ENGINEERING TRIPOS PART IIA

Friday 12 May 2006 2.30 to 4

Module 3D6

ENVIRONMENTAL ENGINEERING II

*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.*

Attachments: Special data sheets (6 pages)

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS
Engineering Data Book
CUED approved calculator allowed
Extra copy of Fig. 1 (Question 1)

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

1 (a) Describe how the process of weathering of rocks leads to the formation of sedimented soils. Comment on the nature of layering that can occur in soil formations and how this affects the hydraulic conductivity of the soil. [10%]

(b) Assuming Darcy's law for steady state seepage through porous media is valid and that such seepage flow can be described by a *curvilinear square* flownet, derive an expression for the volume of water flow through a soil of hydraulic conductivity K. [20%]

(c) The foundation of a bridge is to be built on a river bed. The river bed is to be exposed by driving sheet pile walls 6 m deep into the granular soil forming the river bed as shown in Fig. 1. The water between the sheet pile walls is to be pumped constantly to maintain the water table at the river bed level. Laboratory tests revealed that the hydraulic conductivity of the granular soil is 5×10^{-3} m s^{-1}.

(i) Draw a flownet for seepage on the copy of Fig. 1 provided in the attachments. This sheet must be handed in with your answer. Draw attention to any shortcomings in your solution. [20%]

(ii) Estimate the potential heads and pore pressures at points A, B and C in Fig. 1. [15%]

(iii) Estimate the rate at which pumping has to be carried out to maintain the water table within the sheet pile walls at the river bed level, considering a 1 m section of the sheet pile wall into the plane of the paper. [15%]

(d) If the pumping system were to fail suddenly in the problem described in part (c) above, how long will it take for the water level in between the sheet pile walls to rise by 0.5 m. What assumptions did you have to make in estimating this time? [20%]

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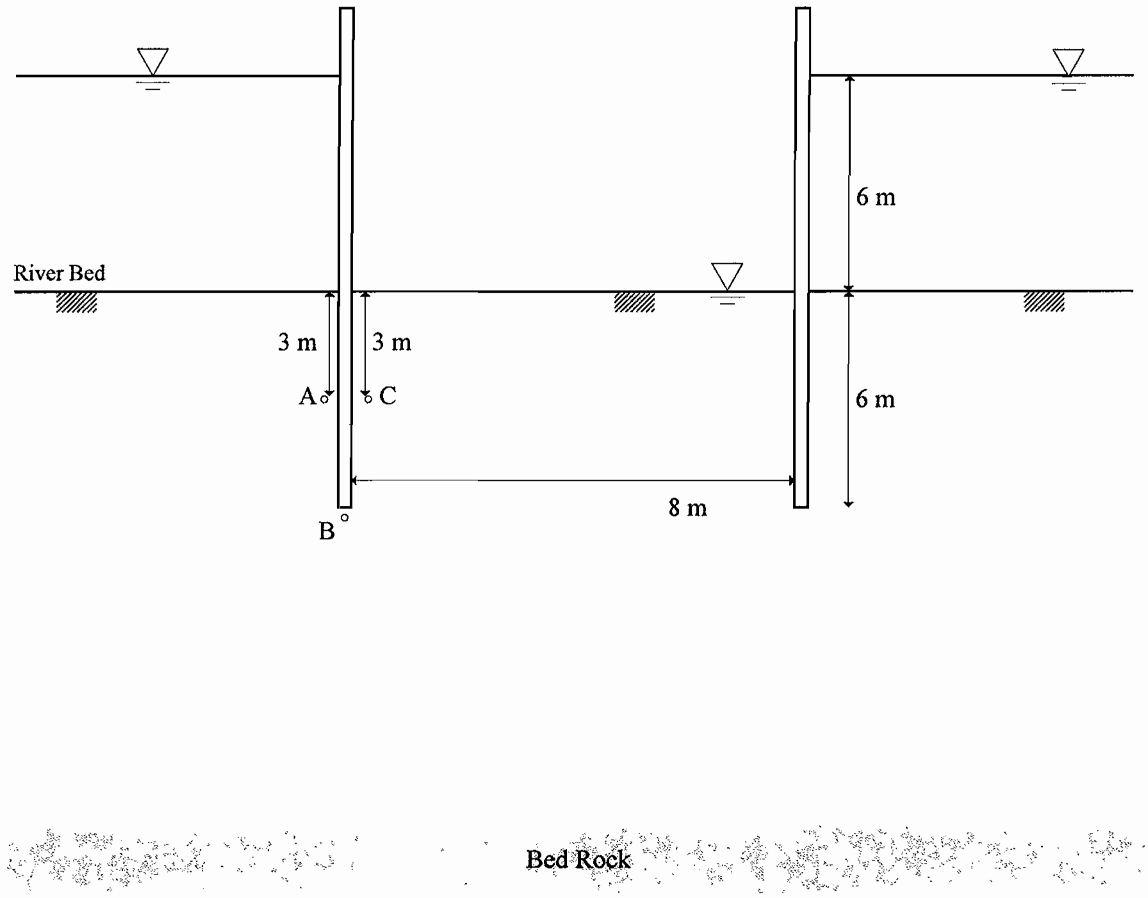

