1. (a)

Arithmetic sample mean of y(=logx) values = 2.16

Standard deviation of y values Sy = 0.204

Outlier test statistic T = (log(350)-2.16)/0.204 = 1.88

T = 1.88 is less than the 10% critical value of 1.91 (see Databook). Hence, the largest number of 350 mg/L is not an outlier.

(b)

t value for n = 8 is 1.895 from Databook.

$US_{95} = X + ts/\text{sqrt}(n) = 161 + (1.895)(87)/\text{sqrt}(8) =$ 219 mg/Kg

(c)

For benzene, Log Kow = 2.13 (from Databook).

$\log K_{oc} = 0.544 (\log K_{ow}) + 1.377 = 0.544 \times 2.13 + 1.377 = 2.54$

Kp = foc Koc = 0.02 x 347 = 6.9.

Using the linear isotherm model X= KC, 219 = 6.9 x C, C = 31.7 mg/L.

(d)

For benzene, H = 5.55 atm/M.

Convert the aqueous phase concentration from mg/L to M.

31.7 mg/L $= 31.7$ (mg/L) x (1/78.1) (M/g) x 10^{-3} (g/mg) = 4.05×10^{-4} M.

The vapour concentration then becomes Pvap = $5.55 \times 4.05 \times 10^{-4} = 2.25 \times 10^{-3}$ atm = 2250 ppmV.

(e)

Convert vapour concentration in mg/L

P = 2250 ppmV = 2250 x 78.1/24.05 (mg/m^3) x 10^{-3} (m^3/L) = 7.31 mg/L.

Total mass = gas + aqueous + soil = 0.30 x 200 x 10^3 x 7.31 + 0.05 x 200 x 10^3 x 31.7 + 219 x 1800 x 200 = 438600 + 317000 + 78840000 = 79.6 kg.

(f)

Air sparging and soil vapour extraction– Air is injected under the gasoline source that is often floating on top of the water table. The injected air will volitilize the nonaqueous phase liquid and the contaminated vapour is extracted via extraction wells placed on unsaturated zone.

Dual phase pumping – Two pumps are installed on top of a single well. One pump is used to extract the groundwater and this creates localised groundwater depreciation. The gasoline sitting on top of the water table moves toward the well by the depreciation and the other pump is used to extract the gasoline.

(g)

Benzene plume can be stable because

- The biodegradation rate of benzene is high.
- Benzene volatilizes gradually from the top of water table.
- Byproducts by biodegradation tend to be safe.

However, the change in size and concentration of degrading products are needed to be monitored carefully in the field to show that natural attenuation is occurring.

2 (a)

Used as a metal degreaser and has been available worldwide for about 50 years. Aircraft and engine maintenance and production, cleaning rock hardware, and automotive industry.

(b)

DNAPL will migrate vertically down and pool at the bottom of the aquifer.
The subsequent movement depends on the slope of the impermeable boundary.
Continuously pollute the water through dissolution.
Migrate into fractures in the impermeable boundary, making it difficult to remediate.

(c)

Surfactant washing – enhanced dissolution and mobilisation
Air or steam heating – enhanced volatilisation

(d)

Advection, diffusion, disperson, biodegradation, chemical degradation, sorption.

(e)

For TCE, $\text{Log}(K_{ow}) = 2.38$

$\log K_{oc} = 1.00 (\log K_{ow}) - 0.21 = 1.00 \times 2.38 - 0.21 = 2.17$

$Kp = focKoc = 0.01 \times 10^{2.17} = 1.48$

$R = 1 + \rho_d Kp/\phi = 1 + 1.8 \times 1.48/0.35 = \underline{8.61}$

(f)

Groundwater velocity $= ki/\phi = 40 \times 0.005/0.35 = 0.57$ m/day.

Plume velocity = 0.57/8.61 = 0.066 m/day

The travel distance is 800 m. Time taken = 800/0.066 = 12121 days = 33.2 years.

(g)

Darcy's velocity $u = ki = 0.20$ m/day $= 1.39 \times 10^{-4}$ m/min

Distance between the streamlines at the line of the well

$Q/Bu = 0.2 \text{ (m}^3\text{/min)}/ 25 \text{ (m)}/1.39 \times 10^{-4} \text{ (m/min)} = 57.6 \text{ (m)}$ (A-A')

