National Exams May 2012

98-Civ-A5, 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
   - a Casio or Sharp approved calculator is permitted

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: $Q = 0.278CD^{2.63}S^{0.54}$, $S = \Delta h/L$
   - Manning's: $Q = \frac{A}{n}R^{2/3}S^{0.5}$, $S = \Delta h/L$
   - Darcy-Weisbach: $\Delta h = \frac{fL}{D} \cdot \frac{V^2}{2g}$
   - Loop Corrections: $q_l = -\frac{\sum_{\text{loop}} k_i Q_i |Q_i|^{n-1}}{n \sum_{\text{loop}} k_i |Q_i|^{n-1}}$, $n = 1.852$ (Hazen-Williams)
   - Total Dynamic Head: 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 ρ = 1,000 kg/m^3 and kinematic viscosity υ = 1.31 x 10^{-6} m^2/s.

/20 1. A local distribution main is being designed in a cul-de-sac section of a sub-division (Figure 1). The distribution main has a Hazen-Williams 'C' factor of 130, an internal diameter of 152 mm and a length of 134 m. The hydraulic grade line (HGL) in the trunk main is fixed at 65 m and the centerline pipe elevation at the hydrant is 7.5 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?

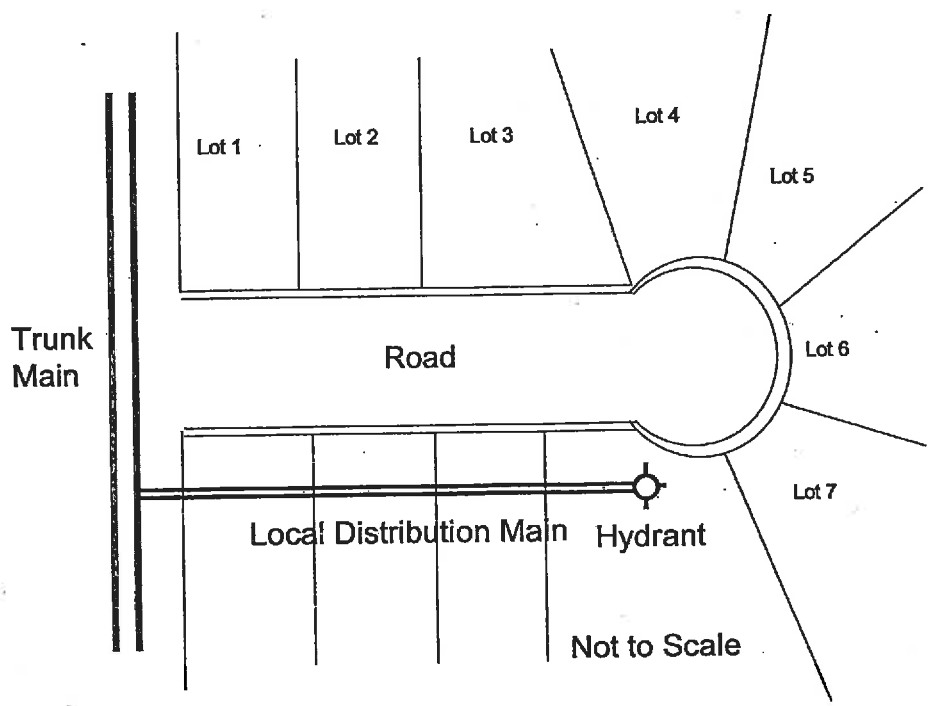

Figure 1. Trunk and local distribution main in cul-de-sac.

/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 30 m) to a downstream reservoir (water level of 60 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 = 60 - 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 $m^{5/2}/s$), H = hydraulic head upstream of valve, H_0 = hydraulic head downstream of valve.