Fig. 1

(TURN OVER

2 (a) An irrigation well of radius r_w is to be driven into an aquifer of thickness b in a field as shown in Fig. 2. The hydraulic conductivity of the aquifer in this field is K. Derive an expression for the rate of pumping Q, if the drawdown in the well is h_w and if the drawdown reduces to h_1 at a distance of r_1 from the axis of the well as shown in Fig. 2. [20%]

(b) A circular tube well of internal diameter 200 mm was driven into an aquifer of uniform thickness 3 m at this field. The hydraulic conductivity of the aquifer was determined to be 3.8×10^{-3} m s^{-1}. For a pumping out rate of Q the drawdown in the well was observed to be 2 m below the normal water table. A pore pressure transducer located at a distance of 5 m from the axis of the tube well recorded a drop in pressure of 15 kPa compared with the pressure before pumping. Calculate the pumping rate Q. [25%]

(c) For the pumping rate Q calculated in part (b) above, estimate the distance R from the axis of the circular tube well where the drawdown below the water table would be 1 m. [30%]

(d) To irrigate rice crops in this area, a number of circular tube wells identical to the well analysed above are to be located in a square field to meet a required flow rate of 8784 litres per minute. Estimate the minimum size of the field required to accommodate these wells using the distance R calculated in part (c). You may assume that this distance R is the radius of influence and that wells should be separated by twice this distance to maintain maximum pumping efficiency. Sketch the plan view of a possible arrangement of these wells. [25%]

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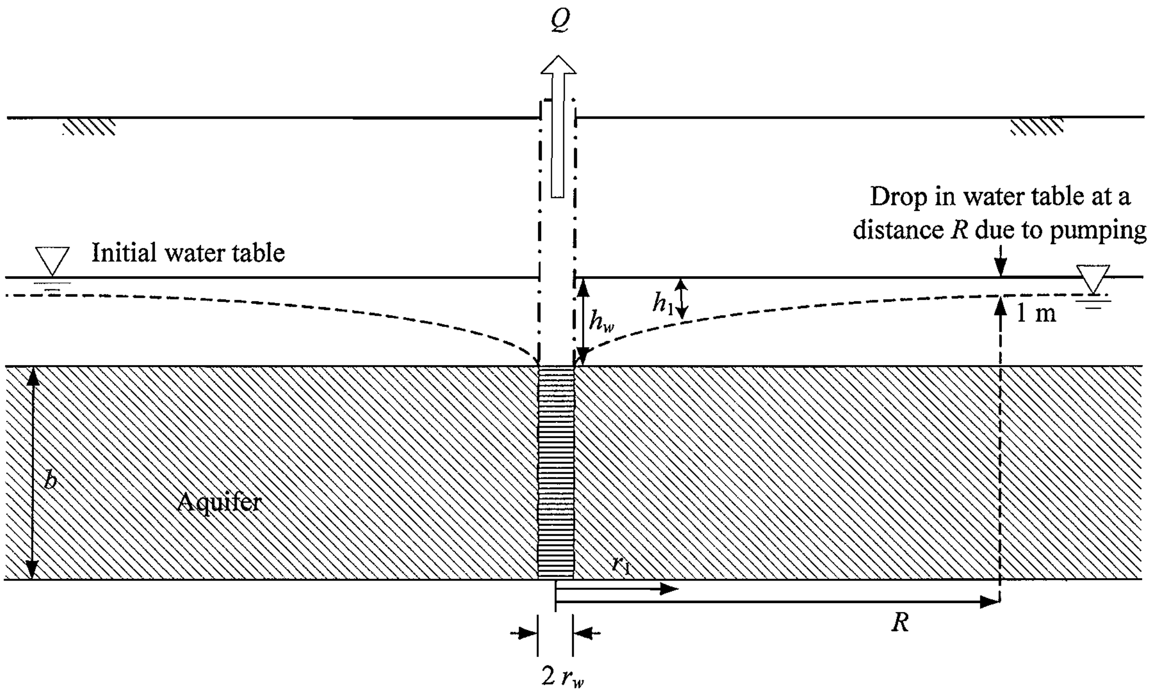

