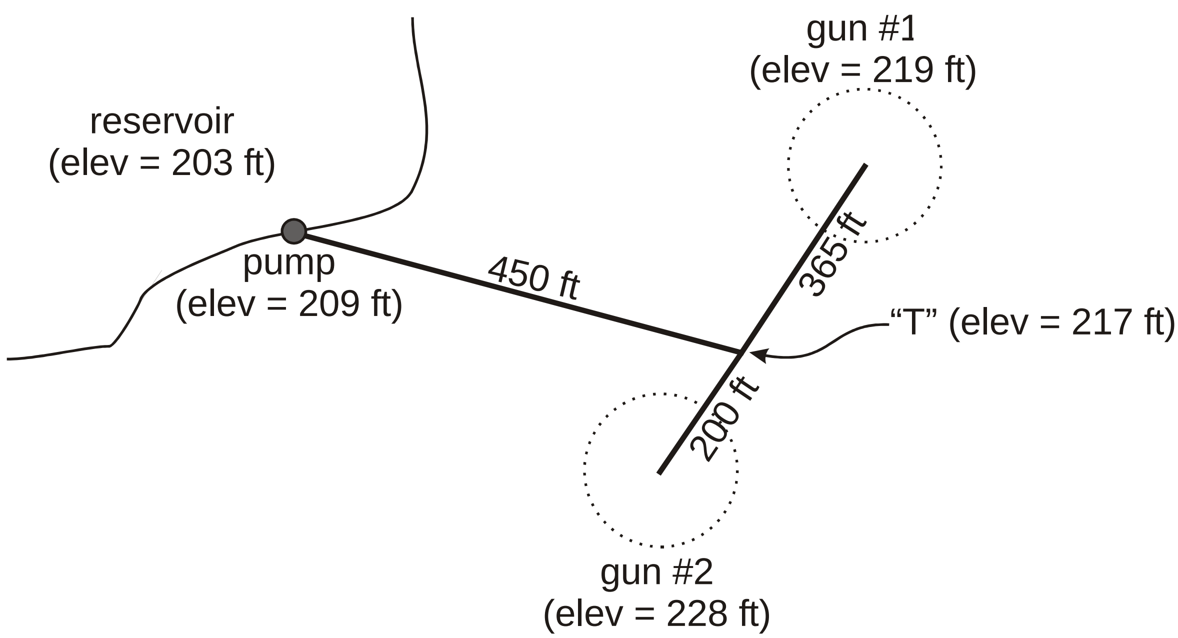
BIE 5110/6110
Sprinkle & Trickle Irrigation
Fall Semester 2004 – Exam #2

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

Name___________________________________

1. (60 pts) Two gun sprinklers are supplied water from a pump at an open reservoir (water surface at 203 ft above msl), as shown in the figure below:



There is a common 4-inch (ID = 4.280") PVC supply line from the pump to a "T". The supply line is 450 ft long.

A 3-inch (ID = 3.284") PVC pipe goes 365 ft from the "T" to gun #1, and another 3-inch pipe goes 200 ft from the "T" to gun #2. The sprinkler height above the buried lateral pipe is h_r = 8.00 ft for both guns.

The flow rate vs. pressure data for the gun sprinkler give the following relationship:

$$q = 11.7P^{0.49}$$

for q in gpm; and P in psi.

The suction side of the pump has the same 4-inch PVC pipe as the supply line, 12 ft in length, with two 45-degree long-radius, flanged elbows, a basket strainer, and a foot valve.

a) Develop one point on the system curve using the Hazen-Williams equation (with C = 150) for friction losses. Use a flow rate of 80 gpm for gun sprinkler #1.
b) Calculate the flow rate for gun sprinkler #2.
c) Calculate the total system flow rate, Q_s.
d) Calculate TDH for this flow rate. Show your calculations for minor losses.

2. (20 pts) For the B2TPM Berkeley™ pump and 6-½” impeller, and the same system, suppose now that the desired operating point is for Q = 150 gpm.

   a) From the pump curves, determine $NPSH_r$.
   b) Calculate $NPSH_a$ (water temperature is 12°C).
   c) Determine whether the pump is expected to cavitate at the operating point.

