ENGINEERING TRIPOS PART IIA 2004

Solutions to Module 3D6
Environmental Engineering II
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1 (a) Predictions of effects due to climate change have been achieved by modelling interactions of complex systems over long periods by specialist bodies such as the Hadley Centre in the UK. Describe the difficulties that arise from the uncertainties associated with these models in terms of water resources management now. [20%]

Engineers' judgement (and standard codes of practice) define what risk to take - we cannot afford 'no risk'.

Run -off equation: Run-off rate = Area x Coefficient x Rainfall Intensity

In the run-off equation, only the Area is 'fact'...and even there we have to predict 'how much future development?'. The run-off Coefficient is an estimate, varying perhaps +/- 20% due to antecedent conditions – which may now change due to the cumulative effect of rainfall increase.

The Rainfall Intensity has a past statistical relationship to frequency of occurrence, and we have to decide 'how often can we flood?' Now climate change uncertainty means that the relationship between frequency and rainfall amount is changing – for instance a 'one in 50 years' event may now turn out to be occurring with a one in ten years frequency. It is difficult to separate these long term changes from the 'noise' of normal statistical variation.

Having to design for precipitation changes but not really being certain about what they will be. How much to design for? Not investing sufficient now may mean not being able to meet future needs.

Need for bigger pipes, but not certain of how big?

Uncertainties about flood frequency changes so difficult to assess risks of flood or design storage facilities.

(b) Describe the ways in which Urban Pollution Management (UPM) and integrated modelling can help to meet the requirements of the *environmental*, *social* and *economic* systems. [30%]

UPM is to help make complex interactions more comprehensible using integrated modelling, it aims to quantify impact on the environment of changes to the system and identify cost-effective solutions to water quality problems.

UPM's much improved analysis of catchment hydrology and hydraulics allows us to make much tighter predictions of drainage capacity needed, compared with the old 'rules of thumb' used in the past. It also allows us confidence in making cleverer and more complex uses of existing systems, including the use of 'real time control', in which engineers chose how to route flows, and store them, during the storm itself.

Economic effect – more service level for less cost than before. It is expected that the cost of the extra modelling study work will be much outweighed by savings in the solution.
Environmental effect – more service with more resource efficiency – less use of natural resources and materials, less energy use (and CO" release).

Social effect – ability to run more options for solutions in a realistic time, and to try out more complex solutions with less impact on the community than large drainage channels, for instance.

(c) Conventional urban drainage has been based on the concept of removing surface water as fast as possible. Discuss the problems that arise from this type of system with regards to:

(i) capacity; [10%]

(ii) pollution; [10%]

(iii) groundwater; [10%]

(iv) habitats. [10%]

i ***capacity – conventional systems are a fixed volume 'hole in the ground', no space to accommodate peak flood flows, conventional systems already reaching full capacity so any increases will require major new build.***

ii ***pollution – conventional systems carry water with pollutants without any potential degradation so the water and the pollution arrive at a new location unchanged.***

iii ***groundwater – conventional systems prevent groundwater recharge.***

iv ***habitats – conventional systems replace natural water courses and do not provide habitat possibilities. Fast flowing drainage water in concrete channels do not replicate river habitat.***

(d) The technical components of sustainable water management systems tend to be fairly simple, but in order for them to be effective, the engineer must also carry out consultation with stakeholders. Describe the involvement and likely priorities and suggest ways in which various requirements may be accommodated in terms of an integrated water resources management scheme. [10%]

Often more careful consultation with stakeholders may complicate the planning and design process, but will lead to more cost-effective 'social plus technical' solutions.

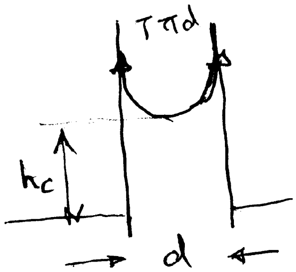
Stakeholders may be consulted and informed at community meetings or through newsletters. Priorities may include, safety, aesthetics, habitat, environment, noise, smell, construction hazards and duration, maintenance requirements, safety of children near open water basins, etc.

