National Exams December 2009

07-Str-B11. Hydraulic Engineering

3 hours duration

NOTES:

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.

2. This is a CLOSED BOOK examination. The following are permitted:

   - one 8.5 x 11 inch aid sheet (both sides may be used); and
   - one of two calculators is permitted any Casio of Sharp approved models

3. This examination has a total of six questions. You are required to complete any five of the six exam questions. Indicate clearly on your examination answer booklet which questions you have attempted. The first five questions as they appear in the answer book will be marked. All questions are of equal value. If any question has more than one part, each is of equal value.

4. The following equations may be useful:

   - Hazen-Williams: $Q = 0.278 C D^{2.63} S^{0.54}$, $S = \Delta h / L$
   - Manning's: $Q = \dfrac{A}{n} R^{2/3} S^{0.5}$, $S = \Delta h / L$
   - Darcy-Weisbach: $\Delta h = \dfrac{fL}{D} \cdot \dfrac{V^2}{2g}$
   - Loop Corrections: $q_l = -\dfrac{\sum_{\text{loop}} k_i Q_i |Q_i|^{n-1}}{n \sum_{\text{loop}} k_i |Q_i|^{n-1}}$, $n = 1.852$ (Hazen-Williams)
   - Total Dynamic Head: $\text{TDH} = H_s + H_f$, H_s=static head; H_f=friction losses.

5. Unless otherwise stated, (i) assume that local losses and velocity head are negligible, (ii) that the given values for pipe diameters are nominal pipe diameters and (iii) that the flow involves water with a density $\rho = 1{,}000$ kg/m^3 and kinematic viscosity $\nu = 1.31 \times 10^{-6}$ m^2/s.

/20 1. A local distribution main is being designed in a cul-de-sac section of a subdivision (Figure 1). The distribution main has a Hazen-Williams 'C' factor of 150, an internal diameter of 152 mm and a length of 100 m. The hydraulic grade line (HGL) in the trunk main is fixed at 70 m and the centerline pipe elevation at the hydrant is 5 m.

a) Check if the distribution main can provide a pressure head of 60 m H_20 for an average day demand of 0.1 L/s. (Assume that demand occurs at the downstream point of the distribution main.)

b) Check if the distribution main can provide a pressure head of 20 m H_20 for a maximum hour demand of 0.2 L/s at the downstream point. (Assume that demand occurs at the downstream point of the distribution main.)

c) Check if the distribution main can provide a pressure head of 14 m H_20 for a maximum day demand of 0.18 L/s plus a fire flow of 32 L/s. (Assume that demand and fire flow both occur at the downstream point of the distribution main.)

d) Based on your answers in a), b), and c), does water demand or fire flow govern local distribution main sizing?