3. (20 pts) For the same B2TPM Berkeley™ pump and 6-½” impeller, suppose that the desired operating point is 150 gpm at a TDH of 150 ft. If the nominal pump speed is 3,600 RPM, what is the required speed for the desired operating point?

4. (5 bonus pts) Which of the following are a function of a center pivot’s radial speed? (check all that apply)

   ☐ wetted width, w
   ☐ net application depth, d_n
   ☐ average application rate, AR_{avg}
   ☐ maximum application rate, AR_x
   ☐ friction loss in the lateral pipe, h_f

Solutions:

1. (60 pts) Two gun sprinklers are supplied water from a pump at an open reservoir (water surface at 203 ft above msl), as shown in the figure below:

   Move along the pipes from sprinkler #1 to the "T," then to sprinkler #2 to determine the flow rate there, then get the system flow rate ($Q_s = Q_1 + Q_2$), and finally move to the pump to determine P_{pump}.

   I. Flow rate at sprinkler #2:

   Pressure at gun sprinkler #1:

$$P_1 = \left(\frac{80}{11.7}\right)^{1/0.49} = 50.6 \text{ psi}$$

   Pressure head at gun sprinkler #1:

$$h_1 = (50.6 \text{ psi})(2.31 \text{ ft/psi}) = 117 \text{ ft}$$

   Pressure head at the "T":

$$\begin{aligned} h_T &= h_1 + h_r + \Delta h_e + h_f \\ h_T &= 117 + 8 + (219 - 217) + 10.5(365)\left(\frac{80}{150}\right)^{1.852}(3.284)^{-4.87} \\ h_T &= 127 + 0.00109(80)^{1.852} \\ h_T &= 131 \text{ ft} \end{aligned}$$

   Pressure head at gun sprinkler #2:

$$\begin{aligned} h_2 &= h_T + \Delta h_e - h_f - h_r \\ h_2 &= 131 + (217 - 228) - 10.5(200)\left(\frac{Q_2}{150}\right)^{1.852}(3.284)^{-4.87} - 8 \\ h_2 &= 131 - 11 - 0.000599\,Q_2^{1.852} - 8 \\ h_2 &= 112 - 0.000599\,Q_2^{1.852} \end{aligned}$$

Flow rate at gun sprinkler #2:

$$Q_2 = 11.7\left(\frac{h_2}{2.31}\right)^{0.49} = 11.7\left(\frac{112 - 0.000599\,Q_2^{1.852}}{2.31}\right)^{0.49}$$

giving Q_2 = 77.7 gpm.

II. System flow rate:

$$Q_s = Q_1 + Q_2 = 80 + 77.7 \cong 158 \text{ gpm}$$

III. Pressure at pump outlet:

Pressure head at pump outlet:

$$h_{pump} = h_T + \Delta h_e + h_f$$
$$h_{pump} = 131 + (217 - 209) + 0.000371 Q_s^{1.852}$$
$$h_{pump} = 139 + 4.38 = 143 \text{ ft}$$

Pressure at pump outlet:

$$P_{pump} = \frac{h_{pump}}{2.31} = \frac{143 \text{ ft}}{2.31} = 61.9 \text{ psi}$$

IV. Suction side of the pump:

From Table 11.2, for a 4-inch pipe:

Item	**Count**	**K_r**	**Total**
Foot valve	1	0.80	0.80
Basket strainer	1	1.05	1.05
45-deg elbow	2	0.18	0.36
		Total:	**2.21**

Velocity head:

$$\frac{V^2}{2g} = \frac{8Q^2}{g\pi^2 D^4} = \frac{8\left(Q/448.86\right)^2}{32.2\pi^2(4.280/12)^4} = 7.72(10)^{-6}\,Q_s^2$$

Minor losses (see the above table):

$$\left(h_{f,minor}\right)_{suction} = 2.21\left(\frac{V^2}{2g}\right)$$

Pipe friction loss:

$$\left(h_f\right)_{suction} = 10.5(12)\left(\frac{Q_s}{150}\right)^{1.852}(4.280)^{-4.87} = 9.89(10)^{-6}Q_s^{1.852}$$

