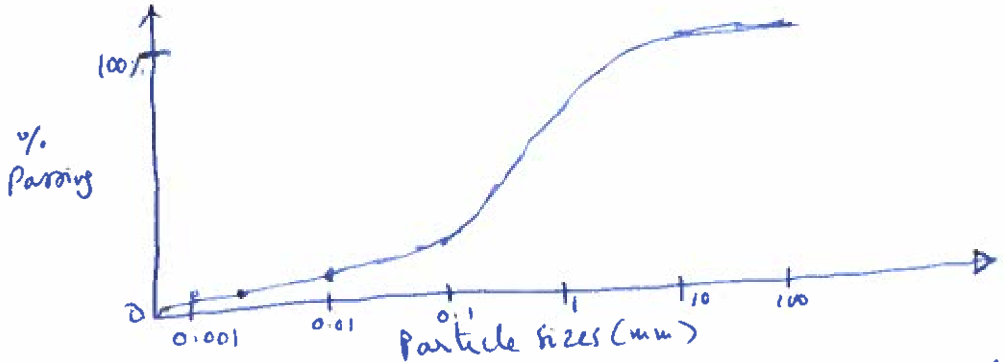
3D8 Gibs

1 a) To construct a particle size distribution (PSD) curve for a given soil sample, it is seived through a set of sieves with standard aperture sizes. A known quantity of soil sample, say 100 grams is placed on the top, coarsest sieve. The stack of sieves are shaken for a given amount of time on a shaker. The soil mass that remains on each sieve is weighed and the percentage of soil passing through the sieve is determined. A cumulative frequency plot shown below is constructed. The sieve sizes are plotted on the x axis on log scale.



Based on the PSD, we can say if the soil is uniformly graded or poorly graded depending on the particle sizes we can say if the soil is predominantly sand or silt. To determine the clay sized particles we need to conduct a hygrometer analyses and use Stoke's law [10%]

b) Intrinsic permeability of a granular medium is the measure of space between the soil particles. It has units of m^2. and we use k to represent it

Hydraulic conductivity K depends both on the internal space between the particles of the granular medium and the properties of the fluid passing through the medium.

$$K = k \frac{\gamma_f}{\mu_f}$$

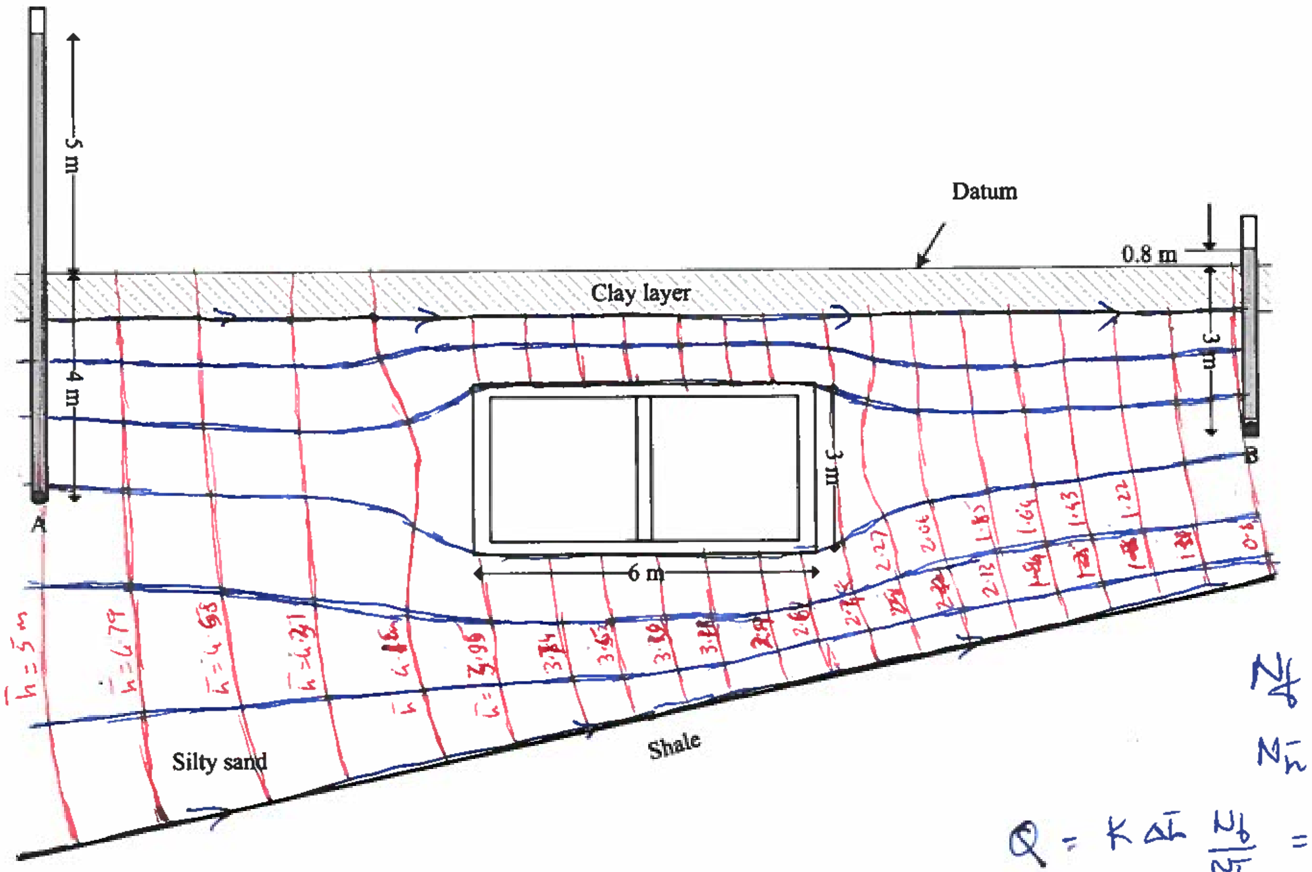
where γ_f - fluid density and μ_f is fluid viscosity. [10%]