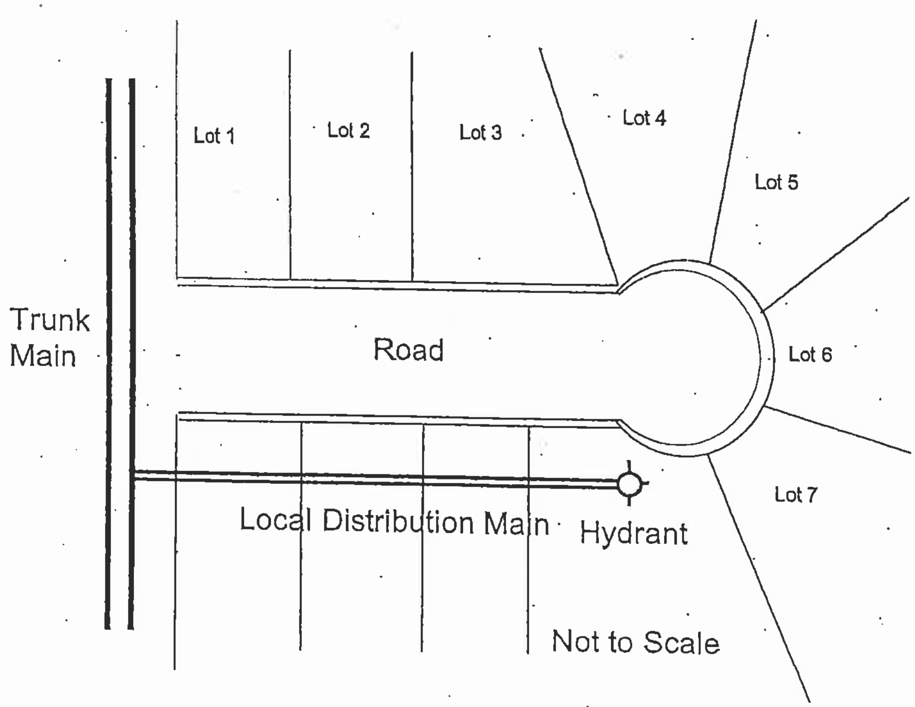

Figure 1. Trunk and local distribution mains in cul-de-sac.

/20 2. A pump forces water through a 2 km long pipeline in Figure 2. Water is conveyed from an upstream reservoir (water level of 60 m) to a downstream reservoir (water level of 30 m). The pipe has an internal diameter of 400 mm and a Darcy-Weisbach friction factor of 0.015. Friction losses in the pipeline are accurately determined by the Darcy-Weisbach equation. Two pumps are connected in series at the upstream reservoir. Each pump has a characteristic curve described by TDH = 30 - 10 Q^2, in which TDH is the total dynamic head of the pump (in metres) and Q is the pump discharge in m^3/s. Flow is controlled by a valve downstream of the pipeline and approximated with the valve equation .

$$Q_v = \tau E_s \sqrt{H - H_0}$$

where Q_v = valve discharge (in m^3/s), E_s = valve discharge constant (E_s = 0.25 $\cdot m^{5/2}/s$), H = hydraulic head upstream of valve, H_0 = hydraulic head downstream of valve.

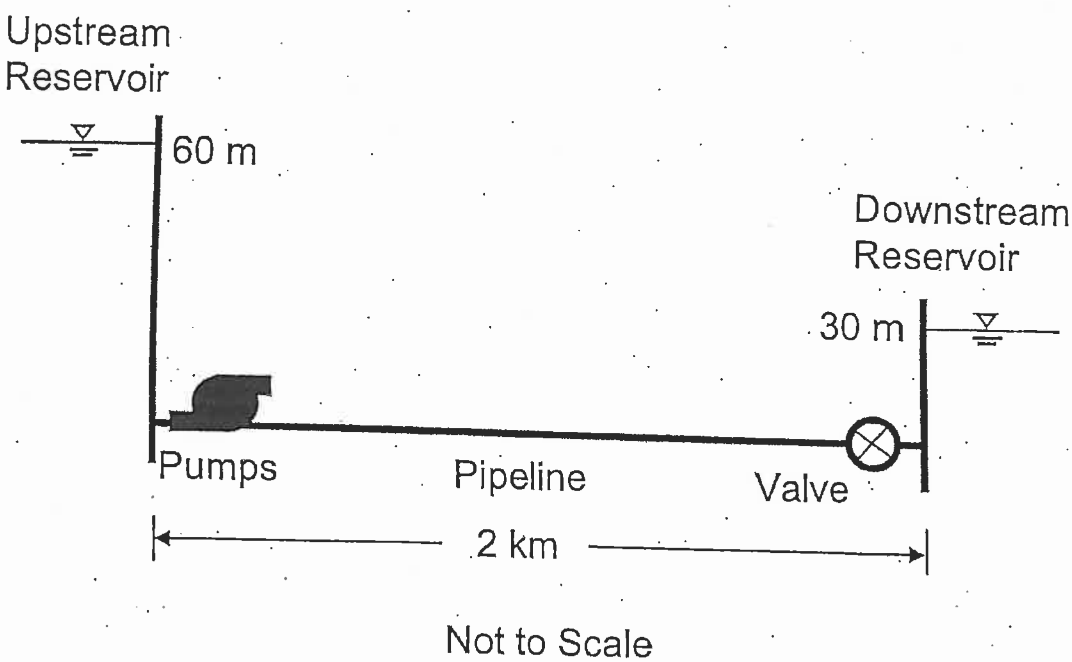

Figure 2. Pipeline system with pumps and downstream valve.