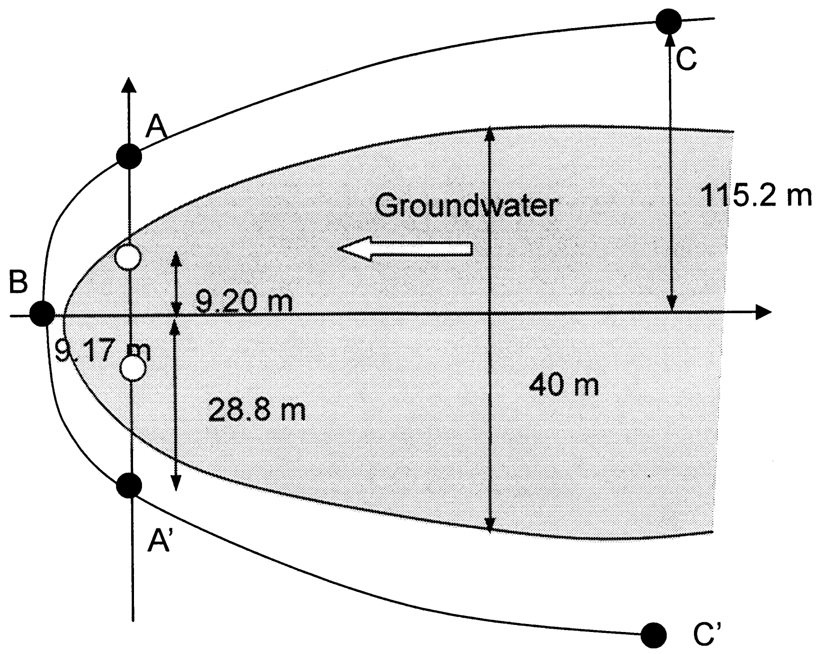
Downstream distance from the well to the stagnation point of the envelope

$Q/2\pi Bu = 0.2/2\pi/25/1.39x10^{-4} = 9.17$ (m) (O-B)

Sidestream distance of the envelope far upstream from the well.

$2Q/Bu = 115.2$ (m). (C-C')

Distance between the two wells = $0.32Q/Bu = 18.40$ (m)



Solution to Question :

4 a) Reactions within the waste in a land fill can be broadly classified into Biochemical and chemical reactions.

Biochemical reactions consist of converting complex organic compounds into simpler compounds, converting insoluble solids into water-soluble substances. These reactions consist of hydrolysis, oxidation and reduction into liquid form. The organic matter is initially degraded by aerobic action and converted into nitrates, sulphates, CO_2 and water. Once free air is exhausted reactions take place under anaerobic conditions and convert unstable matter into gases such as methane, ammonia, CO_2, H_2S.

Chemical reactions that take place in the landfill are mainly

i) Neutralisation
ii) Precipitation.
iii) Reduction.

Examples of chemical reactions include neutralisation of acids and alkali waste causing precipitation of heavy metals as sulphides, hydroxides and carbonates. Reduction of sulphates to H_2S etc. [20%]

b) In landfills waste is placed next to the low permeability soil such as clay. Landfills may be located in natural clay deposits or a clay liner constructed to form a barrier. In either case the waste can react with the clay resulting in changes to the properties of the clay. This is termed as 'waste-soil interaction'.

Among all the properties of the clay liner of a landfill, one of the most important one is the hydraulic conductivity. This property determines how effective the clay liner will be in keeping the leachate produced within the landfill from reaching the ground water. Therefore the changes to the hydraulic conductivity due to waste-soil interaction are very important.

certain chemicals such as acetone can change the hydraulic conductivity by a factor of 1400 in bentonite - sandy soil. Similarly Naphtha can increase the hydraulic conductivity of Ca-Montmorillonite clays by a factor of 40000. Many hydrocarbons have an effect on hydraulic conductivity of clayey soils. It is beleived that the hydrocarbons change the thickness of the 'double layer' between clay platelets causing a change in the hydraulic conductivity. [20%.]

4 c) The new landfill will receive waste for 8 years. It takes 1 year to construct.

Population increases at a rate of 10%..
∴ By the time the landfill is ready the population will be

$$P_1 = P_{current}\left(1+\frac{r}{100}\right)^n$$

$$P_1 = 680000\left(1+\frac{10}{100}\right)^1 = 748000.$$

Subsequent increase in population can be calculated in a similar way. The waste produced per person is 20 kg/week. Using this the waste generated can be estimated as shown in table below. No waste is received during construction.

Year	year of operation	Population	Waste (tons)
2	1	822,800	16,456 x 52
3	2	905,080	18,101.6 x52
4	3	995,558	19,911.76 x52
5	4	1,095,147	21,902.94 x52
6	5	1,204,661	24,093.23 x52
7	6	1,325,128	26,502.55 x52
8	7	1,457,640	29,152.81 x52
9	8	1,603,404	32,068.09 x52
		Total waste (tons)	188,189 x52

= 9785828 tons

4 c) i) Volume of the landfill to accommodate the waste

Density achieved = 900 kg/m^3 (unit weight = 9 kN/m^3)

$\therefore$ Volume $= \frac{52 \times 188,189 \times 1000}{900} = 10,873,142$ m^3.