Version AAT/8

Candidate No:

ENGINEERING TRIPOS PART IIA FRIDAY 26 APRIL 2024 09:30 TO 11:10

Module 3D8 Question 1 (c)(i) DRAWN TO SCALE



$N_f = 6$

$N_h = 20$

$Q = k \Delta \bar{h} \frac{N_f}{N_h} = 2.6 \times 10^{-6} \times 4.2 \times \frac{6}{20}$

$= 3.276 \times 10^{-6}$ m³/s/m.

$\bar{h}_A = h_A + y_A$

$y_A = -4$m (below datum)

$h_A = 9$m.

$\therefore \bar{h}_A = 9 - 4 = 5$m.

$\bar{h}_B = 3.8 - 3 = 0.8$m

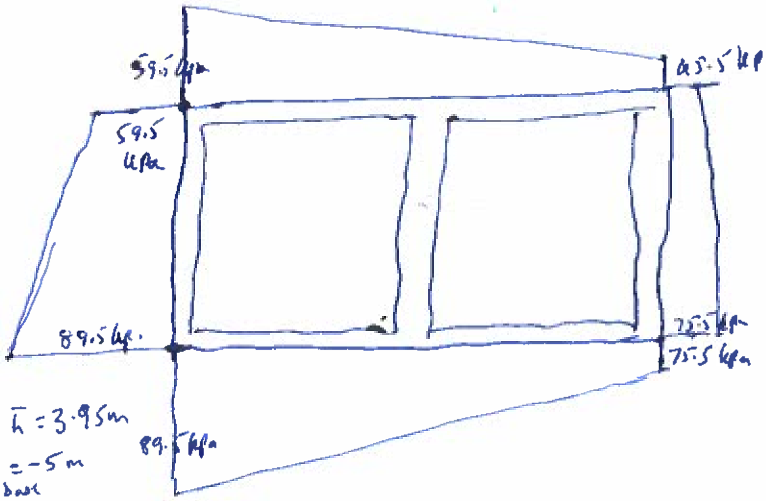
$\Delta \bar{h} = 5 - 0.8 = 4.2$m

Extra Copy of Fig. 1 Question 1 (c)(i)

[20%]

1c ii) Seepage pressure distribution on the tunnel

use $\bar{h} = h + y$



LH edge $\bar{h} = 3.95m$
$y_{base} = -5m$
$h = 8.95$
$P_{base} = 89.5 \, kPa$
$y_{top} = -2.00$
$h = 5.95m$
$P_{top} = 59.5 \, kPa$

RH edge $\simeq 2.55m = \bar{h}$
$y_{base} = -5m$
$h = 7.55m$
$P_{base} = 75.5 \, kPa$
$y_{top} = -2m \quad h = 4.55m$
$P_{top} = 45.5 \, kPa$

[25%]

1c iii) When there is no seepage, hydrostatic pressures exist.