a) Calculate the flow in the pipeline when the valve is set to τ = 0.3.

b) Re-calculate the flow in the pipeline when the valve is set to τ = 0.5.

c) Compute the percent of total headloss that occurs across the valve in parts a) and b). What can you say about the relationship between τ-values and percent of total headloss that occurs across the valve?

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3. The 5-pipe water distribution network shown in Figure 3 has a fixed-head reservoir (R_1) with water level of 70 m. The pipe (P_1) that connects the fixed-head reservoir to the rest of the network is 100 m in length, and has an inner diameter of 610 mm and a 'C' factor of 140. Pipes 2 to 5 have the following parameters: length = 500 m, Hazen-Williams 'C' factor = 130, and inner diameter = 203 mm. Node 1 is at elevation 5 m, Node 2 at elevation 10 m, Node 3 at elevation 25 m and Node 4 at elevation 15 m. Demand at Node 1 is Q_1 = 50 L/s, demand at Node 2 is Q_2 = 23 L/s, demand at Node 3 is Q_3 = 18 L/s, and demand at Node 4 is Q_4 = 17 L/s.

a) Calculate the flows in the 5 pipes.

b) Calculate the pressure head at all nodes.

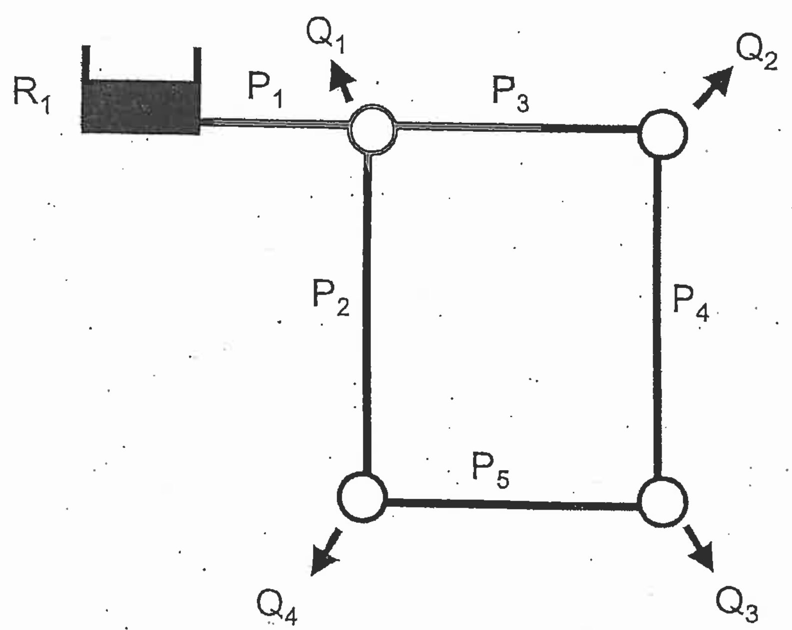

Figure 3. Water network with fixed-head reservoir.

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4. A sudden slope failure causes a large amount of gravel and rock material to slide into a river. This failure completely blocks the flow of the river.

a) Describe the hydraulic conditions just upstream and downstream of the blockage immediately following the slope failure. Structure your explanation in relation to continuity, momentum, and energy principles. Be as specific as possible.

b) Located immediately upstream of the blockage is a storm water sewer outfall from a small town. What potential impact(s) can the river blockage have on the sewer outfall and town? Be as specific as possible.