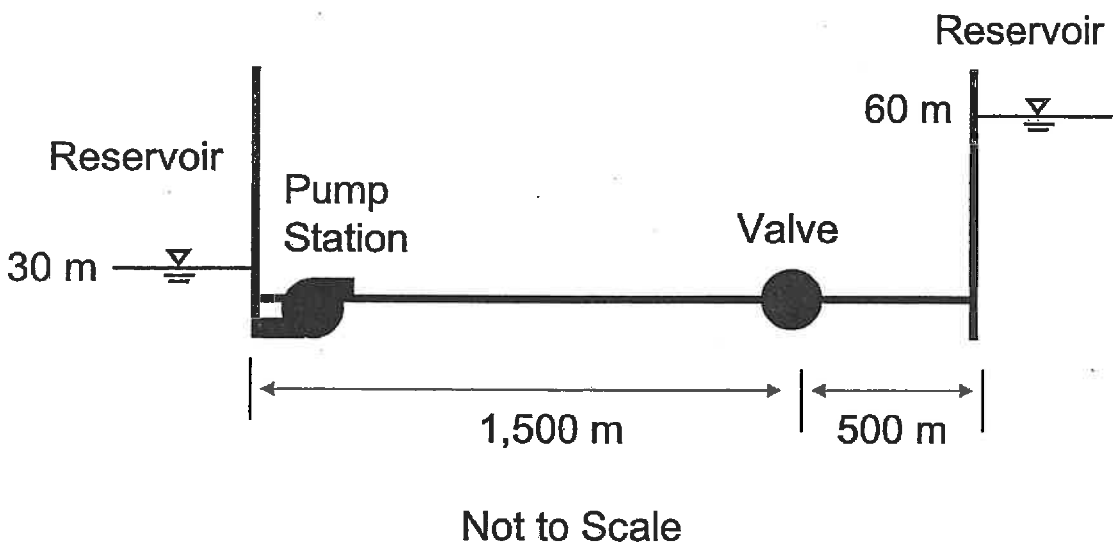

Figure 2. Pipeline system with pumps and downstream valve.

a) Calculate the flow in the pipeline when the valve is set to τ = 0.2.

b) Re-calculate the flow in the pipeline when the valve is set to τ = 0.6.

/20 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 115 m in length, and has an inner diameter of 510 mm and a 'C' factor of 130. Pipes 2-5 have the following parameters: length = 400 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.

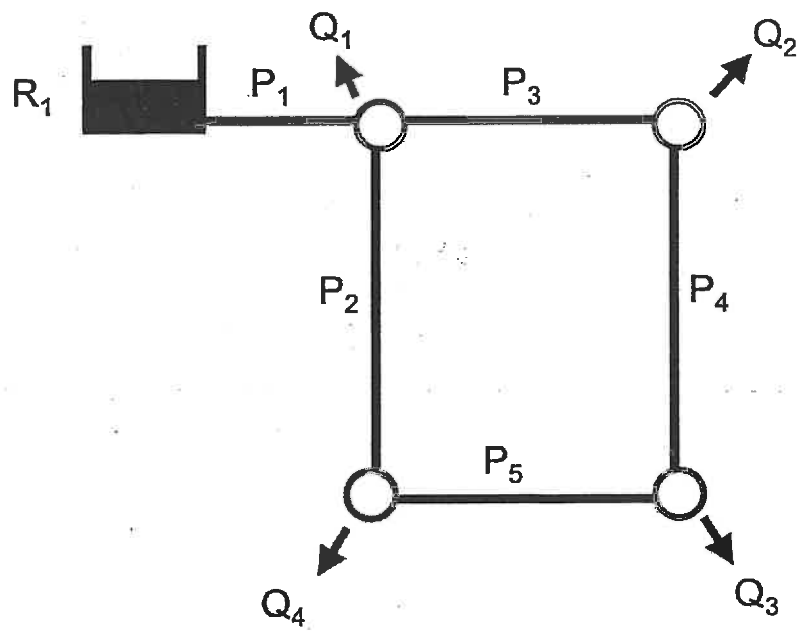

Figure 3. Water network with fixed-head reservoir.

/20 4. Water levels in a river are controlled by a dam with spillways that discharge water to penstocks to produce hydroelectric power. Describe the hydraulic conditions just upstream and downstream of the dam when its sluice gate is closed suddenly. Structure your explanation in relation to the St. Venant equations and explain the flow conditions with respect to each term of these equations. Be as specific as possible.

/20 5. The open channel in Figure 4 carries flow under steady-state, uniform, and laminar conditions. Pressure in the fluid column is hydrostatic. Under these conditions, a momentum equation can be written to describe the balance between the self weight and shear force that act on the elemental volume of fluid such that

$$W \sin\theta - \tau \Delta s = 0$$

Starting from the momentum expression above, derive a closed-form equation that describes fluid velocity as a function of fluid depth y. You can assume that the shearing stress is proportional to the velocity gradient such that

