

4D14 Contaminated Land and Waste Containment Systems

Cribs 2015/2016

1 a) Waste can be classified based on its origin as follows;

- i) Municipal Solid Waste or Commercial waste – Examples include food waste, paper, paint
- ii) Municipal Liquid waste – Waste water – Examples include bleach, de-scalers etc.
- iii) Agricultural Waste. Examples include fertilisers, pesticides, insecticides etc.
- iv) Industrial Waste. Waste depends on type of industry. Examples for Steel industry may be Ferrous oxides, Calcium oxide, Silicone dioxide etc.

[10%]

1 b) Top cover liners are used to cover the landfill cells that are filled up. The main function of top cover is to prevent the infiltration of rainfall into the landfill and prevent the outward flow of landfill gases.

Design Criteria

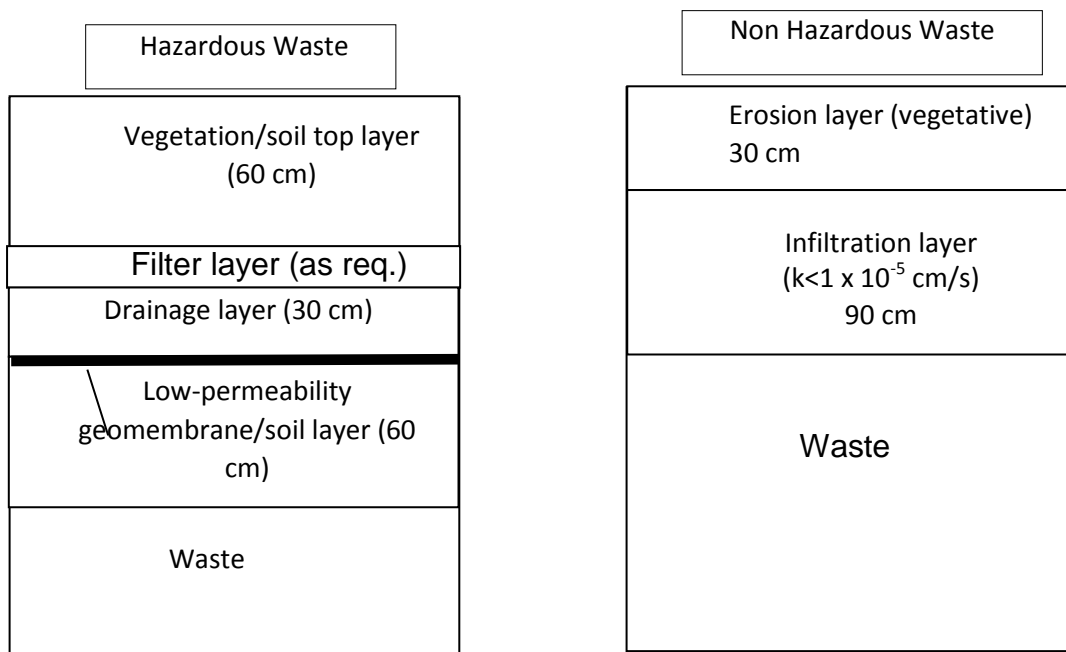
- Minimise infiltration of rainfall into the waste
- promote good surface drainage
- Resist erosion
- Restrict landfill gas migration
- Separate waste from animals, insects and rodents
- Protect human health and the environment

[15%]

1 c) The top cover design specification changes depending on type of waste. For landfills that receive hazardous waste the top cover design is thicker with higher specification. For non-hazardous waste landfills the top cover can be thinner.

Top Cover Specification

(Dimensions for depth of cover given in brackets in each figure)



[15%]

1 d) i) The hydraulic gradient $i = \frac{d\bar{h}}{ds} = \frac{2.75}{20} = 0.1375$

Darcy velocity $= v = K i = 3.2 \times 10^{-4} \times 0.1375 = 4.4 \times 10^{-5} \text{ m/s}$

Intrinsic velocity $v_f = \frac{v}{n}$

Void ratio $e = 0.6$

Porosity $n = \frac{e}{(1+e)} = \frac{0.6}{1.6} = 0.375$

$\therefore v_f = \frac{4.4 \times 10^{-5}}{0.375} = 1.1733 \times 10^{-4} \text{ m/s}$

Time taken for spillage to reach the water reservoir =

$$t = \frac{1200}{1.1733 \times 10^{-4}} = 10.22 \times 10^6 \text{ s or } \mathbf{118.37} \text{ days}$$

This is obviously too quick and therefore there is a serious concern about any accidental spillage from the petro-chemical factory reaching the water reservoir. [20%]

1 d) ii) From the above part, some remedial measures will be required to protect the water reservoir. One option is to have abstraction wells downstream of the chemical factory so that any contaminant can be removed from these wells. However, there will be some risk of contaminant getting past the abstraction wells. A more permanent solution would be to construct a slurry wall.