Weight of the tunnel (/m) $= [6 \times 3 - 4.5 \times 2] 24 = 216 \, kN/m$

Buoyancy force $= 6 \times 3 \times 10 = 180 \, kN/m$ (assume $\gamma_w \approx 10 \, kN/m^3$)

$\therefore$ Net weight $W' = 216 - 180 = \underline{\underline{36 \, kN/m}}$

The tunnel will also be held in place by the overburden weight/stress of the soil above + shear strength of the soil.

[10%]

1c iv) Upwards force along the base $= \left[\dfrac{89.5 + 75.5}{2}\right] \times 6 = 495 \, kN/m$

Downward force on the top of the tunnel $= \left[\dfrac{59.5 + 45.5}{2}\right] \times 6 = 315 \, kN/m$

$\therefore$ Net upwards force $= 495 - 315 = 180 \, kN/m$

Weight of the tunnel $= 216 \, kN/m$

$\therefore$ Net weight of the tunnel $= 216 - 180 = \underline{\underline{36 \, kN/m}}$ ← No change.

The stability of the tunnel does not change. This is because the seepage velocity is very low and therefore seepage pressures are small.

[25%]

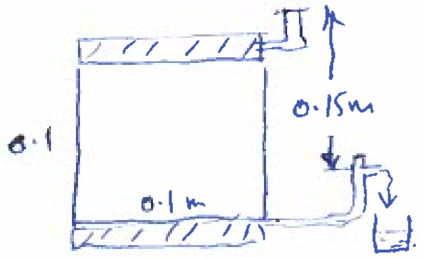
2a) Darcy's law for water flow through granular media states that the flow velocity $v = K i$ where K is hydraulic conductivity and $i = \frac{d\bar{h}}{ds}$ is the hydraulic gradient.

Fourier's law is equivalent for heat flow where Heat flux is $H = \lambda \frac{dT}{dx}$ where λ is the thermal conductivity and $\frac{dT}{dx}$ is the temperature gradient.

Both v & H depend on the gradient of potential head $\bar{h}$ or temperature T.
Both laws were determined based on experimental evidence. [10%]

b) As seen in 308 experiments, the main difference between fluid flow and heat flow is the time it takes to establish the steady state.
In case of fluid flow, the steady state, after a hydraulic gradient is applied, reaches very quickly, where as for a heat flow, the thermal steady state can take much longer time to establish. [10%]

c)



$Q = 100$ ml in 30 min.

$$= \frac{100 \times 10^{-3} \times 10^{-3}}{30 \times 60} = 0.055 \times 10^{-6} \ m^3/s.$$

Using Darcy's law $Q = K i A$

$A = 0.1 \times 0.1 \ m^2$.

$i = \frac{0.15}{0.1} = 1.5$

$$\therefore K = \frac{Q}{i A} = \frac{0.0555 \times 10^{-6}}{0.1^2 \times 1.5} = \underline{\underline{3.7037 \times 10^{-6} \ m/s}}.$$

[20%]

2d)

$$K_w = k\frac{\gamma_w}{\nu_w} \qquad K_{oil} = k\frac{\gamma_{oil}}{\nu_{oil}}.$$

$$\therefore \frac{K_{oil}}{K_w} = \frac{\gamma_{oil}}{\nu_{oil}}\,\frac{\nu_w}{\gamma_w} = \frac{862}{1000} \times \frac{1}{32} = 0.026937.$$

$$\therefore K_{oil} = K_w \times 0.0269 = 3.7037 \times 10^{-6} \times 0.026937$$

$$= 99.7684 \times 10^{-9} \text{ m/s}$$

$$\therefore Q_{oil} = K_{oil}\, i\, A = 99.7684 \times 10^{-9} \times 1.5 \times 0.1^2.$$

$$= 1.4965 \times 10^{-9} \text{ m}^3/\text{s}.$$

$$= 1.4965 \times 10^{-3} \text{ ml/s}.$$

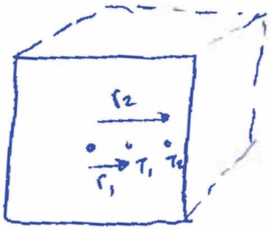
$$= 0.0897 \text{ ml/min}.$$

∴ For 50 ml it will take = 557.413 min.

or <u>9.29 hours</u> !

