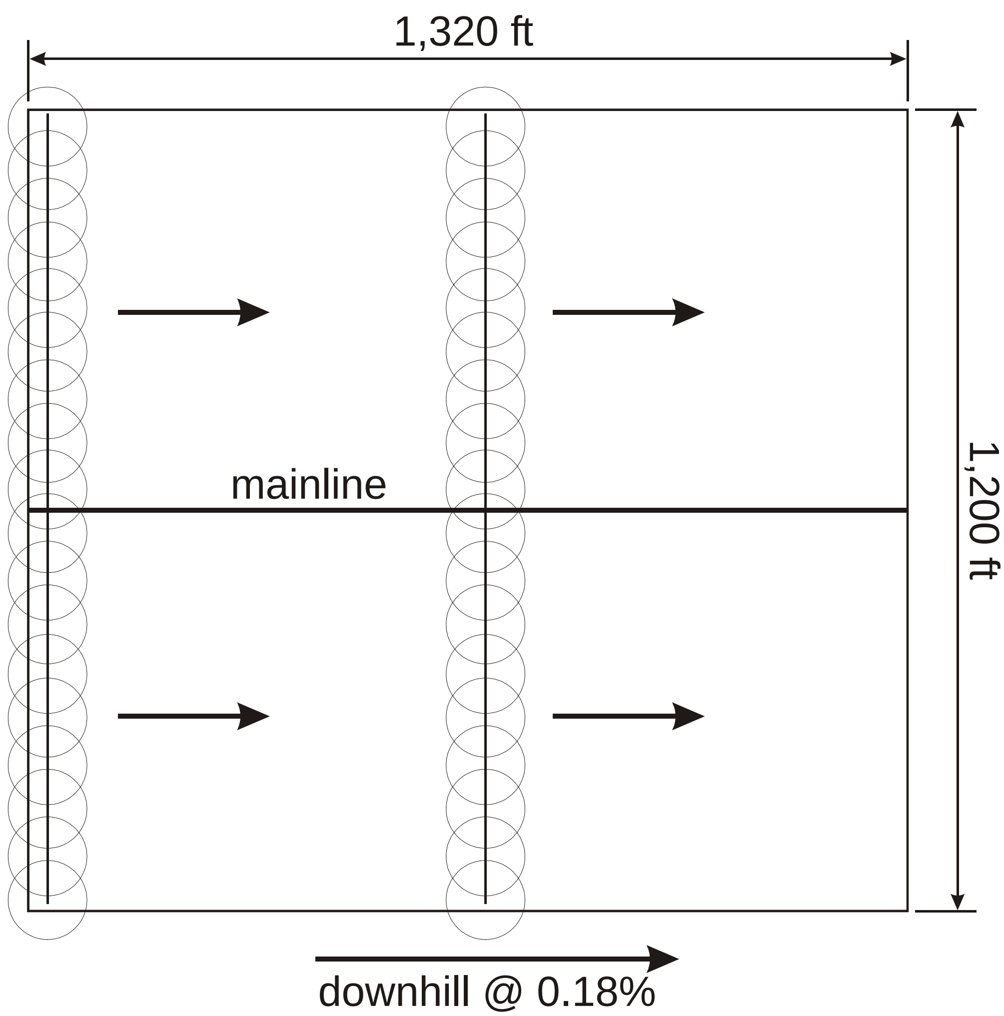
$$(h_f)_{hydrant} = K_r \frac{V^2}{2g} = 7.5\left(\frac{4.77^2}{2(32.2)}\right) = 2.65\text{ ft}$$

Then, the minimum pressure head required in the mainline pipe at a open hydrant is:

$$h_{main} = 102 + 2.65 \approx 105\text{ ft}$$

which is constant for any lateral position.

The following figure gives a schematic plan view of the field area:



Note that for every one of the 22 lateral positions, the second pair of laterals is always 660 ft downstream of the first pair of laterals.