Depth of the landfill = 20 m.

ii) $\therefore$ Plan area $= \frac{10873142}{20} = 543657$ m^2.

Assume 800 m × 700 m which gives a plan area of 560000 m^2 > 543657 m^2 OK

$\therefore$ The landfill must have dimensions of 120 m × 90 m × 20 m.

iii) Profit generated by this project:

Total waste = 9785828 tons.

Flat fee per ton = £ 28.50.

$\therefore$ Revenue generated = 9785828 × 28.50 = £ 278,896,098. → ①
≃ £280 million.

Construction cost = £ 1,300,000 → ②

Running cost £0.45 million × 8 years = £ 3,600,000 → ③

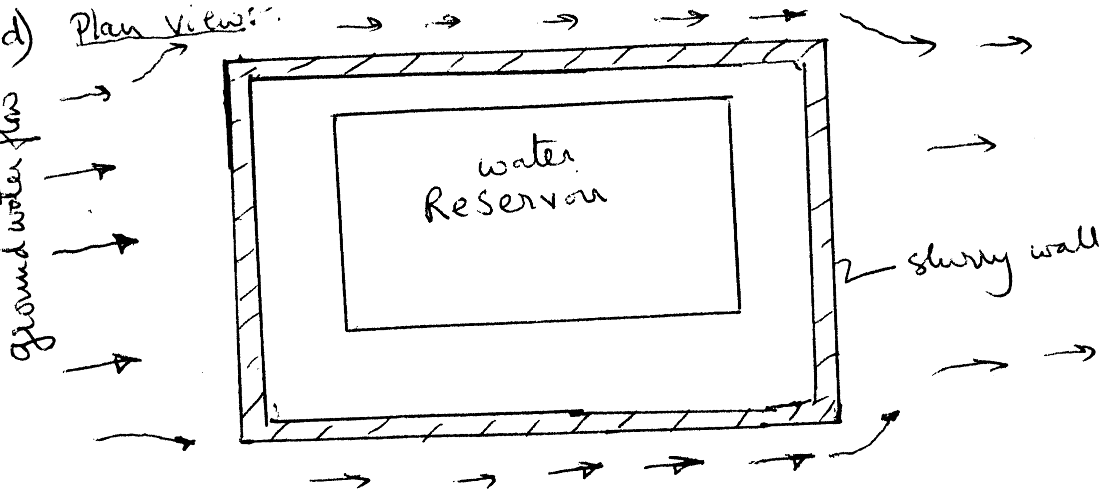
$\therefore$ Net profit = ① − (② + ③) = £ 273996098.

iv) Landfill tax £8/ton × 9785828 = £ 78286624 ≃ £79 million.

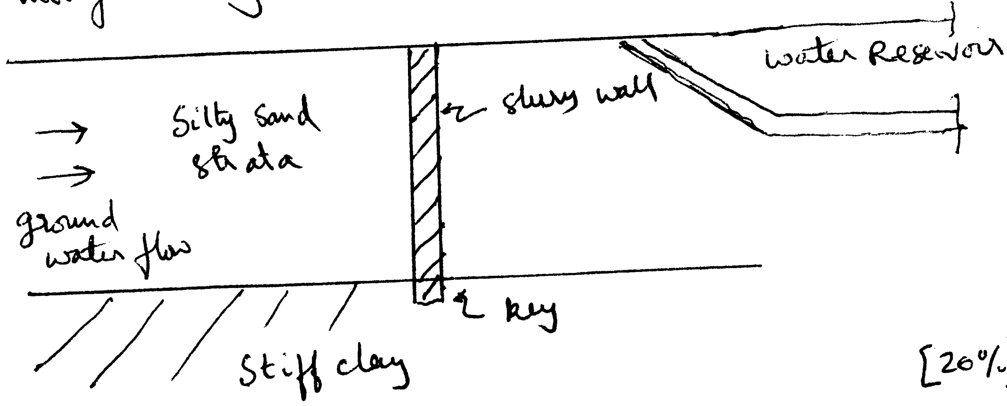
[40%]

4 d) The soil surrounding the water reservoir has sandy-silt strata overlying a thick clay stratum. The slurry walls should therefore go through the sandy-silt strata and be keyed by 2-3 ft into the clay layer. The barrier can be as shown in following sketches.

4 d) Plan view:



section through slurry wall.



