1.

(a) Arithmetic sample mean of y(=logx) values = 1.16

Standard deviation of y values Sy = 0.2046

Outlier test statistic T = (log(35)-1.16)/0.2046 = 1.86

T = 1.86 is less than the 10% critical value of 1.91 (see Databook). Hence, the largest number of 35 mg/L is not an outlier.

(b) t value for n = 8 is 1.895 from Databook.

US_{95} = X + ts/sqrt(n) = 16.1 + (1.895)(8.7)/sqrt(8) = <u>21.9 mg/L</u>

(c) The maximum solubility of PCE is 150 mg/L from Databook. The measured ground water concentration is around 16 to 22 mg/L. This is more than 10% of the maximum solubility. Hence, it is likely that the free phase of PCE exists near the leakage area.

(d) The octanol-water partition coefficient of PCE is logKow=2.6 from Databook.

LogKoc = 1.00 logKow -0.21 = 1.00 x 2.6 – 0.21 = 2.39.

Hence, Koc = 245.

The partitioning coefficient Kp is then estimated Kp = focKoc = 0.02 x 245 = 4.9.

Using the linear isotherm model, X = KpC = 4.9 x 21.9 = <u>108 mg/Kg</u>.

(e) The Darcy's velocity is v = Ki = 40 x 0.01 = 0.4 m/day.

Retardation factor R = 1 + (ρ_d)Kp/ϕ = 1 + 1.8 x 4.9/0.4 = 22.05.

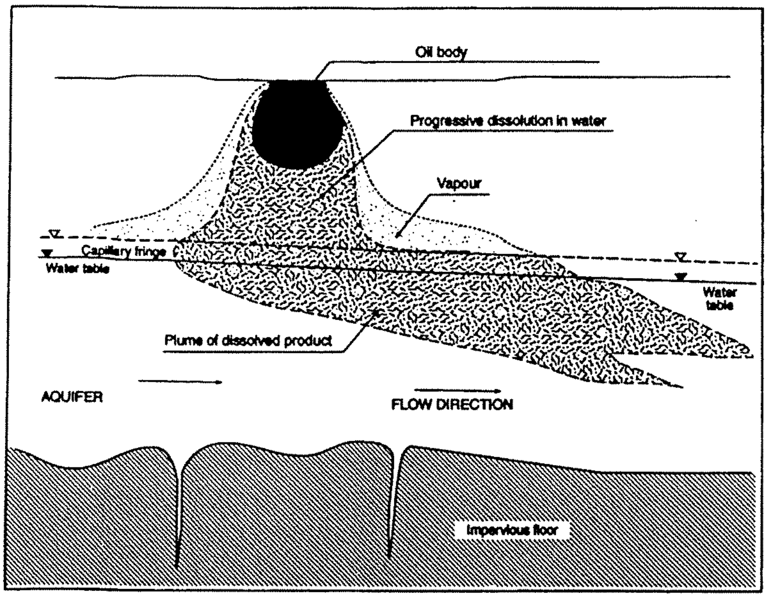
The average PCE velocity is 0.4/22.05/0.4 = 0.045 m/day.

Therefore, the distance traveled after 20 years is 0.045 x 20 x 365 = <u>328.5 m</u>.

2.

(a) Gasoline includes complex mixture of relatively volatile hydrophobic hydrocarbons with 4 to 12 carbon atoms. They are aliphatics, aromatics and additives. The concentration of benzene can be 1 to 4%, whereas that of toluene can be 3 to 20%.

(b)



Transport in the unsaturated zone

(c) Ingestion of drinking water, inhalation of vapours, dermal exposure of contaminated soils, ingestion of homegrown products, inhalation of particulates and ingestion of soils.

(d) Soil vapour extraction and air sparging.

(e) Pump and treat, reactive barrier and phytoremediation.

(f) From Databook, the properties of benzene are

Henry's constant H = 5.55 atm/M

Molecular weight = 78.1

Gas concentration P = 2000 ppmV = 2000×10^{-6} atm = 2×10^{-3} atm.

Using Henry's law, the concentration in soil moisture C = P/H = $2 \times 10^{-3}/5.55$ = 3.6×10^{-4} M.

Convert this to mg/L.
3.6×10^{-4} (M)= 3.6×10^{-4} (mol/L) x 78.1 (g/mol) x 10^3 (mg/g) = 28.2 mg/L.