New stakeholders that engineers will need to engage with, to facilitate and agree on the more complex solutions will include: politicians & public; housing managers; town planners; developers and insurers.

They will need to discuss mixed responsibilities, - who does what, and who will maintain systems, and who pays?

Designers may need to try out draft ideas on SUDS type solutions in discussion in the community.

Q2. a) Height of Capillary rise in a tube of diameter d



Force due to surface tension

$= \pi d T \rightarrow (1)$

weight of fluid in the column hc high

$$W = \frac{\pi d^2}{4} h_c \cdot \gamma_w \rightarrow (2)$$

Equating (1) and (2)

$$h_c = \frac{4T}{\gamma_w d}$$ [20%]

b) From the particle size distribution (PSD) curve, we can see that the $D_{10} = 0.00003$ mm.

D_{10} size represents the average pore size in the soil.

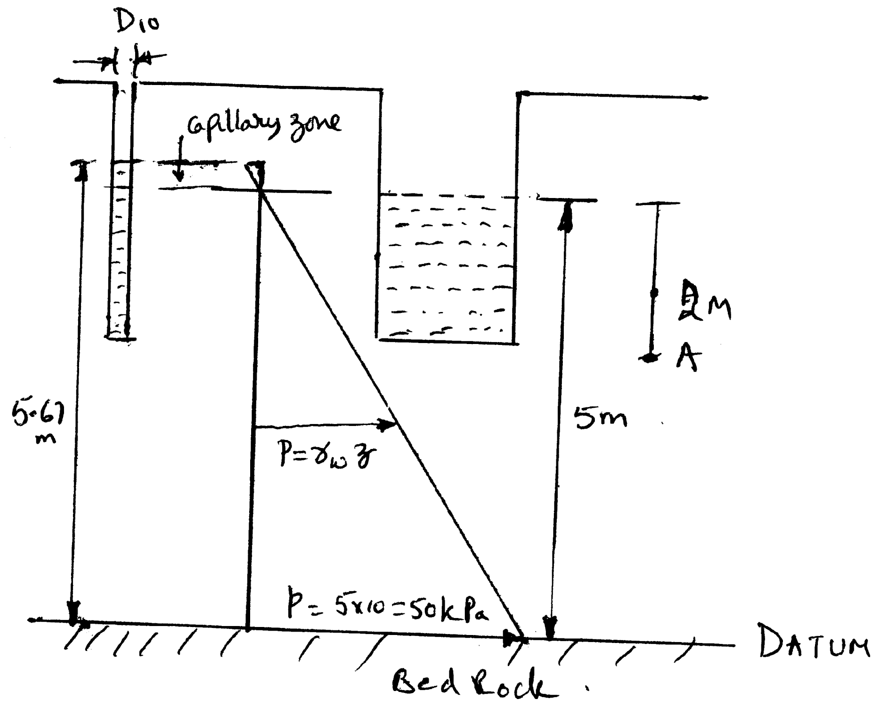
Surface tension T at ambient temp of water $= 5 \times 10^{-5}$ kN/m

$\gamma_w = 10$ kN/m³.

$$\therefore h_c = \frac{4 \times 5 \times 10^{-5}}{10 \times 0.00003} = \underline{\underline{0.67 \text{ m}}}.$$ [20%]

c) The water pressure below water table will increase as $p = \gamma_w z$.