[20 %]

2e)



Spherical heat flow from a point source. Use Fourier's law;

$$H = \frac{E}{4\pi r^2} = -\lambda\frac{dT}{dr}.$$

$$\frac{E}{4\pi}\int_{r_1}^{r_2}\frac{dr}{r^2} = -\lambda\int_{T_1}^{T_2} dT.$$

Integrating ⟹

$$\frac{E}{4\pi}\left.\frac{r^{-1}}{-1}\right]_{r_1}^{r_2} = -\lambda\,(T_2 - T_1)$$

$$\frac{E}{4\pi}\left[\frac{1}{r_1} - \frac{1}{r_2}\right] = -\lambda\,(T_2 - T_1) \qquad E = 100 \text{ watts}$$

$$\frac{100}{4\pi}\left[\frac{1}{0.03} - \frac{1}{0.035}\right] = -\lambda\,(50 - 60)$$

$$7.9577 \times 4.761\bar{3} = +\lambda \times 10$$

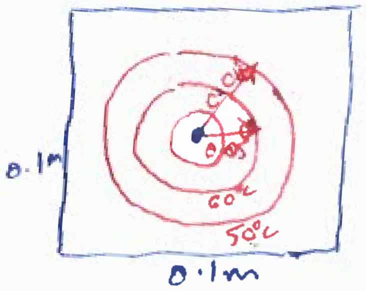
$$\frac{37.89}{10} = \lambda$$

∴ Thermal Conductivity of the sample = <u>3.789</u> W/m/°C.

[[illegible]]

2 e) Isotherms. – Concentric spheres.

C/S view:



[25%]

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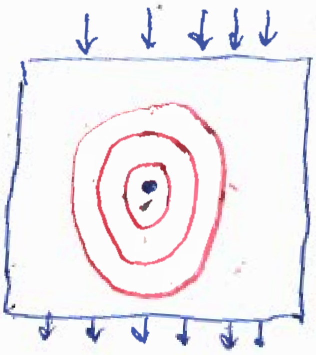
2 f) With seepage flow, the heat contours.



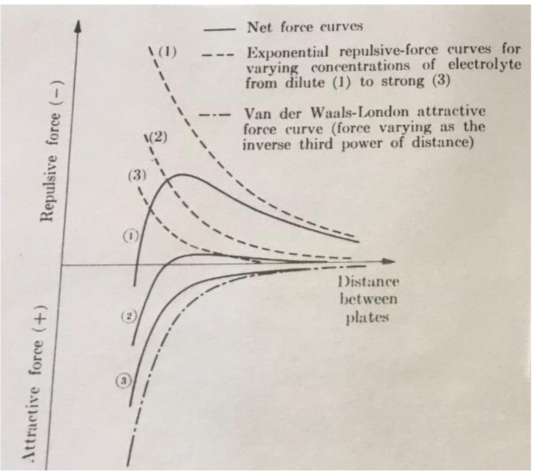
The isotherms become oval (in c/s view) due to the seepage flow i.e, more heat flows towards the base of the sample. In the 3D sample the shape will be spheroidal. Solution for this Combined seepage + Heat flow can be obtained by using error-functions similar to advection + dispersion problems in contaminant transport.

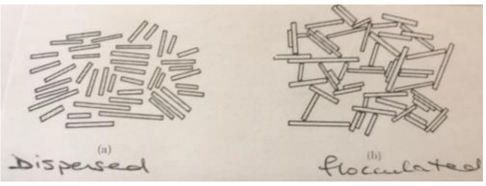
[15%]

3 (a)

(i) Clay minerals can exhibit two types of charge: [10%]

- Permanent or constant charge: Constant charge results from isomorphous substitution. This is when some of the Si or Al ions in the clay crystal are replaced with other elements, with the crystal structure remaining unchanged. A lower valency ion e.g. Mg^{2+} replacing Al^{3+} leaves the crystal with a net negative change. Broken edges of the clay platelets also results in a net change on those edge. These permanent charges are invariant with the soil pH.
- Variable or pH-dependent charge: The variable charge component in soils changes with pH due to protonation and deprotonation of functional groups on the surface of the inorganic soil minerals or soil organic matter.