Fig. 2

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3 (a) Explain how you would distinguish between the dominant contaminant transport mechanisms using the Peclet Number P_e. [20%]

(b) A contaminant with a concentration c_o is to be kept in a surface impoundment formed by a clay side liner as shown in the sectional view in Fig. 3. The thickness of the clay liner is 5 m. The effective coefficient of diffusion of the contaminant D_d* in the clay liner is 2.6×10^{-9} m^2 s^{-1}. The concentration of the contaminant c in the clay liner can be related to the maximum concentration c_o using the following expression:

$$\frac{c}{c_o} = erfc\left[\frac{z}{\sqrt{4D_d^*t}}\right]$$

where *erfc* is the complementary error function, z is the distance into the clay liner, D_d* is the effective coefficient of diffusion and t is the time. Assume that sorption of this contaminant is negligible. You may also assume that the maximum concentration of this contaminant remains constant at the source.

(i) Calculate the shortest time it takes for traces of the contaminant to be detected at the monitoring point A in Fig. 3, just outside the clay liner. [20%]

(ii) Sketch the distribution of the concentration of the contaminant with the liner thickness at this stage, marking the concentrations in terms of c_o at quarter, half and three quarter points within the clay liner. [30%]

(iii) The Environment Agency advises you that the safe allowable limit of this contaminant in natural soil is 10% of the concentration c_o in the surface impoundment. Estimate how long it will take for the contaminant to reach this allowable limit at the monitoring point A in Fig. 3. [20%]

(c) If you want to increase the breakthrough time calculated in part (b) above, what type of geosynthetic would you consider using in the construction of the liner. [10%]