/20 5. The sub-division indicated in Figure 4 is comprised of five drainage areas that drain to two ditches. The runoff from each drainage area is indicated in Figure 4. Ditch #1 conveys the runoff from Areas 1 and 2, and Ditch #2 conveys the runoff from Areas 1 to 5. Ditch #1 (from points A to B) will have a triangular cross section with 2:1 side slopes, a length of 500 m, a longitudinal slope of 0.5%, and will be covered with grass (Manning's n=0.045). Ditch #2 (from points B to C) will have a trapezoidal cross section with 3:1 side slopes, a 5 m wide bottom, a length of 400 m, a longitudinal slope of 0.3%, and will be covered with grass (Manning's n=0.045). Determine the design height of Ditches #1 and #2 to convey the flows from the five drainage areas.

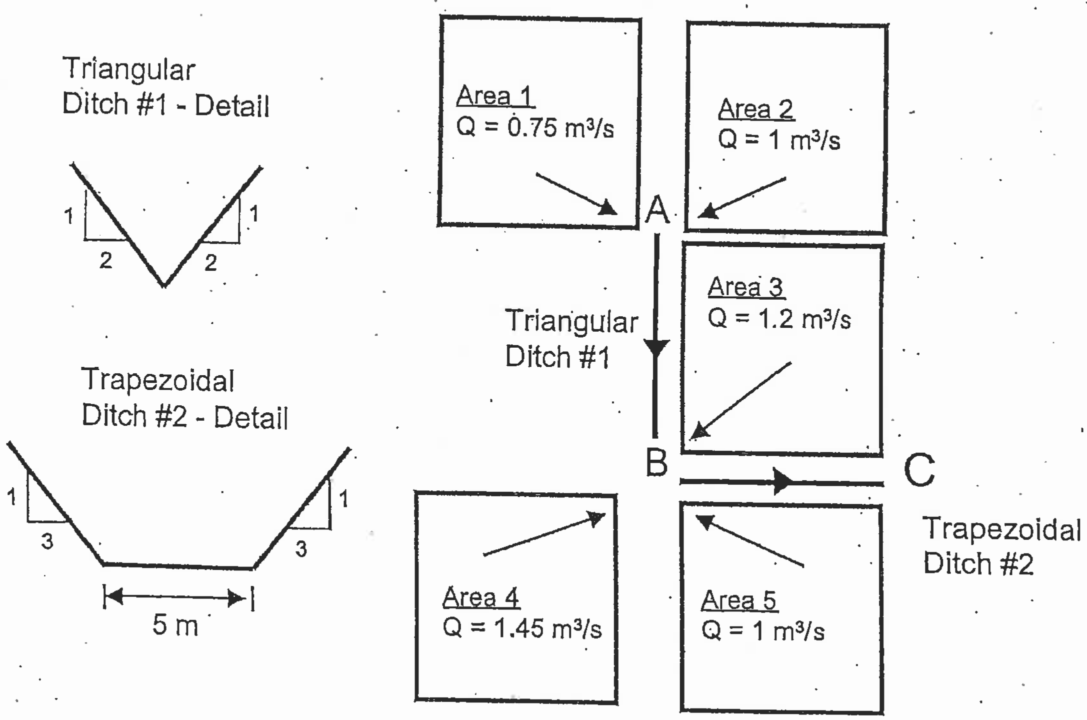

Figure 4: Drainage areas and design details of Ditches #1 and #2.