[10%]

1 e) i) Thickness of the slurry wall = 1m = 1000 mm

Backfill permeability $k_b = 3.3 \times 10^{-8} \text{ m/s}$

Filter cake permeability $k_c = 1.8 \times 10^{-9} \text{ m/s}$

Overall hydraulic conductivity =

$$k = \frac{t_b}{\left(\frac{t_b}{k_b}\right) + 2\left(\frac{t_c}{k_c}\right)} = \frac{1}{\left(\frac{1}{3.3 \times 10^{-8}}\right) + 2\left(\frac{0.003}{1.8 \times 10^{-9}}\right)}$$

$k = 2.973 \times 10^{-8} \text{ m/s}$ [15%]

ii) Darcy velocity $v = K i = 2.973 \times 10^{-8} \times \frac{0.75}{20} = 1.115 \times 10^{-9} \text{ m/s}$.

$\therefore v_f = \frac{1.115 \times 10^{-9}}{0.375} = 2.973 \times 10^{-9} \text{ m/s}$

$t = \frac{1200}{2.973 \times 10^{-9}} = 403.64 \times 10^9 \text{ s or } \mathbf{12799.23} \text{ years i.e. a very long time.}$

In reality, once the slurry wall is constructed the ground water flow regime can change. [15%]

Examiners comments: This question tested the candidates on their knowledge of waste classification, hazardous waste disposal and contaminant transport. Most popular question and was answered well by most candidates. Generally a straight forward question with part description and part calculations. The second part was done well. Loss of marks in the first half was mainly due to incomplete descriptions. In the second half a surprising number of students did not calculate the porosity given the void ratio of the soil.

2. a) The Ocean water is stratified due to variations in density, temperatures and salinity with depth. Circulation of water at shallow depth is effected by waves which depend on the prevailing wind conditions. Salinity is high here due to evaporation. The zones of rapidly changing temperature or density are called thermoclines or pycnoclines.

Dissolved oxygen content also reduces from shallow waters to deep waters.

Between 150m to 1000m relatively, low dissolved oxygen exists. This level is referred to as 'oxygen minimum zone'. Two important considerations regarding considering the ocean as a waste repository are;

- permanent pycnocline and
- oxygen minimum zone.

[10%]

2 b) Waste disposal schemes must consider the location of the dump site and determine its extent of spread following waste deposition.

Continental Shelf

Continental shelves are shallow platforms adjacent to land masses.

Ocean floor here is characterised by irregular topography with banks, basins and valleys.

Total width is around 75 km.

The depth here ranges from 100 m to 200 m.

Continental Slope

This is the region between the Deep Ocean floor and the continental shelf.

Their width ranges from 20 km to 100 km.

They cover about 10 to 15 % of earth's surface.

Deep Ocean Regimes: These include

Abyssal Plains

The Ocean floor under the deep waters which are nearly flat and are called the Abyssal plains.

These are sedimentary deposits consisting of

- a) pelagic clays
- b) hemipelagic muds
- c) calcareous oozes
- d) turbidite deposits

Stratification is very variable in these regions. Deep seated faults may exist with possible tectonic activity. Also thermal activity may be present.

Abyssal hills

Relatively small hills on Abyssal plains with slopes ranging from 1 to 15%.

May adversely affect the range of area through which waste deposited can migrate.

The deposited waste may be affected by physical and chemical processes.

[15%]

2 c) The following provide some guidance on Siting of high level radio-active waste repository

- Suitable host rock must be identified
- The host rock must have sufficient thickness with
 - a) high degree of homogeneity
 - b) must occur as a stratified unit or non-bedded rock mass
- The lateral extent of the host rock must be continuous over several square kilometres accommodating the actual repository as well as sufficient buffer zone

- The site must have high degree of predictable geological stability such that it is not effected by
 1. erosion effects
 2. uplift
 3. frequent (or strong) seismic activity during the 'period of concern'.