(g) Gas concentration P = 2000 ppmV = 2000 x 78.1/24.5 (mg/m^3) x 10^{-3} (m^3/L) = 6.38 mg/L.
Mass of benzene inhaled = 6.38 (mg/L) x 2 (m^3) x 10^3 (L/m^3) = 12660 mg.
Mass of benzene ingested = 1000 (mg/kg) x 1.8 (g/cm^3) x 10 (cm^3) x 10^{-3} (kg/g) = 18 mg.
Hence, Inhalation >> Ingestion.

Answers

3. (a). What are the main design criteria for a domestic waste landfill? *Give at least five.*

(20%)

To provide safe storage for solid waste,
Protect human health and the environment;
Separate waste from animals, insects and rodents
Minimise infiltration of rainfall into the waste
Promote good surface drainage
Resist erosion
Restrict landfill gas migration

(b) Which geotechnical materials would you choose for constructing (i) the base liner (ii) the batter (slope) liners; and (iii) the top cover of the landfill. Assume that the underlying soil is predominantly silty sand.

(20%)

(i) From the top (below the waste): sand to protect filter (optional); geotextile filter; granular leachate collection layer; geomembrane, typically 60 mil (1.5mm) HDPE; low permeability soil (clay or bentonite / sand mixture), $K < 1 \times 10^{-9}$ m/sec, at least 600 mm thick. It may be described as a composite base liner, with these components, starting with geotextile filter, and ending with low permeability soil. The low permeability soil may be descibed as compacted clay liner.

(ii) Batter liners: Same as for base liner, but optionally it may not contain a leachate collection layer.

(iii) Top cover: from the top: vegetative soil;
flexible membrane liner, minimum 20 mil (0.5mm) HDPE, (or LDPE which is more flexible),
Infiltration layer (hydraulic barrier) $K < 1 \times 10^{-7}$ m/sec;

(c) What additions to the design would be necessary if the landfill were to be used only for hazardous waste?

(20%)

Additional secondary leachate collection system and another geomembrane, which is underneath the primary geomembrane.

(d) Assuming that the batter (side slope) angle is limited by the operation of the construction plant to 1 in 2.5, sketch an approximate design for a landfill which would be appropriate for disposing of waste from a town over a five year period. The volume of waste for landfill in the first year is estimated to be 100,000 m^3; and assume a 3 % annual reduction for the remaining time. Assume the depth of waste to be 20 m.
(Sketch a section and a plan view).

(40%)

Total volume of waste in 5 years:

$$10^5 \left(1 + 0.97 + 0.97^2 + 0.97^3 + 0.97^4\right)$$

$$= 470,886 \ m^3$$

The height of the landfill is 20 m

∴ approx area of landfill : $\frac{470,886}{20} = 23544 \ m^2$

$= (153.4)^2$

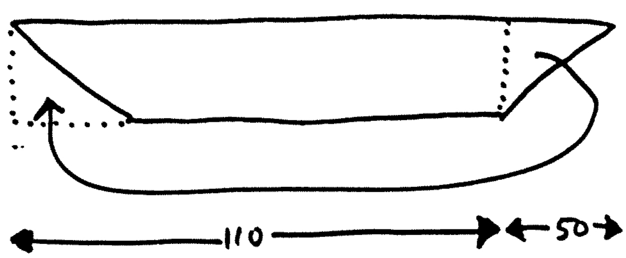
This area could be a square of 153 × 153, or perhaps a 2 × 1 rectangle. Area $2x^2 = 23544$.

$\therefore x = \sqrt{11772} = 108.5 \ m$

This is approximately a rectangle of 110 × 220 m, if sides were vertical. The side slopes are 1 in 2.5, so if height is 20 m

Y = 50 m.

Because the sides are sloping the area will be larger than 110 × 220, by 50 m extra, on both the length and the width.