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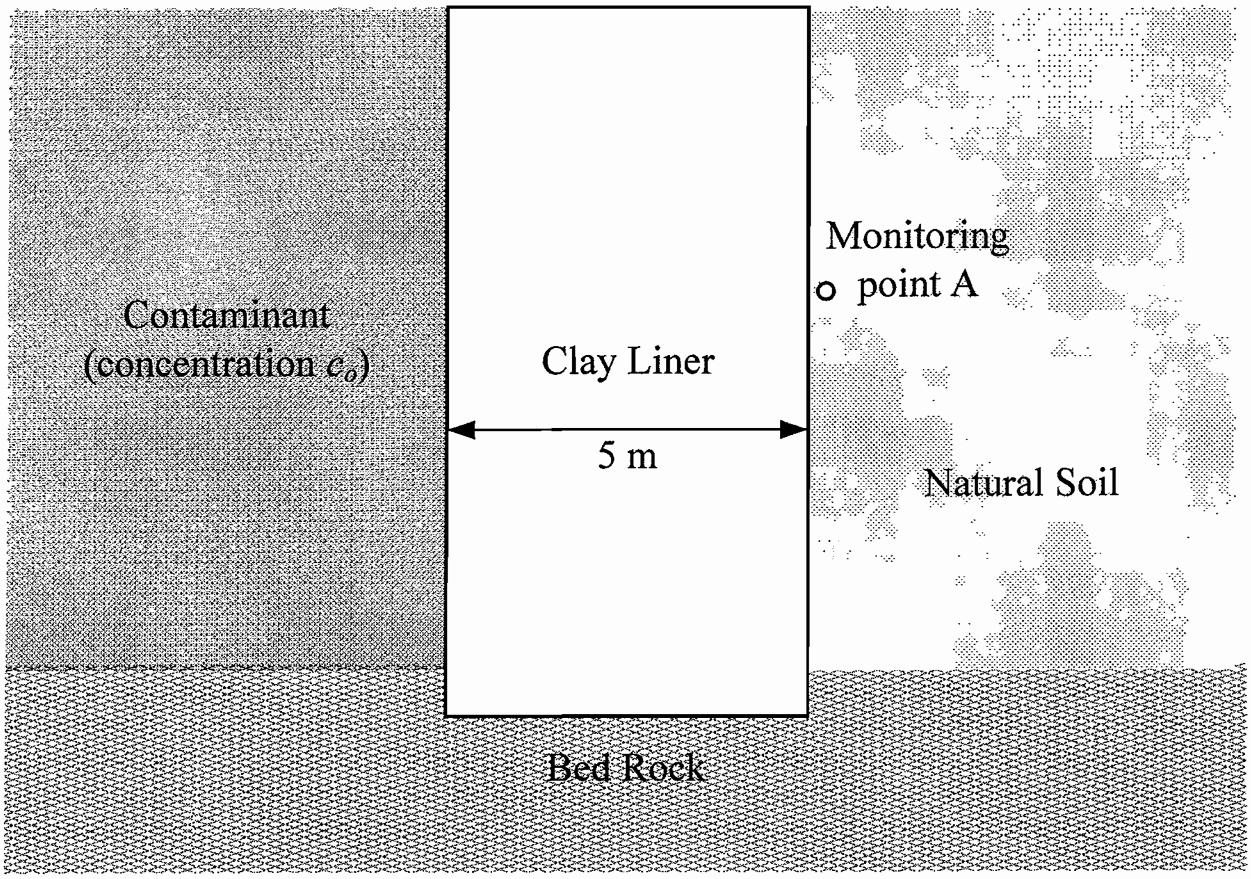

Fig. 3

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4 (a) A number of decision support tools are available to present information in a logical and regimented way in order to simplify the decision making process. Briefly discuss the principles of each of the following three decision support tools highlighting their advantages and disadvantages in the context of contaminated land remediation:

(i) cost-benefit analysis; [15%]

(ii) multi-criteria analysis; [15%]

(iii) life-cycle analysis. [20%]

(b) The Landfill Directive, as implemented in England and Wales by the Landfill Regulations 2002, will have a significant impact on the management of all wastes. One such impact is the drive towards sustainable waste management practices.

(i) What are the main requirements of the Landfill Directive? [20%]

(ii) Briefly discuss the three main elements of sustainable waste management. [30%]

END OF PAPER

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Engineering Tripos Part IIA Paper 3D6