[10%]

2 d) One of the most popular Rock Salt formation for hazardous waste containment is domal salt. For this the advantages and disadvantages are as below:

Advantages:

- Essentially homogeneous since the process of formation includes displacement due to buoyancy (density driven flow), plasticity mechanism during dome development.
- Intrabed sedimentary layers, which may act as path ways for water are absent in this type of formation.
- Roof cave-ins are absent
- Relatively dense and impermeable due to repeated stages of recrystallisation during formation
- Geologically stable on the order of millions of years
- Nonreactive material and is not expected to react with solidified hazardous waste.

Disadvantages:

- May contain naturally occurring brine solution
- Rock salt is more soluble than other potential host rocks by at least two orders of magnitude.
- Inadvertent leakage of water into the repository may have serious consequences
- The brine solutions, when occurring, may migrate towards the radioactive canisters. This may result in corrosion of the canisters exposing the radioactive waste.
- If toxic wastes are stored in these sites, the chemical compatibility of the waste and the rock salt must be investigated.

[15%]

2 e) LCRS Analysis:

Total rainfall over the top cover of the landfill = $250 \times 400 \times 0.65 = 65000.m^3$

Assume that 10% of this ends up as leachate in the landfill:

$$= 0.1 \times 65000 = 6500.m^3$$

Also let us say that leachate produced in the landfill will be of similar order as this.

Therefore, Total volume of leachate = $2 \times 6500 = 13000.m^3$

We need to find the head of leachate created at the base of the landfill to ensure that the thickness of the drainage layer is sufficient. If the landfill was empty then the head of water created at the base will be:

$$= \frac{13000}{250 \times 400} = 0.13.m$$

However, the landfill is filled up with waste, consequently there will a head of leachate higher than this (as all of the liquid has to be accommodated in the voids between the solids).

Porosity of the waste $n = 0.5$

$$n = \frac{v_v}{V} = 0.5 \quad \therefore V = \frac{v_v}{0.5}$$

The height to which the leachate will rise above the base of the drain will be

$$h = \frac{0.13}{0.5} = 0.26.m = 26.cm + 5.cm = 31cm < 50cm ; \text{ so OK}$$

Therefore, the given depth of the base drain of 0.5 m is sufficient.

Calculation of spacing of the drainage pipes:

Drainage layer has a permeability = $k = 5.5 \times 10^{-2}.m/s$

Flow can be calculated as ;

$$Q = \frac{13000}{365 \times 24 \times 3600} = 4.1223 \times 10^{-4}.m^3/s$$

Assuming uniform flow rate across the breadth, we can find the flow rate:

$$q = \frac{4.1223 \times 10^{-4}}{400} = 1.0306 \times 10^{-6}.m^2/s$$

Let us say that the maximum height of the leachate is allowed reach is equal to the thickness of the drainage layer i.e. 0.4 m (i.e. 10 cm below the surface of the drainage layer).

For our problem,

$$h_{\max} = 0.4.m$$

Therefore, from the data sheets;

$$L = 2 \times h_{\max} \times \sqrt{\frac{k}{q}}$$

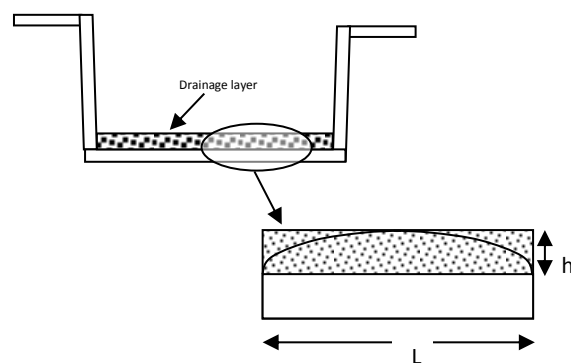
$$L = 2 \times 0.4 \times \sqrt{\frac{5.5 \times 10^{-2}}{1.0306 \times 10^{-6}}} = 184.8.m$$

Let us choose, a drainage pipe spacing of 200 m. i.e. 2 pipes for 400 m width.