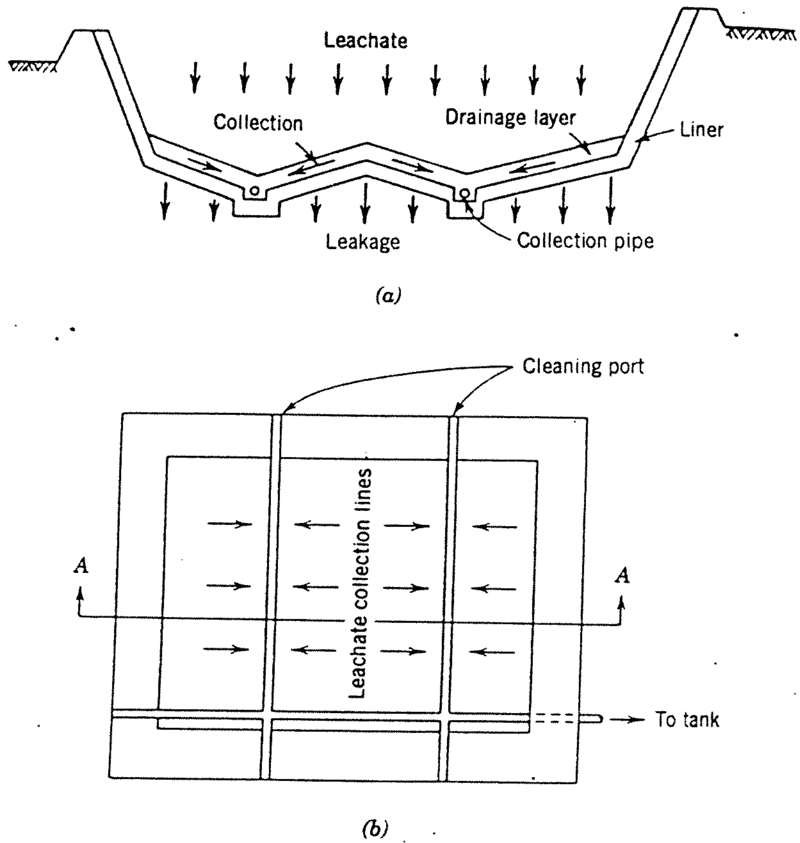
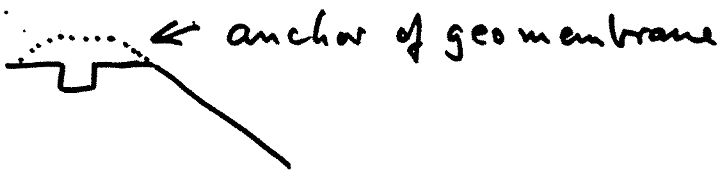


Figure 9.2 Typical LCRS layouts. (From Bagchi, 1990.)



OR

4 *(a) During the construction of a landfill, the composite base liner was unfortunately damaged, resulting in a 1 cm^2 hole in the membrane. However, it is reasonable to assume that the membrane remained in good contact with the lower layer. If the leachate was maintained at 1 m above the membrane, estimate the leakage flow rate (in m^3 / day) which is likely to result from this defect. Assume that the hydraulic conductivity of the lower layer is 1×10^{-9} m/ sec.*

[30%]

Leakage flow rate through hole in liner $Q = 0.7 \times a^{0.1} \times K^{0.88} \times h$ (from Data Book)

$$= 0.7 \times (10^{-4})^{0.1} \times (10^{-9})^{0.88} \times 1$$
$$= 3.3 \times 10^{-9} \text{ m}^3/\text{s}$$
$$= 2.89 \times 10^{-4} \text{ m}^3/\text{day}$$

(b) Analysis of the leachate in the landfill showed that the concentration of copper was 500 times greater than the level of the drinking water standard. Is the leak likely to pose a threat to the quality of groundwater passing underneath the landfill in the sandy sub-soil? Discuss this by comparing the relative flow rates of leachate leakage and groundwater. The approximate width of the landfill is 100 m; the depth of the sandy soil stratum is 5 m; the hydraulic conductivity in this layer is 1×10^{-4} m/sec; the difference in water level in two boreholes which are down gradient from the landfill, and 50 m apart is 0.75 m.

[35%]

Cross-sectional area of "aquifer" under the landfill: 100 x 5 = 500m^2
Flow rate in aquifer Q = A K i
hydraulic gradient, i = 0.75 /50 = 0.015
$Q = 500 \times 1.10^{-4} \times 0.015$ $m^3/s = 7.5 \times 10^{-4}$ m^3/s

Compare the leachate leakage and aquifer flow rates:
Leachate flow rate/ Aquifer flow rate = $\frac{3.3 \times 10^{-9}}{7.5 \times 10^{-4}} = 4.4 \times 10^{-6}$,

equals 1 part in 227,272

The leakage is very small in comparison with the groundwater flow. The leachate requires only a dilution of 500 to reduce the copper concentration to drinking water standard. If the dilution process is estimated (very crudely) to follow the ratio of the aquifer to leakage flow rates, 227,272, the copper level should be well below the drinking water limit. (227,272 / 500 = 454 times lower than the drinking water limit) *(c) What remedial action may be taken to prevent an old leaking landfill site from contaminating a water abstraction borehole situated about 1 km down gradient? Sketch a possible solution and explain its function.*

(35%)

- slurry wall, slurry trench – bentonite/soil or bentonite/cement – low permeability barrier.