Version DL/2

EGT2
ENGINEERING TRIPOS PART IIA

Wednesday 29 April 2015 14.00 to 15.30

Module 3D5

WATER ENGINEERING

*Answer not more than **three** questions.*

All questions carry the same number of marks.

*The **approximate** percentage of marks allocated to each part of a question is indicated in the right margin.*

*Write your candidate number **not** your name on the cover sheet.*

The values of relevant parameters are listed at the end of the Data Book unless otherwise noted in the question.

STATIONERY REQUIREMENTS
Single-sided script paper
Graph paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Attachment: 3D5 Water Engineering Data Book (5 pages).
Engineering Data Book

10 minutes reading time is allowed for this paper.

You may not start to read the questions printed on the subsequent pages of this question paper until instructed to do so.

1 (a) When a soil sample is dry, its infiltration capacity is 20 mm h^{-1}. Given sufficient water supply at the top for one and two hours, the infiltration rate decreases to 10 mm h^{-1} and 5 mm h^{-1}, respectively.

(i) Show that the infiltration rate for this soil tends to zero after a long time. [15%]

(ii) Rain falls over a catchment made of this soil at a rate of 30 mm h^{-1} for one hour, during which time 4 mm of rain is found to infiltrate into the soil. Assuming the catchment area to be 5 km^2, calculate the volume of water stored in the catchment soil prior to this 30 mm h^{-1} rainfall. [40%]

(b) Rain falls uniformly over a catchment for 8 hours and then stops. The average rainfall-induced discharge over successive hours at the outlet of the catchment is measured to be:

Duration (h)	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
Average discharge (m^3 s^{-1})	3	10	20	35	45	50	50	50

(i) The above table only gives the discharge distribution during the rainfall. Estimate the discharge distribution after the rainfall and plot the complete hydrograph. [20%]

(ii) Derive the one-hour unit hydrograph of the catchment in the form of the discharge percentage per hour. [15%]

(c) Briefly explain what aspect of the water quality is described by the BOD value. [10%]

2 (a) Water flows steadily along a horizontal rectangular channel at a unit-width discharge of 4 $m^2 s^{-1}$. The flow passes over a spillway, decreases in depth significantly, and then encounters a hydraulic jump as shown in Fig. 1. Far upstream of the spillway, the flow depth h_0 is 6 m. Ignoring all losses other than those occurring at the hydraulic jump, show that:

(i) the depth h_1 upstream of the hydraulic jump is about 0.38 m. [15%]

(ii) the depth h_2 downstream of the hydraulic jump is about 2.74 m. [15%]

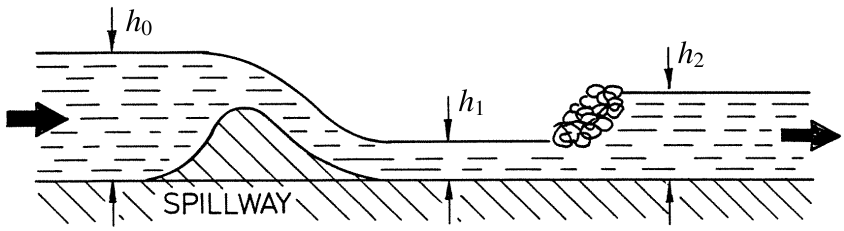

Fig. 1

(b) A long rectangular channel has a width of 10 m, Manning's roughness coefficient of 0.02 s $m^{-1/3}$, bed slope of 0.0005 and flow rate of 50 $m^3 s^{-1}$.

(i) If the flow is uniform, show that the normal water depth is around 2.96 m. [10%]

(ii) Calculate the critical water depth. [10%]

(iii) A sluice gate is installed at a cross-section to raise the local water depth to 4 m. Estimate how far upstream of the sluice gate the water level will be increased by only 2% of the normal depth. [15%]

(c) Water in a wide estuary is initially of constant depth 1 m and flows out to sea at a speed of 1 m s^{-1}. A tidal wave then enters the estuary. The variation of water depth at the mouth of the estuary h_b is given by:

$$h_b = \begin{cases} 1 & t \leq 0 \\ 4 - 3\cos\left(\dfrac{t}{7105}\right) & t > 0 \end{cases}$$

where h_b is measured in metres and t in seconds. Neglect the effects of bed friction and bed slope. At what time does the first high tide arrive at an observing point 1000 m upstream of the mouth of the estuary? At what time does the following low tide arrive at this point? [35%]

3 (a) A pollutant is released at a rate $\dot{M}$ into a wide shallow estuary of rectangular cross-section. The estuary is of depth h and width W. The flow in it is uniform with a velocity of U. Assume a constant mixing coefficient of D_t in all directions of the flow.

(i) The release is at a distance L from one side of the estuary and far away from the other side so that $W>>L>>h$. Write a formula describing the concentration of the pollutant along the edge of the estuary and determine where the maximum concentration at the edge occurs. [25%]

(ii) If the release is at the midpoint of the estuary width, $L = W/2$, write a formula describing the variation of concentration along one edge of the estuary. If the solution is found to include an infinite series, write the first four terms. [15%]

(b) The concentration of sediment is measured 1 m below the surface of a wide river of depth 5 m and bed slope 0.001, and is found to be 0.2 kg m^{-3}. The median grain size of the sediment is 0.24 mm.

(i) Calculate the depth-averaged concentration of the suspended sediment. The following equation may be used. [35%]

$$\int_0^h \left(\frac{h-z}{z}\right)^{\alpha} dz = \frac{\alpha \pi h}{\sin(\alpha \pi)}$$

(ii) If the bed roughness height is 0.3 m, estimate the depth-averaged velocity and the suspended load between 0.5 mm above the bed and the water surface. [25%]

4 (a) The drainage for a 200 m × 200 m impervious square is made of a cast iron pipe with a roughness height of 0.1 mm. The pipe is 2 km long, and the maximum allowable total head loss is 2 m. Estimate the minimum diameter of the pipe so that the drainage can cope with an unceasing rainfall of intensity 50 mm h^{-1}. [40%]

(b) A flood protection scheme involves the replacement of a meandering section of river of overall length 1 km by a straight cut-off channel of length 400 m. The average roughness height of the bed and banks of the cut-off channel is 0.005 m, while the Manning's roughness coefficient of the river is 0.025 s $m^{-1/3}$. Both the river and the cut-off channel may be assumed to be of rectangular cross-section 5.1 m wide and 2.6 m deep. Estimate the ratio of the flow rate in the cut-off channel to that in the river when both are full. [25%]

(c) An impounding reservoir at elevation 200 m delivers water to a service reservoir at elevation 80 m through a 20 km long 500 mm diameter pipeline with roughness height 0.03 mm. Allowing for local head losses of $20U^2/(2g)$:

(i) Show that the discharge is around 410 l/s. [10%]

(ii) A booster pump having the tabulated characteristics is to be installed at the mid-length of the pipeline to increase the discharge. Determine the increased discharge and the power consumption. [25%]

Q (l s^{-1})	0	100	200	300	400	500	600
H (m)	60.0	58.0	54.0	47.0	38.4	26.0	8.0
η (%)	-	33.0	53.0	62.0	62.0	54.0	28.0

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Answers

1.

(a.ii) 104300 m^3

2.

(b.ii) 1.366 m

(b.iii) 5.9 km

(c.i) 22366.5 s

45088.4 s

3.

(b.i) 0.44 kg/m^3

(b.ii) 2.92 m/s

14.7 kg m^{-1} s^{-1}

4.

(a) 0.815 m

(b) 2.38

(c.ii) 0.465 m^3 s^{-1}

251.67 kW

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