Pipe Size:

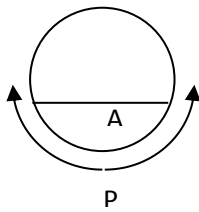
Flow $Q = 4.1223 \times 10^{-4}.m^3/s$. This is carried in two pipes. Therefore each pipe carries a flow of $= 2.06115 \times 10^{-4}.m^3/s$.

Choose HDPE pipe, so that Manning's constant $n = 0.009$



Limit the velocity of flow in the pipes to 0.25 m/s.

Also the pipes are allowed to run quarter-full. Assume a slope of 1/1500 along the breadth direction (remember the flow in these drainage pipes is under gravity and they are not designed to run full normally).



$$V = \frac{1.486}{n} R_h^{2/3} \cdot S^{1/2}$$

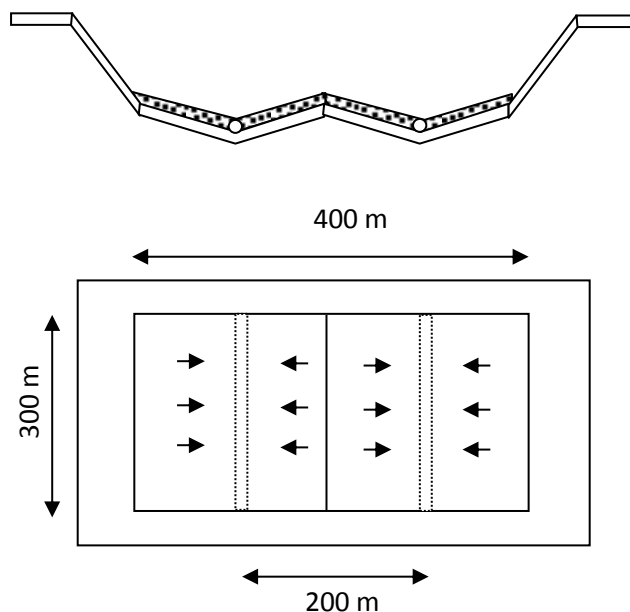
$$R_h = \frac{A}{P} = \frac{\pi \cdot r^2 / 4}{\frac{\pi \cdot r}{2}} = \frac{r}{2}$$

Limiting velocity in the pipe = 0.25 m/s

$$0.25 = \frac{1.486}{0.009} \left(\frac{r}{2}\right)^{2/3} \cdot \left(\frac{1}{1500}\right)^{1/2}$$

$$\text{Radius} = r = 0.028\text{m}$$

Choose a pipe with a diameter of 60 mm.



[50%]

Examiners comments: A question that covered different areas. The first half was descriptive and more challenging than the second half, which was mainly calculations. Most students did much better in the first half than the second. The first half requires a siting criteria & suitability of rock formations for hazardous waste repository; many students presented part of the answers required and were rather vague. The second part required the students to carryout design of a Leachate collection and removal system. Some students made numerical errors in design calculations but most students managed to produce a reasonable design

3

(a) i. Physical integrity of the cut-off wall has been compromised, due to cracking, shrinkage, of the cement-bentonite mix over time
ii. effect of contaminants on wall material leading to degradation of the wall material,
iii. The keying into the bedrock was not effective, hence contaminants leaking from underneath the wall
iv. Wall not constructed well, hence weak permeable sections, lumps of soil present within the wall.
v. Extent of original contamination on the site not located properly so the wall is constructed within the contaminated soil.
vi. Contamination from elsewhere, not related to the site contamination. [20%]

(b) i. The high pH environment of the cement-based cut off wall suggests that the heavy metals were immobilised within the wall material and that the wall was not able to immobilise the organics.
ii. Cement-bentonite alone is not suitable for immobilising a wide range of organic contaminants.
iii. The contaminants are from a different source outside the site boundary. [10%]

(c) i. Chemical or biological degradation of the original organic contaminants into daughter compounds.
ii. Contaminants were not originally analysed as part of the site investigation.
iii. The contaminants are from a different source outside the site boundary. [10%]

(d) i. Investigate further the location, depth and concentration of the contaminants on both sides of the wall to assess whether the external contamination is related to the contamination within the site boundary or is from a separate source. Do site sampling and analysis at different depths and for both heavy metals and organics.
ii. Investigate the integrity of the wall, both in terms of potential leakage through the wall or due to keying into the underlying bedrock issues. [15%]