/20 6. A rainwater harvesting and re-use system in a single-family house is being designed and is indicated in Figure 5. The system consists of roof gutters that collect rainwater from the roof and convey it (Q_{in}) to a small reservoir at the side of the house. The reservoir is cylindrical with a 4 m diameter and has a free water surface. The reservoir is connected to Type 'L' copper pipe with a 3 inch (76 mm) internal diameter that conveys the rainwater by gravity to an outside tap (Q_{out}) for outdoor lawn and garden irrigation. The total length of the copper pipe is 25 m and has a 'C' factor of 120. The flow through the copper pipe is controlled by a tap. The flow through the tap is estimated with the valve equation

$$Q_v = \tau E_s \sqrt{H - H_0}$$

where Q_v = valve discharge (in m^3/s), E_s = valve discharge constant (E_s = 0.95 $m^{5/2}/s$), H = hydraulic head upstream of valve, H_0 = hydraulic head downstream of valve (tap discharges to the atmosphere). Both the bottom of the reservoir and the centerline of the tap are at the same elevation.

a) Write the governing equations that describe the quasi-steady state conditions in the reservoir-pipe-valve system.

b) The inflow hydrograph to the reservoir for a 6-hour period is indicated in Figure 5. Assuming that the tap is fully opened (τ = 1.0) at time 2 hours and closed (τ = 0) at time 4 hours, determine the design height of the reservoir to prevent overflow. The initial water depth in the reservoir is 0.0 m.

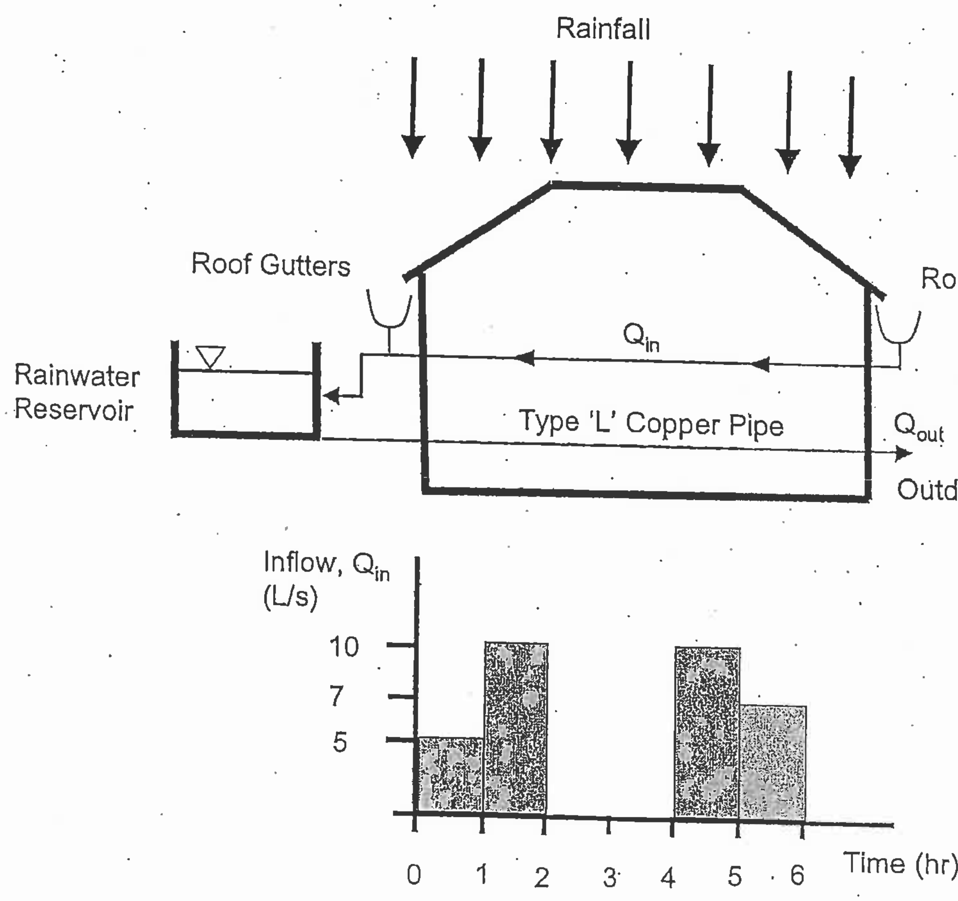

Figure 5. Rainwater harvesting system for single-family house.