Static lift:

$$\left(h_{lift}\right)_{suction} = 209 - 203 = 6 \text{ ft}$$

V. Total dynamic head (TDH):

$$TDH = \frac{P_{pump}}{\gamma} + \left(h_f\right)_{suction} + \left(h_{f,minor}\right)_{suction} + \left(h_{lift}\right)_{suction} + \frac{V^2}{2g}$$

where P_{pump} is the pressure at the pump outlet. Simplifying,

$$TDH = h_{pump} + 9.89(10)^{-6}Q_s^{1.852} + 2.48(10)^{-5}Q_s^2 + 6$$

then,

$$TDH = 143 + 9.89(10)^{-6}(158)^{1.852} + 2.48(10)^{-5}(158)^2 + 6$$
$$TDH = 143 + 0.117 + 0.619 + 6$$
$$TDH = 150 \text{ ft}$$

VI. System curve point:

TDH = 150 ft at Q_s = 158 gpm

2. (20 pts) For the B2TPM Berkeley™ pump and 6-½" impeller, and the same system, suppose now that the desired operating point is for Q = 150 gpm.

   a) From the pump curves, determine $NPSH_r$.
   b) Calculate $NPSH_a$ (water temperature is 12°C).
   c) Determine whether the pump is expected to cavitate at the operating point.

From the pump curves, at 150 gpm, $NPSH_r \approx 9$ ft.

Mean atmospheric pressure head:

$$h_{atm} = \frac{10.3 - 0.00105(203 * 0.3048)}{0.3048} = 33.6 \text{ ft}$$

For water at 12°C,

$$h_{vapor} = 0.0623 \exp\left(\frac{17.27(12)}{12 + 237.3}\right) = 0.143 \text{ m } (0.469 \text{ ft})$$

Velocity head:

$$\frac{V^2}{2g} = 7.72(10)^{-6} Q_s^2 = 7.72(10)^{-6}(150)^2 = 0.174 \text{ ft}$$

Minor losses:

$$\left(h_{f,minor}\right)_{suction} = 2.21\left(\frac{V^2}{2g}\right) = 2.21(0.174) = 0.384 \text{ ft}$$

Pipe friction loss:

$$\left(h_f\right)_{suction} = 10.5(12)\left(\frac{150}{150}\right)^{1.852} (4.280)^{-4.87} = 0.106 \text{ ft}$$

Static lift:

$$\left(h_{lift}\right)_{suction} = 209 - 203 = 6 \text{ ft}$$

Available NPSH:

$$NPSH_a = h_{atm} - h_{vapor} - \left(h_f\right)_{total} - h_{lift} - \frac{V^2}{2g}$$

$$NPSH_a = 33.6 - 0.469 - 0.382 - 0.106 - 6 - 0.174$$

$$NPSH_a = 26.5 \text{ ft}$$

The pump is not expected to cavitate because $NPSH_a$ >> $NPSH_r$.

3. (20 pts) For the same B2TPM Berkeley™ pump and 6-½" impeller, suppose that the desired operating point is 150 gpm at a TDH of 150 ft. If the nominal pump speed is 3,600 RPM, what is the required speed for the desired operating point?

Follow the steps in the lecture notes. Make a table for the equal efficiency curve, using Q_2 = 150 gpm, and H_2 = 150 ft:

Q_1 (gpm)	H_1 (ft)
100	66.67
120	96.00
140	130.67
160	170.67
180	216.00

Plot the equal efficiency curve and look for the intersection with the pump characteristic curve, defining point (Q_3,H_3). From the graph, $Q_3 \approx$ 158 gpm, and $H_3 \approx$ 167 ft. Then,

$$N_{new} = N_{old}\left(\frac{Q_2}{Q_3}\right) = 3{,}600\left(\frac{150}{158}\right) = 3{,}418 \text{ RPM}$$

4. (5 bonus pts) Which of the following are a function of a center pivot's radial speed? (check all that apply)

- ☐ wetted width, w
- ☑ net application depth, d_n
- ☐ average application rate, AR_{avg}
- ☐ maximum application rate, AR_x
- ☐ friction loss in the lateral pipe, h_f