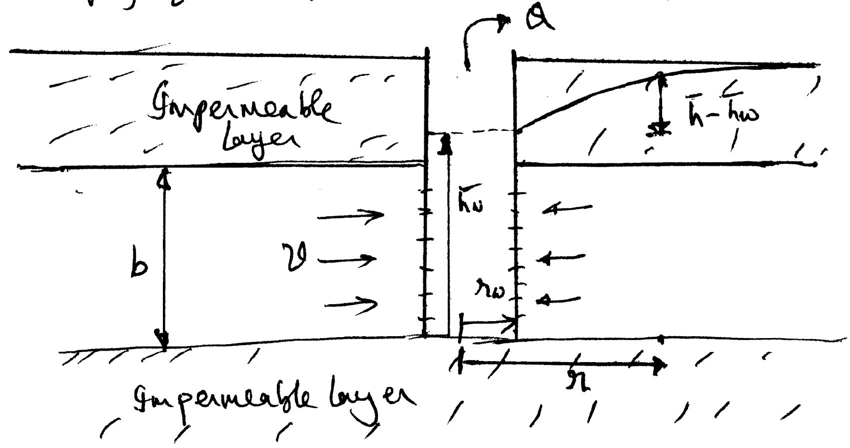
Above the water table, the water will saturate the soil in the capillary zone upto a height of 0.67m PTO



Potential head at point A 2m below the water table.

$= 5m - 2m = 3m.$ [20%]

2 d) Pumping of water from a confined aquifer.



Using continuity of mass

$$Q = A \cdot v = 2\pi r b K \frac{dh}{dr}$$

Transposing

$$d\bar{h} = Q/(2\pi\ bK) \times r\,dr.$$

Integrating with limits r_w to r

$$\int_{\bar{h}_w}^{\bar{h}} dh = \frac{Q}{2\pi\ bK} \int_{r_w}^{r} dr$$

$$\bar{h} - \bar{h}_w = \frac{Q}{2\pi\ bK} \ln \frac{r}{r_w}$$

From data given:

$\bar{h} - \bar{h}_w$ = Draw down = 1.8 m at r = 2.2 m.

$K_h = 1.5 \times 10^{-3}$ m/s

r_w = 60mm = 0.06m

b = 2.5 m

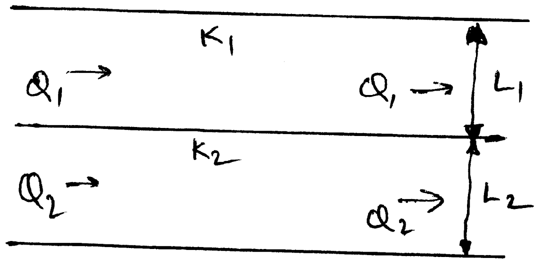
$$\therefore 1.8 = \frac{Q}{2\pi\ 2.5 \times 1.5 \times 10^{-3}} \times \ln \frac{2.2}{0.06}$$

$$\therefore Q = 0.01177\ m^3/s$$

or 11.77 litres/s.

or 706.2 litres/min

3 a) Flow parallel to layers:



$$Q = Q_1 + Q_2 \qquad Q_1 \neq Q_2 \;\Rightarrow\; v_1 \neq v_2$$

The hydraulic gradient driving the flow 'i' is the same for both layers.

$$\therefore Q_1 = v_1 \cdot L_1 \times 1 = K_1 L_1 i$$

Similarly

$$Q_2 = v_2 L_2 \times 1 = K_2 L_2 i$$

$$\therefore Q_1 + Q_2 = (K_1 L_1 + K_2 L_2) i$$

Specific discharge for the whole deposit is

$$v = \frac{Q}{(L_1 + L_2) \times 1} = \frac{(K_1 L_1 + K_2 L_2)}{(L_1 + L_2)} \cdot i$$

But from Darcy's law $v = K_{eq} i$

$$\therefore K_h = \left(\frac{K_1 L_1 + K_2 L_2}{L_1 + L_2} \right)$$

This can be extended to 'n' layers as

$$K_{horizontal} = \frac{K_1 L_1 + K_2 L_2 + \cdots + K_n L_n}{L_1 + L_2 + \cdots + L_n}$$

[30%]

3 b) $K_1 = 2.8 \times 10^{-5}$ m/s $L_1 = 2.8$ m

$K_2 = 1.5 \times 10^{-8}$ m/s. $L_2 = 5.1$ m.