ENVIRONMENTAL ENGINEERING II

DATA BOOK

January 2003

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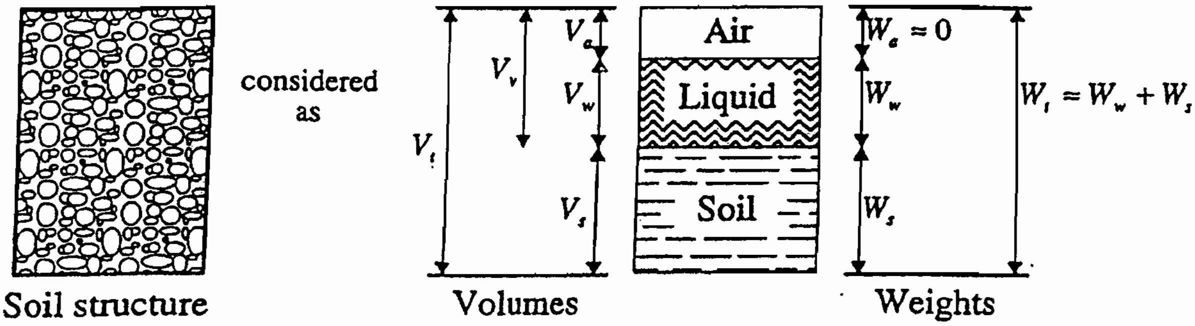
Groundwater

Soil: general definitions



Specific gravity of solid	G_s
Voids ratio	$e = V_v/V_s = n/(1-n)$
Specific volume	$v = V_t/V_s = 1+e$
Porosity	$n = V_v/V_t = e/(1+e)$
Water content	$w = W_w/W_s$
Degree of saturation	$S_r = V_w/V_v = wG_s/e$
Unit weight of water	$\gamma_w = 9.81$ kN/m^3
Unit weight of soil	$\gamma = W_t/V_t = \left(\frac{G_s + S_r e}{1 + e}\right)\gamma_w$
Buoyant unit weight	$\gamma' = \gamma - \gamma_w = \left(\frac{G_s - 1}{1 + e}\right)\gamma_w$ (soil saturated)
Unit weight of dry soil	$\gamma_d = W_s/V_t = \left(\frac{G_s}{1 + e}\right)\gamma_w$

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Classification of particle sizes

Boulders	larger than			200 mm
Cobbles	between	200 mm	and	60 mm
Gravel	between	60 mm	and	2 mm
Sand	between	2 mm	and	0.06 mm
Silt	between	0.06 mm	and	0.002 mm
Clay	smaller than	0.002 mm (two microns)		

D equivalent diameter of soil particle

D_{10}, D_{60} etc. particle size such that 10% (or 60% etc.) by weight of a soil sample is composed of finer grains.

C_U uniformity coefficient D_{60}/D_{10}

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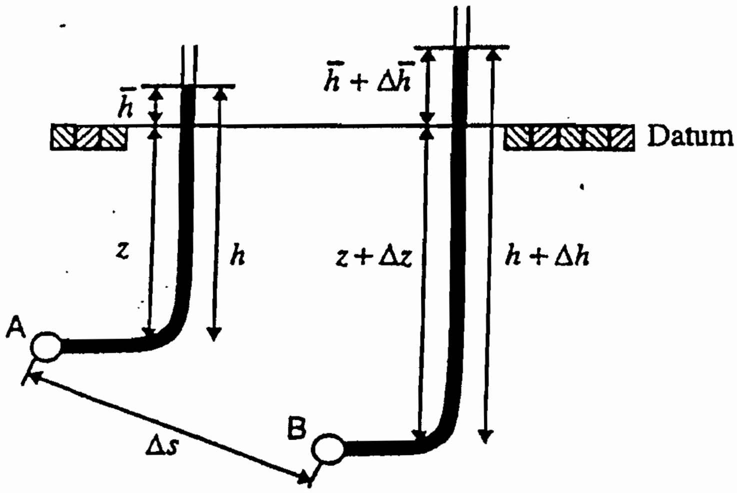
Seepage

Excess pore water pressure



Total gauge pore water pressure at A: $p = \gamma_w h = \gamma_w(\bar{h} + z)$

B: $p + \Delta p = \gamma_w(h + \Delta h) = \gamma_w(\bar{h} + z + \Delta\bar{h} + \Delta z)$

Excess pore water pressure at A: $\bar{p} = \gamma_w \bar{h}$

B: $\bar{p} + \Delta\bar{p} = \gamma_w(\bar{h} + \Delta\bar{h})$

Hydraulic gradient A B

$$i = -\frac{\Delta\bar{h}}{\Delta s} = -\frac{1}{\gamma_w}\frac{\Delta\bar{p}}{\Delta s}$$

