ECMM133

UNIVERSITY OF EXETER
COLLEGE OF ENGINEERING, MATHEMATICS AND PHYSICAL SCIENCES
ENGINEERING

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Water Supply and Distribution Management

Module Convenor: Prof Raziyeh Farmani

Duration: TWO HOURS + 30 minutes upload time

Answer ALL three questions

Materials to be supplied:
Formulae sheet.

This is an **OPEN BOOK** examination.

Question 1 (34 marks)

Water is pumped from a pumping station (PS) into a service reservoir (Figure Q1) from which it supplies a water distribution district following a 24-hour demand pattern (Q_{ws}). The pumping station consists of two fixed-speed pumps delivering water directly to the reservoir. Table Q1a gives the possible pump combinations and respective flows into the reservoir (assuming head losses are accounted for):

Table Q1a. Pump flows

Pump Combination	Flow (l/s)
Both pumps off	0.0
Only Pump 1 on	6.0
Only Pump 2 on	8.0
Pumps 1 and 2 on	11.0

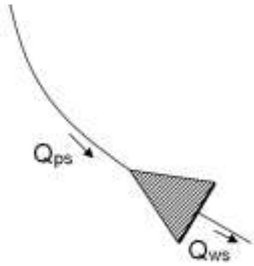

Figure Q1. Reservoir schematic

The flows delivered directly from the reservoir to the distribution district during the 24-hour period are given in Table Q1b. The associated changes in the reservoir storage volume are given in Table Q1c.

Table Q1b. Q_{ws} Flows

Time period	Q_{ws} (l/s)
0 am -4 am	3.15
4 am - 8 am	13.78
8 am - 12 pm	10.625
12 pm - 4 pm	4.73
4 pm - 8 pm	9.47
8 pm - 0 am	5.24

Table Q1c. Reservoir Storage

Time (h)	Reservoir Storage (m^3)
0 am	131.0
4 am	244.0
8 am	204.0
12 pm	51.0
4 pm	98.0
8 pm	48.0
0 am	131.0

(a) Assuming that the level fluctuations in the reservoir are small enough (i.e., do not influence pump flows), determine the water volumes pumped into the reservoir during this 24-hour period. (18 marks)

(b) Comment on the ability of the pumps and the reservoir to supply the specified demands on a long-term basis (assuming that the demand pattern will repeat itself on the 24-hour basis). (4 marks)

(c) Determine which pump combinations were operating during the 24-hour period. (12 marks)

Question 2 (33 marks)

The following pipe network and the associated pipe and node data are given in Figure Q2 and Tables Q2a and Q2b. Node 1 is the large open reservoir with constant water elevation of 60 m and pipe 1 intake at the elevation of 14 m. The kinematic viscosity of water is equal to 1.14 x 10^{-6} m^2/s.

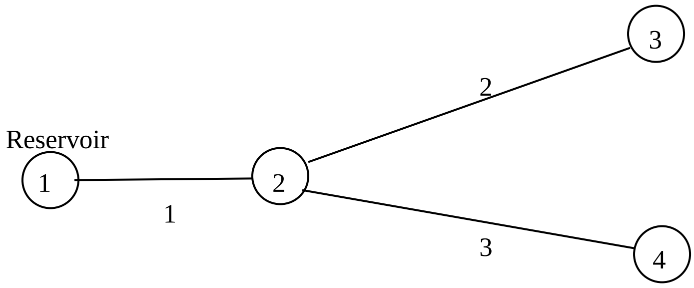

Figure Q2. Network Layout

Table Q2a. Network Pipe Data

Pipe	Length (m)	Diameter (mm)	K (mm)
1	2000	400	0.15
2	1000	300	0.15
3	1000	300	0.15

Table Q2b. Network Node Data

Node	Elevation (m)	Demand (l/s) at 0 hrs	Demand (l/s) at 12 hrs	Demand (l/s) at 24 hrs
2	10	0	0	0
3	11	9	13	9
4	15	15	23	15

(a) Calculate the nodal pressures for a given 24-hour period (i.e. at 0, 12, 24 hrs). Use the Swamee-Jain formula to calculate pipe friction factors. Neglect all local head losses in the system. (18 marks)

(b) A two-setting time modulated Pressure Reducing Valve (PRV) is installed immediately downstream of the reservoir. Calculate the required PRV settings for the 0 - 11:59 h and 12 - 23:59 h time periods to achieve the minimum system pressure of 15 m at the critical node. Calculate the resulting reduced nodal pressures for a given 24-hour period. (15 marks)

Question 3 (33 marks)
The pipe network and the associated pipe and node data are given in Figure Q3 and Tables Q3a and Q3b. The fixed head reservoir (water elevation equal to 50 m) is located at node 1.