[20%]

3 a) Geosynthetic materials used in the design of landfill components include Geotextiles, Geomembranes, Geo-nets, Geo-Grids, and Geosynthetic clay liners (GCL's). High density Polyethelene (HDPE) is used in the manufacture of most of these Geosynthetics.

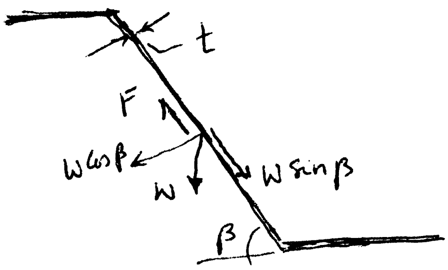
Geo-membranes and GCL's are used in preventing the leachate from landfills escaping into the ground water and therefore constitute barrier systems. They are not structural members. On the other hand geotextiles, Geogrids are used as structural members and are designed to carry loads induced in the landfill components.

[20%]

3. b) Estimation of Self-weight Stress:

Total weight of the geomembrane per metre width } $W = \frac{15\,m}{\sin 70} \times 1 \times 18 \times 9.81$

$= 2.818\ kN/m$



$\sigma_{self\text{-}weight} = \frac{W \sin\beta - F}{1 \times t}$

where F is Frictional force/m
t is thickness of geomembrane

Friction angle between geomembrane & clay liner $\delta_L = 9°$

Frictional force F/m $= W \cos\beta \tan\delta_L$

$= 2.818 \times \cos 70° \times \tan 9°$

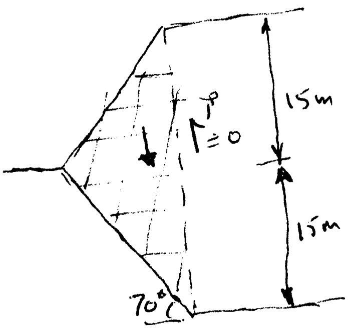
$= 0.1527\ kN/m$

$\therefore\ \sigma_{self\text{-}weight} = \frac{2.818 \times \sin 70° - 0.1527}{1 \times 0.004}$

$= 624\ kN/m^2 = 0.624\ MPa$ [20%]

3. c) Down drag stress:

Assume that the shear strength of the waste is negligible. This is a conservative assumption. The shaded Δle will contribute to the down drag stress.



width of the Δle = 15 m × Tan 20°

= 5.46 m

Area of the Δle = $\frac{1}{2} \times 30 \times 5.46$

$= 81.893\ m^2$

3 c) Weight of the waste in shaded ole

$= \gamma_w \times \text{Area} = 6 \text{ kN/m}^3 \times 81.893 \text{ m}^2$

$= 491.36 \text{ kN/m}$

Down drag stress $\sigma_{Down} = \dfrac{W_{waste} \times \cos\beta \cdot \tan\delta_u}{1 \times t}$

$= \dfrac{491.36 \times \cos 70^\circ \tan 6^\circ}{1 \times 0.004}$

$= 4.418 \text{ MPa}$.

Note additional friction generated on the underside of the geomembrane due to downdrag is neglected in this calculation.

Total stress in the geomembrane $= \sigma_{self} + \sigma_{downdrag} = 0.624 + 4.415$

$= 5.039 \text{ MPa} < 13.8 \text{ MPa}$ (Yield stress for geomembrane.)

OK

In the above calculation, the shear strength of waste was neglected. This is a conservative assumption. The shear strength of waste will resist the settlement of the waste and therefore reduces the downdrag stress.

The magnitude of this reduction in downdrag stress can be estimated if the shear strength of waste is known and an estimate of the horizontal effective stress can be made, in other words if the co-efficient of earth pressure can be measured or estimated.

[30%]

3 d) The siting criteria used for locating underground injection wells are

1) The presence of a water bearing zone of non-beneficial use (saline or economically of little value) that is of sufficient thickness and lateral extent.

2) The above layer must have sufficient porosity and permeability to accept the waste at the required rate.

3) Confinement of the waste receiving zone both above and below by impermeable zones of sufficient thickness and lateral extent.

4) Absence of faults, fractures, joint systems that could result in migration of waste into other acquifers.

The radial extent of the disposed waste can be estimated using volumetric method.

Volume of Injected waste $V = \pi r^2 b n$.

where r is radial extent, b is thickness of the layer & n is porosity.

Using above equation $r = \sqrt{\dfrac{V}{\pi b n}}$

The injected waste will of course undergo dispersion. The above radius can be corrected for dispersion as

$$r' = r + 2.3\sqrt{D_d \cdot r}$$

where D_d is the Co-efficient of dispersion. (about 1m for sandstone).

[30%]