Darcy's law $v = Ki$

v = superficial seepage velocity

K = coefficient of permeability or hydraulic conductivity

Typical hydraulic conductivities

$D_{10} > 10$ mm	:	non-laminar flow
10 mm $> D_{10} >$ 1µm	:	$K \cong 0.01\ (D_{10}$ in mm$)^2$ m/s
clays	:	$K \cong 10^{-9}$ to 10^{-11} m/s

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Contaminant transport

Darcy's law

$$v_f = -\frac{k}{\mu n}\nabla(p + \rho g z)$$

where:
- v_f : pore fluid velocity $= \frac{v}{n}$
- v : Darcy superficial velocity or specific discharge
- n : porosity
- k : intrinsic permeability $= \frac{K\mu}{\rho g}$
- K : Darcy permeability or hydraulic conductivity
- μ : dynamic viscosity of pore fluid
- ρ : density of pore fluid
- p : fluid pressure

Governing equation for one-dimensional transport in homogeneous media

$$\frac{\partial c}{\partial t} = D_l \frac{\partial^2 c}{\partial x^2} - v_f \frac{\partial c}{\partial x} \pm \frac{\Phi}{n}$$

where:
- c : mass of pollutant per unit volume of pore fluid (concentration)
- D_l : coefficient of hydrodynamic dispersion $= D_d^* + D$
- D_d^* : effective diffusion coefficient for pollutant in soil $= D_d \tau$
- D_d : diffusion coefficient for pollutant in solution
- τ : tortuosity of medium
- D : coefficient of mechanical dispersion $= \alpha_l v_f$
- α_l : dispersivity of the medium
- Φ : chemical reactions

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Error function tables

Relationships:

$$\mathrm{erf}(\beta)=\frac{2}{\sqrt{\pi}}\int_0^\beta \exp(-t^2)\,dt$$

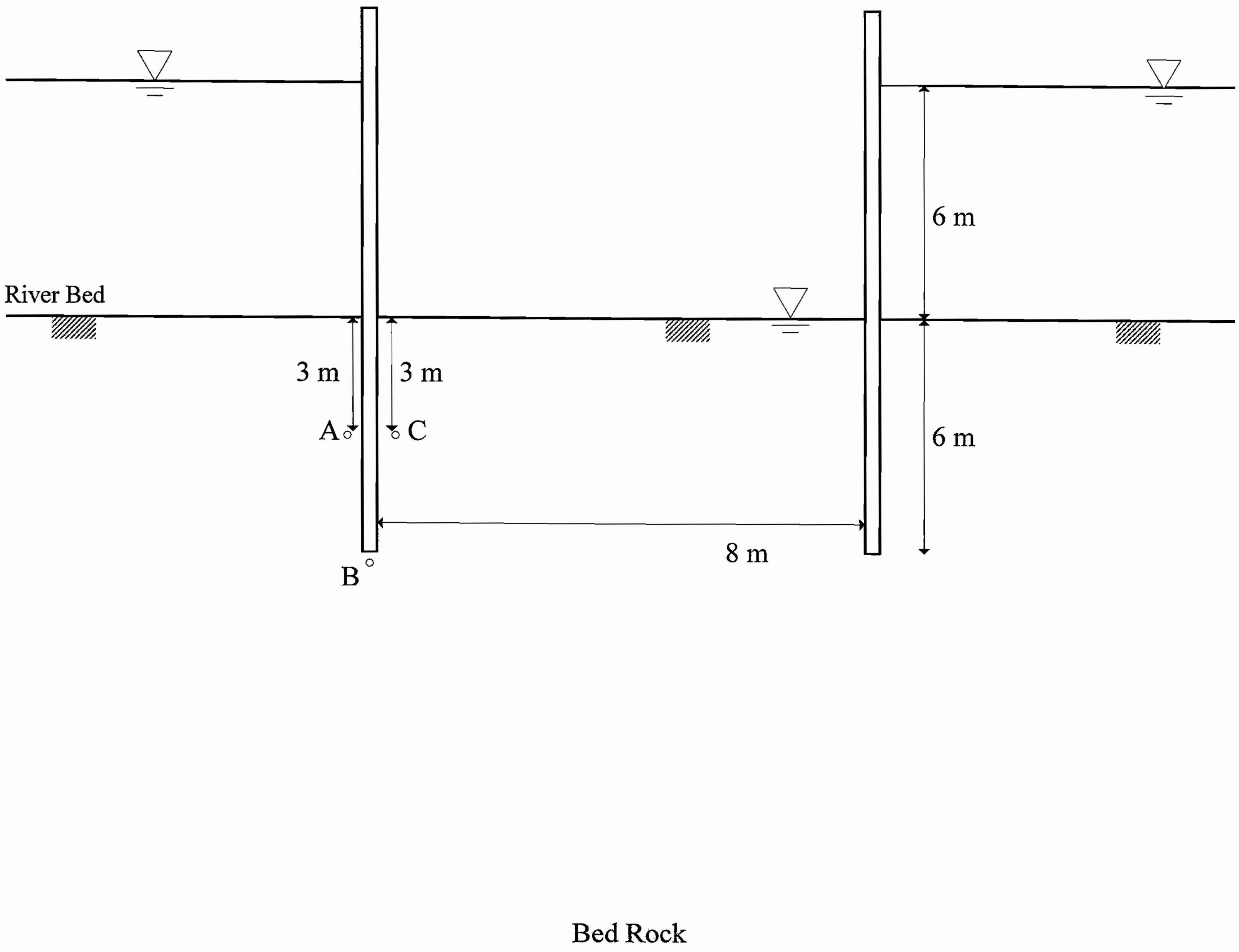
$$\mathrm{erfc}(\beta)=1-\mathrm{erf}(\beta)$$

