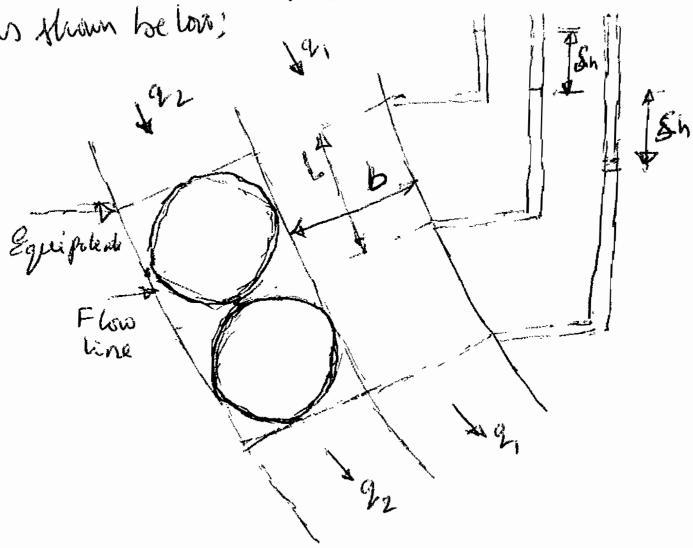
1. a) Weathering of rocks occurs under the action of thermal cycles, frost, rain and other geological processes. Rocks can crack or disintegrate under these actions to form soils. The nature of the soil formed depends to certain extent on the parent rock. The soil particles thus formed can be transported by either wind or by water.

Soil particles transported by air or water will be deposited largely according to the particle sizes. As a result soil deposits tend to have a horizontal layering present in them. This can have a significant influence on the hydraulic conductivity of the soil. For example, the horizontal hydraulic conductivity K_x can be very much greater than the vertical hydraulic conductivity K_y ($K_x >> K_y$).

[10%]

b) Consider a set of flow lines and equipotentials through a porous medium as shown below;



Consider a flow tube formed by elements of breadth 'b' and length 'l', through which flow of q_1 can be achieved.

Applying Darcy's law;

$$v_1 = K i_1$$

where K is the hydraulic conductivity of the granular/porous medium.

Let us assume that the head drop between successive equipotentials is 'δh'.

$$\therefore v_1 = K \frac{\delta h}{l}$$

The flow through this flow tube will be

$$q_1 = A_1 v_1 = (b \times 1) \times K \times \frac{\delta h}{l} = K\, \delta h \times \frac{b}{l}$$

If the flow net is drawn as 'curvilinear square' then $b = l$

$$\therefore q_1 = K\, \delta h$$

If the number of equipotentials that are drawn to describe a head drop of $\Delta \bar{h}$ is N_h, then $\delta h = \frac{\Delta \bar{h}}{N_h}$

$$\therefore q_1 = K \frac{\Delta \bar{h}}{N_h} \text{ for each tube.}$$

Again using the curvilinear square flow net assumption, each flow tube will have the same flow rate

$\therefore q_1 = q_2 = q_3$ etc

If there are N_f flow tubes in the flownet, the total quantity of flow will be $q = N_f K \frac{\Delta \bar{h}}{N_h} = K \Delta \bar{h} \frac{N_f}{N_h}$ m^3/s /m length

This expression is used to estimate flow through porous media by using the flownets. [20%]

1c) i) using the symmetry of the problem, the flow net is drawn on the page provided with $N_f = 3.5$ $N_{\bar{h}} = 12$ [20%]

ii) Potential heads at A, B, C from flow net are

$\bar{h}_A = 5.2$ m

$\bar{h}_B = 3.5$ m

$\bar{h}_C = 1.25$ m

Porepressures are $P_A = 52$ kPa

$P_B = 35$ kPa

$P_C = 12.5$ kPa [15%]

iii) The flow rate into the space between the sheet pile walls will be

$q = 2 \times K \Delta \bar{h} \frac{N_f}{N_{\bar{h}}}$. $K = 5 \times 10^{-3}$ m/s $\Delta \bar{h} = 6$m