(ii) If two clay particles approach each other in a suspension, the forces acting on them are:

(a) Van der Waals forces of attraction which are independent of the aqueous medium

Van der Waals forces are an attraction force resulting from the movement of electrons in their orbit around atoms causing an electric field around molecules, which attracts other electric fields around other molecules. This force varies inversely as a high power of distance or molecular spacing. For two flat parallel surfaces, this varies inversely as the cube or fourth power of distance between them.

(b) The repulsion between the two ionised adsorption layers which is dependent on the concentration of ions in the solution. As the concentration increases, the repulsive force between the clay particles at a given distance decreases. [20%]

(iii) At very small separations, the Van der Waals forces are always the larger, and particles which approach sufficiently closely will adhere. However, the Van der Waals forces decrease rapidly with increasing separation. If the adsorbed layer is thick (e.g. in dilute solutions), the repulsion will be large at distances from the surface at which the Van der Waals forces are small. There will therefore be a net repulsive force, and particles will tend to settle independently (though very slowly) and will remain dispersed. Contact will only be established if an external force is applied which is large enough to overcome it.

On the other hand, if the adsorbed layer is thin (e.g. in high concentration solution), there will be little or no net repulsion at any distance, and random movements of the particles will be enough to bring them into contact. Groups of such particles will form and will settle together comparatively rapidly, through the suspension. This process is called flocculation. The net forces of repulsion are greatest in the case of particles approaching face to face. As a result flocculating particles tend to make contact in edge-to-face arrangement.

Examples: Clays deposited through seawater, in which the ion concentration is high so that the adsorbed layer is thin, generally have a flocculated structures. Clays deposited in freshwater lakes generally have a dispersed structures. Adding Ca (say through gypsum (calcium sulphate)) to sodic soil (soil rich in Na) will cause it to flocculate. Lime treatment of soils leads to flocculation and enhanced properties. Rain (slightly acidic) could lead to erosion of soils, through leaching out ions from solution leading to a dispersive soil structure, which becomes weaker and the particles become more eroded. [30%]

(b) Answering this question requires extracts from various part of the course material and the answers below are not exhaustive. Below are bullet points and the students are expected to elaborate on their chosen answers.

Why is contamination of the subsurface a complex challenge: [20%]

- Contamination is hidden underground, so not easy to see or monitor.
- The subsurface is a complex system, both of the soil and groundwater. The ground varies from location to location and contamination is highly dependent on this variability and the groundwater level.

- There are 100s or even 1000s of contaminants, with different physical and chemical properties and hence their transport and fate within the surface various.
- Many contaminants are a mix of 100s of compounds and their varying chemical and physical properties mean that the spread differently within the subsurface.
- The soil type will significant impact the transport mechanism and fate of contaminants within the subsurface.
- The persistence of contaminants vary within the subsurface and some transform to other forms, which could be unknown.

Why is risk-based remediation approaches are the most effective and sustainable solutions: [20%]

- Given the above challenges with contaminants within the subsurface, it is difficult, and actually impossible, to know where contaminants are. This means that sampling, of soil and groundwater, provides limited information and statistical methods need to be applied to provide an average contaminant concentration to be used in the remediation. This does not reflect the actual contaminant concentration in the ground, which is usually very varied and hence the remediation approach needs to deal with varied concentrations and will provide varied outcome and results.
- It is very difficult to ensure direct contact between any treatment additive and the contaminants, given the extent of the unknowns and the difficulty of introducing additives into the subsurface.
- Different contaminants bind differently to different soil fractions and hence their extraction would usually require different processes, increasing costs. Hence methods that can target a broad range of contaminants, but to different degrees, offer more cost-effective solutions and enables a risk-based approach.
- It is difficult to target all contaminants within a subsurface and hence the effectiveness of any remediation approach will be better for some contaminants than others.
- It is much more efficient to perform remediation for a specific end use of the site, e.g. commercial, residential or allotment, than perform remediation for any purpose. Given that the remediation targets are most stringent for allotment use, remediation of all site for this end use will be extremely expensive and will reduce the number of remediation projects that can be carried out.
- It is usually impossible to remove all contamination from the ground and to know for sure that all contamination has been removed.
- There are acceptable limits, which pose minimal risk to human health that can be used in risk-based remediation approach and for many contaminants humans already intake at least those levels of contaminants as background contamination.