$$\mathrm{erf}(-\beta)=-\mathrm{erf}(\beta)$$

$$\mathrm{erfc}(-\beta)=1+\mathrm{erf}(\beta)$$

Tables (to four significant figures)

β	$\mathrm{erf}(\beta)$	$\mathrm{erfc}(\beta)$
0.00	0.0000	1.0000
0.05	0.0564	0.9436
0.10	0.1125	0.8875
0.15	0.1680	0.8320
0.20	0.2227	0.7773
0.25	0.2763	0.7237
0.30	0.3286	0.6714
0.35	0.3794	0.6206
0.40	0.4284	0.5716
0.45	0.4755	0.5245
0.50	0.5205	0.4795
0.55	0.5633	0.4367
0.60	0.6039	0.3961
0.65	0.6420	0.3580
0.70	0.6778	0.3222
0.75	0.7112	0.2888
0.80	0.7421	0.2579
0.85	0.7707	0.2293
0.90	0.7969	0.2031
0.95	0.8209	0.1791
1.00	0.8427	0.1573
1.10	0.8802	0.1198
1.20	0.9103	0.0897
1.30	0.9340	0.0660
1.40	0.9523	0.0477
1.50	0.9661	0.0339
1.60	0.9763	0.0237
1.70	0.9838	0.0162
1.80	0.9891	0.0109
1.90	0.9928	0.0072
2.00	0.9953	0.0047
2.20	0.9981	0.0019
2.40	0.9993	0.0007
2.60	0.9998	0.0002
2.80	0.9999	0.0001
3.00	1.0000	0.0000



Extra Copy of Fig. 1

3D6 Environmental Engineering II - May 2006

ANSWERS

Q1(c) (ii): $\overline{h}_a$ = 5.2 m & p_a = 52 kPa; $\overline{h}_b$ = 3.5 m & p_b = 35 kPa; and $\overline{h}_c$ = 1.25 m & p_c = 12.5 kPa
1(c) (iii) = 0.0175 $m^3/s/m$

Q2 (b) 9.15 litres/s
2(c) R = 250 m
2 (d) 16 wells

Q3 (b) 9.7 years
3 (b) (iii) 56.1 years