$$\tau = \mu \frac{du}{dy}$$

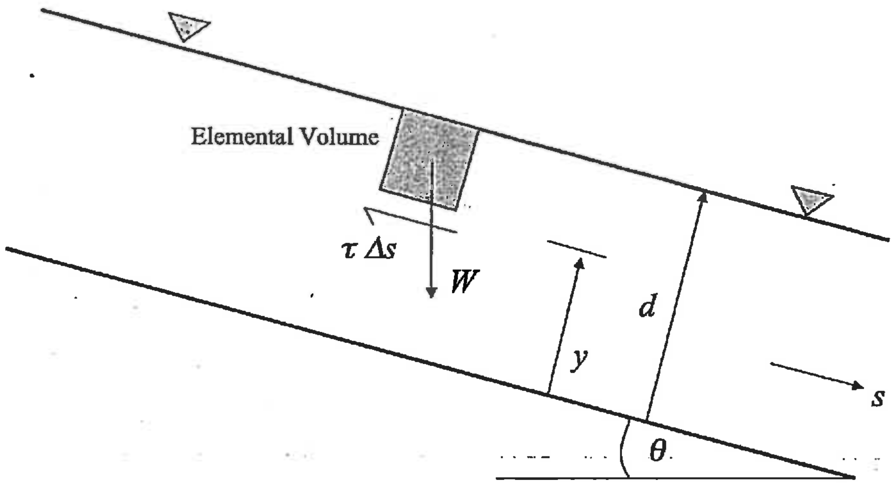

Figure 4. Elevation view of open channel.

/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 4.5 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 30.5 m and has a 'C' factor of 110. 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 (tau = 1.0) at time 2 hours and closed (tau = 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.

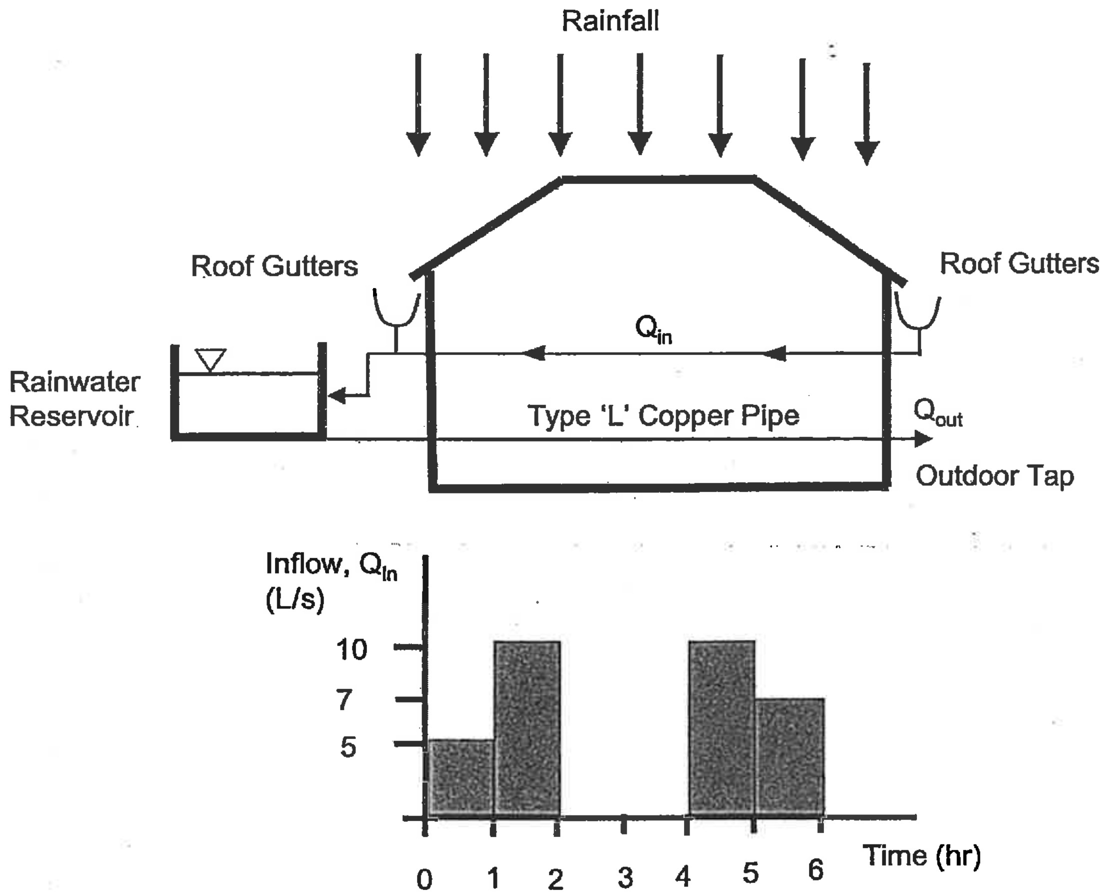

Figure 5. Rainwater harvesting system for single-family house.