4 Information provided:

D = 12m Co = 6.2mg/L Vf = 1.5 x 10-9 m/s Dd* = 1.3 x 10-9 m2/s αL = 0.3 m

(a) DL = Dd* + Vf x αL = 1.3 x 10-9 + 1.5 x 10-9 x 0.3 = 1.75 x 10-9 m2/s

2 x C/Co = 2 x 0.0001 = 0.0002
From erfc Table, β = 2.6

Using equation provided in question:
2.6 = (12 – 1.5 x 10-9 t)/ √(4 x 0.175 x 10-8 x t)
2.175 x 10-4 √t + 1.5 x 10-9 t -12 = 0
Solve quadratic equation
t = 1817477192 sec = 57.63 years [20%]

(b) Acceptable contaminant concentration 3.2mg/L
C/Co = 3.2/6.2 = 0.5161

2 x 0.5161 = erfc [z – 1.5 x 10-9 x 1817477192]/√[4 x 0.175 x 10-8 x 1817477192]

From tables	erfc (β)	leads to β
	1.0564	-0.05
hence	1.0322	-0.0285

-0.0285 = [z -2.7262] / [3.5668]
Hence z = 2.635m
Hence excavate down to a depth of 2.64m below landfill. [20%]

(c) Advective flow will dominate, hence depth/vf = $10/(1.5x10^{-9})$ = 209.3 years. Almost 4 times as slow since dispersion significantly spreads out the contamination along the ‘S’ profile. [10%]

(d) The expected contaminant transport mechanism when the landfill was new would be expected to be diffusion. This means that the time taken for the first sign of the contaminant to reach the aquifer will be longer and hence the transport is slower. The equation to be used is different from that provided: it will have no vf and no ½. Hence the calculations would be as follows:

C/Co = 0.0001, β= 2.8

2.8= 12/√4x0.13x10-8t
t = 3532519225 sec = 112 years. [10%]

(e) Identify location of leaks and seal, either with grouting underneath the landfill or inject sealant within the base of the landfill – but neither is easy. [10%]

(f) Modern design of the landfill with double leakage detection system and geotextile for resilience. Could also include gas venting and capture system. Compact the underlying soil or use grout injection to reduce permeability and repair any cracks. Elaborate. [15%]

(g) The CEC determines the capacity of a soil to retain ions in a form such that they are not susceptible to leaching from the soil profile. In general ions in the soil such as Ca+ are exchanged with heavy metals, hence the latter can be sorbed onto the soil. This leads to less diffusion and transport below the landfill. Any changes in the absorbed ions could change the thickness of the diffuse double layer, altering material properties relevant to contaminant transport process e.g. permeability. [15%]

3D8 Geo-Environmental Engineering 2023-24
Extracts from the Examiners' Report

Q1: Flow net construction around an underground subway tunnel

Many candidates made a decent attempt at drawing the flow net. However a significant number of candidates made errors in determining the water pressures around the tunnel both under hydrostatic condition and with the seepage flow. Initial parts of the question were however answered very well on the construction of particle size distribution curve for granular media and the differences between intrinsic permeability and hydraulic conductivity.

Q2: Groundwater and heat flows in granular media

The initial part of the question was on Darcy & Fourier laws for groundwater and heat flow in granular media. These parts were answered by most candidates very well. The next two parts were on the flow of water and oil through a soil sample. Again most candidate answered this very well and got full marks. The last part of the question was on heat flow in the soil sample. Many candidates understood that the point source gives out spherical isotherms and did integration accordingly. A few candidates however did not do this part well and made both algebraic and numerical errors.

Q3 Forces on clay particles and subsurface remediation

This was a descriptive question of two parts: the first related to the charge and forces present on the surface of clay particles and their impact on performance and the second on the challenges of subsurface contamination and remediation strategies. The question required synthesis of information from different part of the course. Overall the performance was disappointing. The low marks were primarily due to very short answers provided by some students, not reflecting the mark given or time that should have been allocated to answering this question.

Q4 Pollutant transport underneath a landfill

Mainly calculation-based question of seven parts on contaminant transport below a landfill exploring different transport processes and their implications as well as the effect of different design criteria. Some parts required solving 'what if scenario' questions which some students struggled with. In some cases the students resorted to descriptive answers only, although simple calculations were required, and if done would have shown that their intuition was wrong.