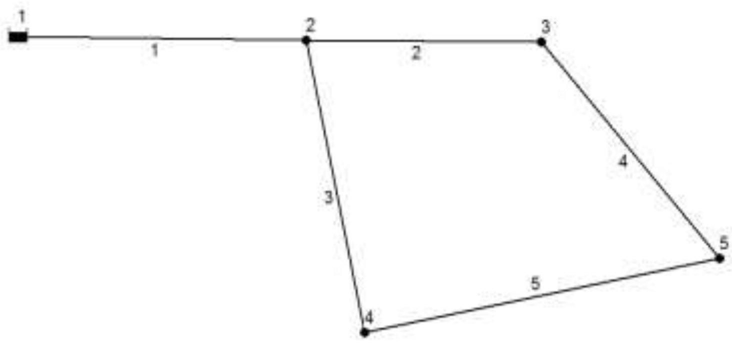

Figure Q3. Network Layout

Table Q3a. Network Pipe Data

Pipe	Length (m)	Diameter (mm)	Hazen-Williams C (-)
1	500	250	130
2	400	150	130
3	1200	100	130
4	600	200	130
5	1000	100	130

Table Q3b. Network Node Data

Node	Elevation (m)	Demand (l/s)
2	12	17
3	22	20
4	17	12
5	22	17

(a) Calculate the unknown pipe flows and nodal pressure heads in the above system by performing the first two iterations of the Hardy-Cross method.

(i) Iteration 1 (19 marks)
(ii) Iteration 2 (10 marks)

(b) Assuming the target (head loss) accuracy of ε_H = 0.01 m, calculate the pipe flows. (4 marks)

<u>ECMM133 Formula Sheet</u>

Pipe Flow Formulae:

Darcy-Weisbach:

$h_f = \lambda L/D \, v^2/2g$

Laminar Flow: $\lambda = 64/R_e$

Turbulent Flow: $1/\sqrt{\lambda} = -2 \log_{10}[k/(3.7D) + 2.51/(R_e \sqrt{\lambda})]$ (Colebrook-White)

$1/\sqrt{\lambda} = -2 \log_{10}[k/(3.7D) + 5.74/(R_e^{0.9})]$ (Swamee-Jain)

Hazen-Williams:

$v = 0.355 \, C \, D^{0.63} S_f^{0.54}$ where $S_f = h_f/L$

General Formulation:

$h_f = R \cdot Q \cdot |Q|^{n-1}$

Darcy-Weisbach: $R = 0.8106 \, \lambda \, L / (gD^5)$ and $n=2.0$

Hazen-Williams: $R = 10.648 \, L / (C^{1.852} D^{4.871})$ and $n=1.852$

Orifice equation:

$$Q = C_d A \sqrt{2g\Delta H}$$

Hydraulic Solvers:

Hardy-Cross Method:

$$\Delta Q_i^{(k)} = \frac{-\sum_i h_{f,i}^{(k)}}{n \sum_i \frac{h_{f,i}^{(k)}}{Q_i^{(k)}}} \qquad Q_i^{(k+1)} = Q_i^{(k)} + \sum_{l \supset i} \Delta Q_{li}^{(k)}$$

Linear Theory Method:

$$H_i^{(k+1)} = \frac{\sum_j^{N_i} \frac{H_j^{(k)}}{U_{ij}^{(k)}} - Q_{d,i}}{\sum_j^{N_i} \frac{1}{U_{ij}^{(k)}}} \qquad Q_{ij}^{(k+1)} = \frac{H_i^{(k+1)} - H_j^{(k+1)}}{U_{ij}^{(k)}} \qquad U_{ij}^{(k)} = R_{ij} \left| Q_{ij}^{(k)} \right|^{n-1}$$

Water Properties:

Density = 1000 kg/m^3

Kinematic Viscosity = 1.14 x 10^{-6} m^2/s

Bulk Modulus (Coefficient of Compressibility) = 2.15 x 10^9 N/m^2

END OF QUESTION PAPER