7(a). Considering the First Pair of Laterals

Make a table of lateral positions in which the number of upstream closed laterals increases by one for each new lateral position (because the pair of laterals moves further from the upstream end of the mainline). Thus, the pipe friction loss and the minor losses due to flow past a closed hydrant increase with each lateral position. On the other hand, the change in elevation partially offsets these friction losses. Note that from the upstream end of the mainline to the first pair of laterals, the discharge is equal to the entire system flow rate. Consider the following table:

First Pair of Laterals						
Lateral Position	Distance to 1st Pair (ft)	Elev Change (ft)	Pipe h_f (ft)	Number of US hydrants	$(h_f)_{minor}$ (ft)	Req'd at Mainline Inlet (ft)
1	30	-0.054	0.98	0	0.00	105.9
2	60	-0.108	1.97	1	0.31	107.2
3	90	-0.162	2.95	2	0.63	108.4
4	120	-0.216	3.93	3	0.94	109.7
5	150	-0.270	4.92	4	1.26	110.9
6	180	-0.324	5.90	5	1.57	112.1
7	210	-0.378	6.88	6	1.88	113.4
8	240	-0.432	7.87	7	2.20	114.6
9	270	-0.486	8.85	8	2.51	115.9
10	300	-0.540	9.84	9	2.83	117.1
11	330	-0.594	10.82	10	3.14	118.4
12	360	-0.648	11.80	11	3.45	119.6
13	390	-0.702	12.79	12	3.77	120.9
14	420	-0.756	13.77	13	4.08	122.1
15	450	-0.810	14.75	14	4.40	123.3
16	480	-0.864	15.74	15	4.71	124.6
17	510	-0.918	16.72	16	5.02	125.8
18	540	-0.972	17.70	17	5.34	127.1
19	570	-1.026	18.69	18	5.65	128.3
20	600	-1.080	19.67	19	5.97	129.6
21	630	-1.134	20.65	20	6.28	130.8
22	660	-1.188	21.64	21	6.59	132.0

7(b). Considering the Second Pair of Laterals

Do the same thing as for the first pair of laterals, but considering that part of the mainline has the full system flow rate, and part has only half of the system flow rate. Also, the minor loss due to “line flow” past one open hydrant (location of the first pair of laterals) must be added to the head losses.

The losses from the second pair of laterals to the upstream end of the mainline must be added to the 105-ft head requirement (see above) in the mainline at the location of the second pair of laterals. These losses include pipe friction and minor losses. Consider the following table (next page):

7(c). Extreme Position

It is seen that for each of the 22 lateral positions, the second pair of laterals require a higher pressure head at the upstream end of the mainline. This is because the downhill slope of the mainline is very small, so the friction losses dominate the pressure variation along the mainline. Thus, the following graph is for the required pressure head at the upstream end of the mainline from the perspective of the second (downstream) pair of laterals for each position, thereby giving more than enough pressure in the mainline at the location of the first pair of laterals.

Second Pair of Laterals							
Position	Distance to 1st Pair (ft)	Distance to 2nd Pair (ft)	Elev Change (ft)	Pipe hf (ft)	Number of closed US hydrants	$(h_f)_{minor}$ (ft)	Req'd at Mainline Inlet (ft)
1	30	690	-1.242	6.70	21	2.10	112.6
2	60	720	-1.296	7.68	22	2.42	113.8
3	90	750	-1.350	8.67	23	2.73	115.0
4	120	780	-1.404	9.65	24	3.05	116.3
5	150	810	-1.458	10.63	25	3.36	117.5
6	180	840	-1.512	11.62	26	3.67	118.8
7	210	870	-1.566	12.60	27	3.99	120.0
8	240	900	-1.620	13.58	28	4.30	121.3
9	270	930	-1.674	14.57	29	4.62	122.5
10	300	960	-1.728	15.55	30	4.93	123.8
11	330	990	-1.782	16.53	31	5.24	125.0
12	360	1,020	-1.836	17.52	32	5.56	126.2
13	390	1,050	-1.890	18.50	33	5.87	127.5
14	420	1,080	-1.944	19.48	34	6.19	128.7
15	450	1,110	-1.998	20.47	35	6.50	130.0
16	480	1,140	-2.052	21.45	36	6.81	131.2
17	510	1,170	-2.106	22.43	37	7.13	132.5
18	540	1,200	-2.160	23.42	38	7.44	133.7
19	570	1,230	-2.214	24.40	39	7.76	134.9
20	600	1,260	-2.268	25.39	40	8.07	136.2
21	630	1,290	-2.322	26.37	41	8.38	137.4
22	660	1,320	-2.376	27.35	42	8.70	138.7