Determine the hydraulic gradient first.

$$i = \frac{d\bar{h}}{ds}$$

Two stand pipes are 10m apart. $\therefore ds = 10$m

Potential head drop $= d\bar{h} = 5$m.

$$\therefore i_h = \frac{5}{10} = 0.5$$

Consider Stratum 1:-

$$Q_1 = v_1 \times L_1 \times 1 = K_1 L_1 \times i$$

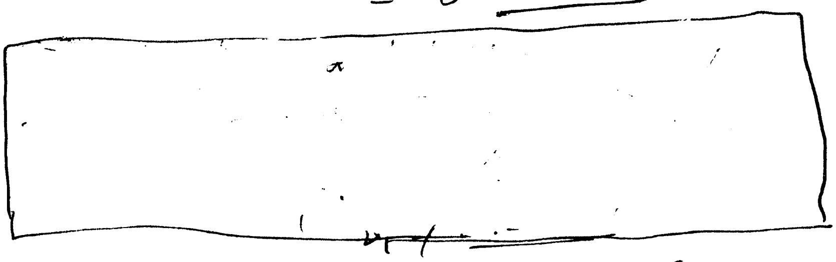
$$= 2.8 \times 10^{-5} \times 2.8 \times 0.5$$

$$= \underline{3.92 \times 10^{-5}} \text{ m}^3/\text{s}.$$

Consider Stratum 2:-

$$Q_2 = v_2 L_2 \times 1 = 1.5 \times 10^{-8} \times 5.1 \times 0.5$$

$$= \underline{3.825 \times 10^{-8}} \text{ m}^3/\text{s}.$$



$$K_h = \frac{K_1 L_1 + K_2 L_2}{L_1 + L_2} = \frac{2.8 \times 10^{-5} \times 2.8 + 1.5 \times 10^{-8} \times 5.1}{2.8 + 5.1}$$

$K_h = 9.934 \times 10^{-6}$ m/s.

3c) Error function

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

Time for break through :

$C/C_0 = 0.000$; Let $\beta = \frac{z}{\sqrt{4 D_d^* t}}$.

From Data book . for $C/C_0 = 0.000$

$C/C_0 = erfc(\beta) = 0.001$ when $\beta = 2.35$.

$$\therefore \frac{z}{\sqrt{4 D_d^* t}} = 2.35$$

Thickness of base liner of landfill $= 2.5$ m $= z = H$

ie Break through happens when leachates diffuses through this thickness

$$\therefore \sqrt{4 D_d^* t} = \frac{2.5}{-} = 1.0638$$

$$4 D_d^* t = 1.1317 \rightarrow (1)$$

Using $D_d^* = D_d \tau$.

{ From Question $D_d = 0.85 \times 10^{-9}$ m²/s⁻¹, $\tau = 0.4$ }

$$D_d^* = 0.85 \times 10^{-9} \times 0.4 = 3.4 \times 10^{-10} \text{ m}^2/\text{s}.$$

$$\therefore t = \frac{1.1317}{4 \times 3.4 \times 10^{-10}} = 8.3216 \times 10^{8} \text{ secs}$$