$q = 2 \times 5 \times 10^{-3} \times 6 \times \frac{3.5}{12} = 0.0175$ m^3/s /m

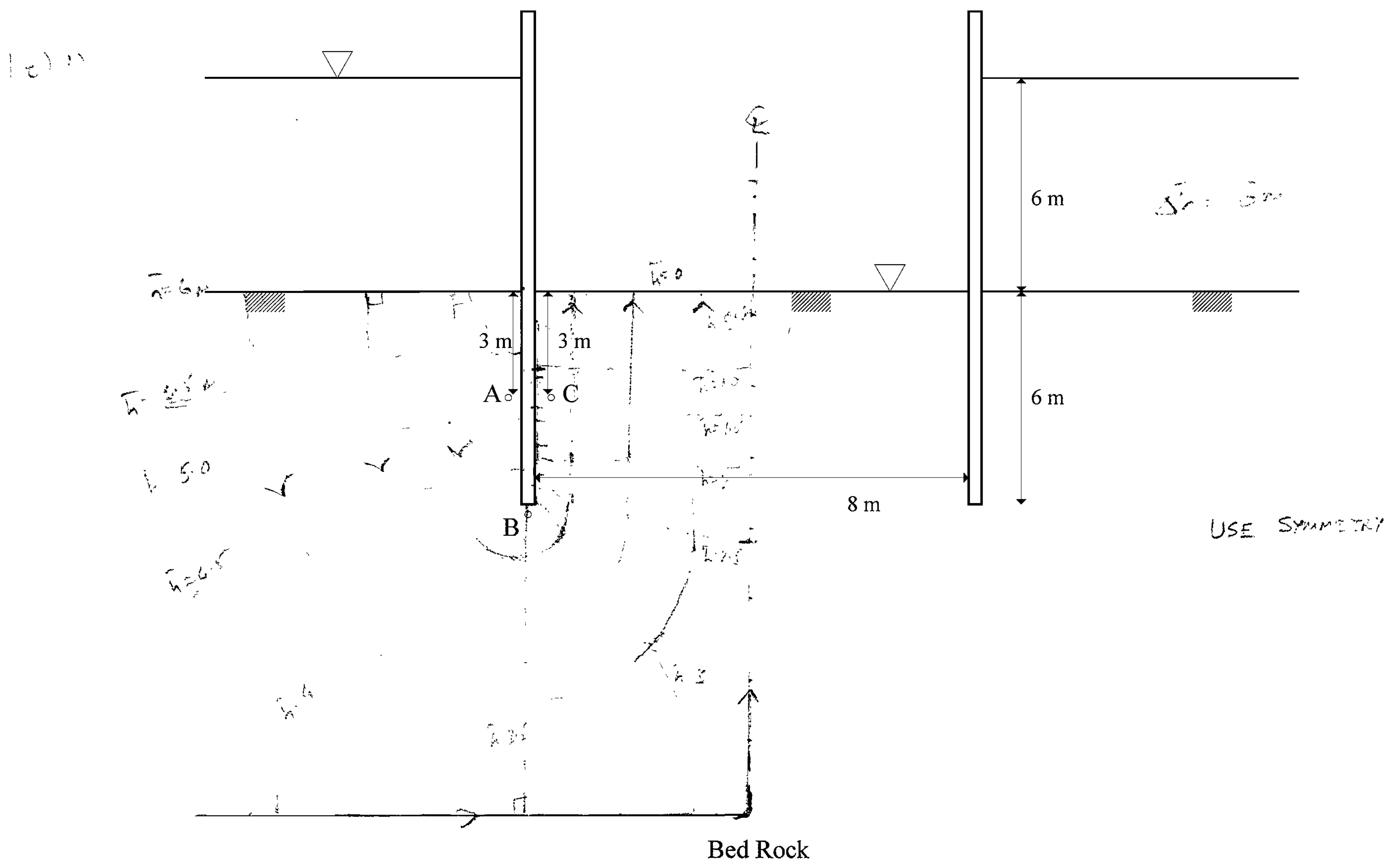
$\therefore$ The pumps must be able to pump at the above rate of 0.0175 m^3/s or 63000 litres/hour. [15%]

1d) The volume that needs to be filled to raise the water level by 0.5 m when the pumps fail $V = 8 \times 0.5 \times 1$ m^3.

$q = 0.0175$ m^3/s

$\therefore$ time $= \frac{4}{0.0175} = 228.6$ sec or 3.8 minutes

Assumptions :- 1) Flow net does not change due to rise in water level
2) This is strictly not true but can be considered satisfactory for small rise in water height [20%]


6 m
6 m
3 m
3 m
A
C
B
8 m
Bed Rock
USE SYMMETRY

2 a) Assuming Darcy's law is applicable;

Flow rate $Q = A\,v$.

& $v = Ki$.

$\therefore Q = KAi$

Considering a drop in potential head of $d\bar{h}$ in an incremental radial distance of dr, we can write

$$Q = K.A.\frac{d\bar{h}}{dr} \quad \text{where } A = 2\pi r b.$$

$$\therefore Q = K\,2\pi r b\,\frac{d\bar{h}}{dr}$$

Reorganising terms

$$\frac{Q}{K\,2\pi\,b}\frac{dr}{r} = d\bar{h}$$

Integrating we get

$$\frac{Q}{K\,2\pi\,b}\int_{r_w}^{r_1}\frac{dr}{r} = \int_{h_w}^{h_1} d\bar{h} \quad \rightarrow (1)$$

$$\frac{Q}{K\,2\pi\,b}\ln\frac{r_1}{r_w} = (h_1 - h_w)$$

$$\therefore Q\ln\frac{r_1}{r_w} = 2\pi\,b\,K\,(h_1 - h_w) \quad \rightarrow (2)$$

[25%]

b) Diameter of the well = 200 mm

$\therefore$ radius of the well $r_w = 0.1$ m.

Hydraulic Conductivity of the aquifer $K = 3.8\times10^{-3}$ m/s

Thickness of the aquifer $b = 3$ m.

We are given that drawdown in the well $h_w = 2$ m.

The piezometer located at a distance r_1 of 5m records a drop in pressure of 15 kPa.

$\therefore$ Equivalent change in head $(h_1) = \frac{15}{10} = 1.5$ m

Using Eq ② above we can write

$$Q \ln \frac{r_1}{r_w} = 2\pi b K (h_1 - h_w)$$

$$Q \ln\left(\frac{5}{0.1}\right) = 2\pi \times 3 \times 3.8 \times 10^{-3} (1.5 - 2)$$

$$Q = -0.00915 \ m^3/sec \text{ or } 9.15 \text{ litres/sec}$$ [20%]

(-ve sign indicates that water is being pumped out)

2c) Recall Eq ① from part (a) for the new limits.

$$\frac{Q}{K 2\pi b} \int_{r_w}^{R} \frac{dr}{r} = \int_{h_w}^{1.0m} dh$$

$$\frac{Q}{K 2\pi b} \ln\left(\frac{R}{r_w}\right) = (1 - h_w)$$

Sub value of Q from b) and taking care of the sign of Q.

$$\left(\frac{-0.00915}{3.8 \times 10^{-3} \times 2\pi \times 3}\right) \ln\left[\frac{R}{0.1}\right] = -1$$

$$\therefore \ln \frac{R}{0.1} = 7.824.$$

$$R = 250 m.$$

∴ Radial distance where the draw down is 1.0m will be 250m.

Alternatively you can use.

$$\frac{h_1 - h_w}{h_2 - h_w} = \frac{\ln r_1 - \ln r_w}{\ln R - \ln r_w}$$ where $h_2 = 1.0$ at R.

$$\frac{1.5 - 2}{1 - 2} = \frac{\ln 5 - \ln 0.1}{\ln R - \ln 0.1}$$

$$\ln 10R = 2 \ln 50$$

$$10R = 2500 \Rightarrow R = 250 m$$ [25%]

2 d) Required flow rate = 8784 litres/min.

= 146.4 litres/sec

= 0.1464 m^3/sec

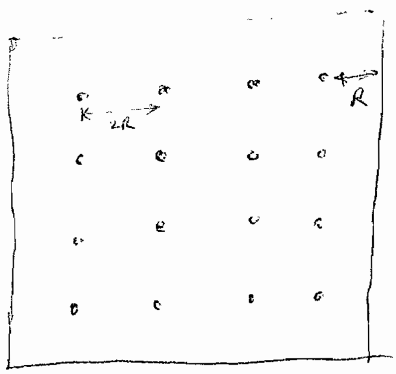
Each well can pump 0.00915 m^3/sec
(from part b).

∴ Number of wells required = $\frac{0.1464}{0.00915}$ = 16 wells

The Radius of influence R = 250m if a maximum drawdown of 1.0m is to be allowed.

Square field ⇒ arrange wells as 4×4.

For maximum efficiency well spacing = 2 × 250 = 500 m.



Dimension of the field

= R + 2R + 2R + 2R + R

= 8R

= 2000 m.

Minimum field dimensions

2000 m × 2000 m

[30 %]

Note: For outer wells provide 'R' to field boundary, so that the drawdown outside the field is also limited to a maximum of 1.0 m. or less.