or 26.39 years

3 c) At what depth $c/c_o = 0.7$

$erfc(\beta) = 0.7$ From Data Sheets

$\beta = 0.25 \quad erfc(\beta) = 0.7237$

$\beta = 0.30 \quad erfc(\beta) = 0.6714$

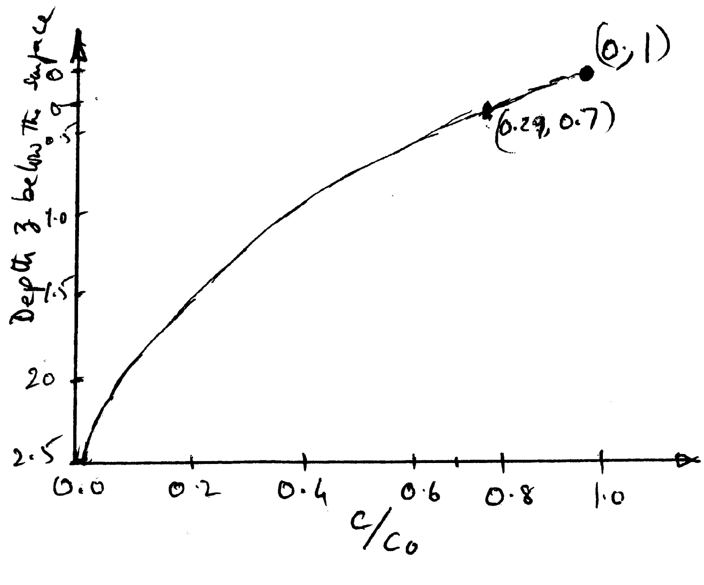
Interpolate for value of β for $erfc(\beta) = 0.7$

$\beta = 0.2748$

$$\therefore \frac{z}{\sqrt{4 D_d^* t}} = 0.2748$$

$$\therefore \frac{z}{\sqrt{4 \times 3.4 \times 10^{-10} \times 8.326 \times 10^{8}}} = 0.2748$$

$z = 0.2923$ m.



4 a) Both molecular diffusion and mechanical dispersion are pollutant transport mechanisms. They cause transport of the pollutant from one place to another.

Molecular diffusion occurs primary) due to a difference in concentration between two points. Higher the concentration gradient higher will be molecular diffusion.

Mechanical dispersion occurs due to transport of the pollutant in ground water flow through porous media. The tortous path taken by pore water between the soil particles causes mechanical dispersion of the pollutant in addition to the advective transport.

At small flow velocities molecular diffusion dominates the transport process. At higher flow velocities mechanical dispersion dominates the solute transport process.

Diffusion is a Fickian process. Diffusion can occur perpendicular to ground water flow direction. Diffusion is largely independent of direction of ground water flow. Mechanical dispersion can also occur normal to the direction of groundwater flow. This is characterised by transverse dispersivity. [25%]

b) Several types of Geosynthetics are used in the landfills.

Top cover design usually consist of Geotextiles and Geomembranes.

Side slopes of a landfill can use

- Geomembranes as contaminant barriers
- Geotextiles to carry tensile loads induced by settling waste
- Geo Grids for same reason as Geotextiles.
- GCLs ~~[illegible]~~ as contaminant barriers.

Base of the land fill can consist of
- Geo membranes or GCL's.
- Geotextiles
- Geo Grids.
- Geonets for drainage.

[25%]

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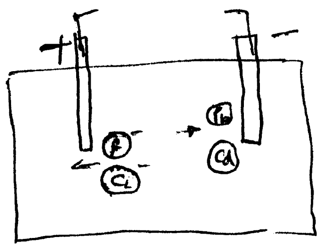
4 c) Electro kinetic clean up method can be used to remediate a contaminated site. It is effectiveness depends on the type of contaminants present at the site. It works well for ionic compounds, heavy metals etc

The method consists of applying a DC electric field causing ions to migrate according to their electric charge.



The contaminents arriving at the electrodes are pumped out and removed. This method works well and contaminants are contained preventing further movement due to advection. Disadvantages are it is expensive and long term.

[25%]

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4 d) In ground barriers can:

a) either prevent movement/escape of contaminants ~~are~~ from a polluted site (active prevention)

or

b) protect a clean source such as drinking water reservoir (passive protection).

In-ground barriers can take the form of ~~sheet~~ sheet piles (expensive) or slurry walls or in-situ ~~deep~~ mixing methods. All of them are hydraulic measures that aim to reduce the effective horizontal hydraulic conductivity.

Slurry walls are quite popular and are used widely. They can be constructed using cement-bentonite or soil-bentonite slurry and can be constructed to required depths.

Advantages are:

- economic solution for large sites
- well established technique
- applicable to wide range of chemicals
- small short-term env & public health impact

Disadvantages are

- the contaminants are not being removed/neutralised
- site is vulnerable if barriers fails
- Barriers may deteriorate with time due to reaction with contaminants.
- Lack of data on long-term performance

[25%]