3a) Peclet number P_E is defined as

$$P_E = \frac{v_f \cdot d}{D_d}$$

where v_f is flow velocity and 'd' is average particle size or average size of heterogeneity. and D_d is the co efficient of diffusion. Peclet number can be used to judge the dominant transport mechanisms.

For example $P_E < 1$ suggests that diffusion is the dominant transport mechanism for the contaminants. (ie $v_f \cdot d < D_d$).

Similarly $P_E > 10$ suggests that diffusion is negligible compared to the mechanical dispersion.

If $1 < P_E < 10$ than both diffusion and mechanical dispersion play a role in the contaminant transport [20%]

3b) i)

$$\frac{C}{C_0} = \operatorname{erfc}\left[\frac{z}{\sqrt{4 D_d^* t}}\right]$$

For trace concentration of 0.01 % at monitoring point A

$$C = \frac{0.01}{100} = 0.0001\, C_0.$$

$$C/C_0 = 0.0001$$

$$\beta = \frac{z}{\sqrt{4 D_d^* t}} \qquad \operatorname{erfc}(\beta) = 0.0001$$

From Data sheets $\beta = 2.8$ for $\operatorname{erfc}(\beta) = 0.0001$

$$\therefore \frac{z}{\sqrt{4 D_d^* t}} = 2.8 \Rightarrow t = \frac{z^2}{2.8^2} \times \frac{1}{4 D_d^*}$$

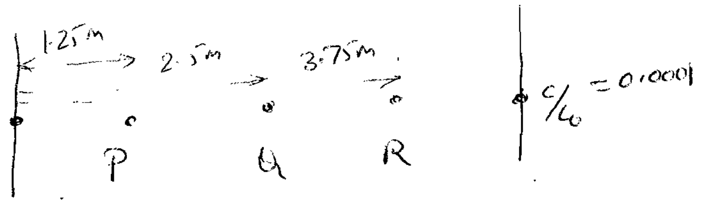
Break through time $t = \frac{5^2}{2.8^2} \times \frac{1}{4 \times 2.6 \times 10^{-9}}$ sec

$= 3.067 \times 10^8$ sec

or 9.72 years

3 b) ii) Consider P, Q & R as shown below

$c/c_0 = 1$



$$c/c_0 = \text{erfc}\left[\frac{z}{\sqrt{4 D_d^* t}}\right]$$

For P :- $z = 1.25$ m $\quad t = 3.067 \times 10^8$ sec

$\therefore \beta = \frac{z}{\sqrt{4 D_d^* t}} = \frac{z}{1.7857} = \frac{1.25}{1.7857} = 0.7$

$\beta = 0.7 \quad \text{erfc}(0.7) = 0.3222$

$\therefore c/c_0 = 0.3222$ (or 32.2 %)

For Q :- $z = 2.5$ m $\quad t = 3.067 \times 10^8$ sec.

$\beta = \frac{z}{1.7857} = \frac{2.5}{1.7857} = 1.4 \Rightarrow \text{erfc}(\beta) = 0.0477$

$\therefore c/c_0 = 0.0477$ (or 4.77%)

For R :- $z = 3.75$ m $\quad t = 3.067 \times 10^8$ sec

$\beta = \frac{z}{1.7857} = \frac{3.75}{1.7857} = 2.1 \Rightarrow \text{erfc}(\beta) = ?$

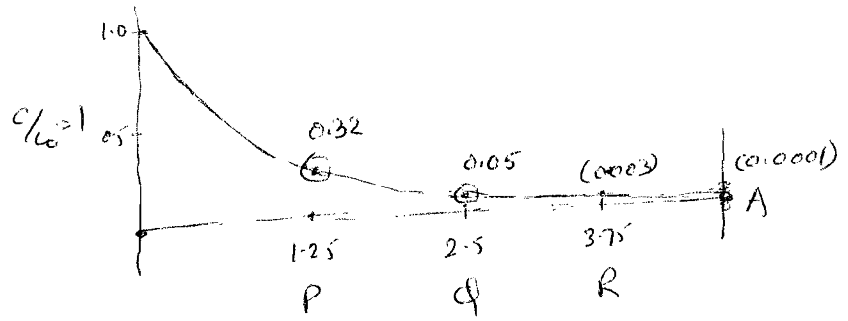
For $\beta = 2.00 \quad \text{erfc}(\beta) \Rightarrow 0.0047$

$\beta = 2.20 \quad \text{erfc}(\beta) \Rightarrow 0.0019$

Interpolating for $\beta = 2.1$

$c/c_0 = 0.0033$

or (0.33 %)



The contaminant concentration reduces rapidly with thickness of the clay liner. [30%]

3 b) iii) According to EA $c/c_0 = 0.1$ is allowable

$$c/c_0 = \text{erfc}\left[\frac{z}{\sqrt{4D_d^* t}}\right]$$

$$0.1 = \text{erfc}(\beta)$$

From data sheets

erfc (β)	→	β
0.1198	→	1.1
0.0897	→	1.2

0.1 → (between 0.1198 and 0.0897)

Interpolating $\beta \rightarrow 1.1658$

$$\therefore \frac{z}{\sqrt{4D_d^* t}} = 1.1658$$

$z = 5m$ & $D_d^* = 2.6 \times 10^{-9}$ m²/s.

$$\frac{5}{\sqrt{4 \times 2.6 \times 10^{-9} \times t}} = 1.1658 \Rightarrow t = 1.7687 \times 10^{9} \text{ sec}$$

or 56.08 years [20%]

3 c) To further increase the break through time, a geomembrane can be installed within the clay liner. This can be either next to the surface impoundment, if UV deterioration is not a problem. Otherwise install geomembrane within the clay liner [10%]

4. (a) (i) Cost-Benefit Analysis (CBA) involves assessment of the benefits (in monetary terms) calculated relative to costs. Advantage: single value calculated as measurement of value of project, with units consistent throughout. Disadvantages: certain aspects (e.g. changes in biodiversity) cannot be measured in monetary terms, hence incomplete analysis. Overcome by combining with a more general multi-criteria analysis (MCA) – Cost-effectiveness (CEA). Method usually applied commercially to determine the best remediation technique for contaminated land remediation projects. [15]

(ii) Multi-Criteria Analysis (MCA) involves the use of scores which are determined for a range of indices: directly: by measurement (e.g. amount of soil going to landfill) and indirectly: by subjective analysis (e.g. stakeholder concerns). Information is then transposed to a common scale. Weighting is then applied to each score depending upon the importance of the particular indicator in that particular case – amended scores then summed. Used in government decision making. Disadvantage: potential subjectivity inherent in outcome. Overcome by use of expert judgement, audit trail & maximum use of measurable data. [15]

(iii) Life-Cycle Analysis (LCA) is 'Cradle to grave' concept, systematic identification and evaluation of all the environmental benefits and disbenefits that result, both directly and indirectly, from a process or product throughout its entire life. For remediation project analysis also takes into account (on top of costs and performance of remediation) impact of any soil disposal to landfill & production, use or disposal of materials. A popular choice for analysis of remediation project. Main disadvantage is that it is extremely data intensive. Advantages: holistic approach, method standardised in ISO 14000 and is used in a number of different industries - applied to any process that has an environmental impact. [20]

(b) (i) The requirements of the Landfill Directive are:

- Certain wastes are prohibited from landfills,
- Biodegradable waste will progressively be diverted from landfill (75% of 1995 figure by 2010, 50% by 2013, 35% by 2020),
- Landfills will be classed according to the type of waste they can accept,
- Waste acceptance at landfills is subject to relevant waste acceptance criteria,
- Most wastes must be treated before landfilling. [20]

(ii) Three elements of sustainable waste management: [30]

- Waste reduction and re-use: e.g. efficient use of materials, government to work together with businesses to identify and exploit opportunities, use of waste from one industry as a raw material for another, households to address their purchasing decisions
- Waste as a Resource – Recycling and Composting: e.g. Production and consumption are usually linear but they need to be cyclical, with the exception of paper, wood and some textiles, most biodegradable organic materials cannot easily be recycled, however, these materials can be made into compost, which growers can use to replace peat and fertilisers - this allows the creation of a similar closed loop.
- Waste as a Fuel (energy from waste): where it does not make sense to recycle, consideration should be given to using the waste as a fuel. This can be done directly in incinerators and in industrial plant such as cement kilns or indirectly by creating refuse derived fuel or through processes e.g. gasification. Not all waste is suitable for use as fuel - inorganic waste such as glass and metals have no calorific value – but highly suitable for recycling. Use as a fuel can reduce CO_2 emissions by displacing the use of more polluting virgin fuel. It sometimes also reduces other emissions e.g. burning tyres in cement kilns reduces the quantity of nitrogen oxides released.

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