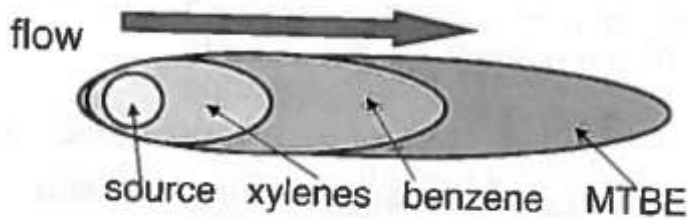
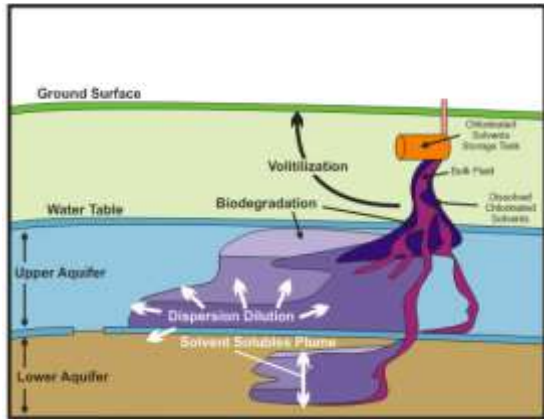
(e) i. Sampling frequency and extent and pattern, based on the previous study and details of the detected contaminants outside the site boundary.
ii. Standard of soil sampling and collection technique
iii. Sampling preservation prior to arrival in laboratory
iv. Selection of most appropriate test method
v. Stated precision of laboratory test method
vi. Application of appropriate level of QA to all aspects of the process of sampling and analysis. [20%]

(f) In the ICRCL suite there is limited number of heavy metal and organic compounds. Some contaminants on the site maybe not detected as a result. Threshold and/or Action Trigger concentrations from the ICRCL might be superseded and hence not applicable any more. [10%]

(g) Repair to the cut-off wall if the damage can be identified and is localised. Strengthening of the whole wall if it is suspected that the construction was faulty to minimise problems elsewhere. Construction of a new in-situ wall in front of the existing wall, which is properly keyed into the bedrock. Do some bioremediation for the organic contaminants on the site to remove some of the contamination, if the level of the heavy metals is not high enough to be toxic. [15%]

Examiners comments: A question of many parts on various aspects of contaminated land, assessment of contamination through field sampling etc.: their properties. This was the least popular question but most students who attempted this question produced a reasonable set of answers.

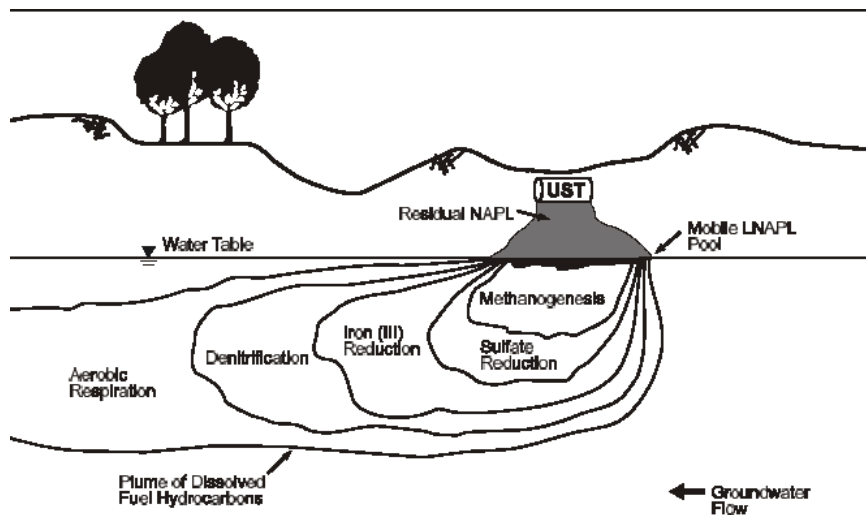
4. (a) Given the complex multi-compound (~100) nature of petroleum products consisting of gasoline, diesel, kerosene, heating oils and lubricating oils, they all have different chemical and physical properties that results in them separating and segregating into the soil and groundwater environment. This happens because of their different solubility, volatility and sorption capacity to soil. It also depends on the nature of the soil stratigraphy, the permeability of the different soil strata and the groundwater conditions. [20%]



(b). Examples of a reaction of process in each zone:

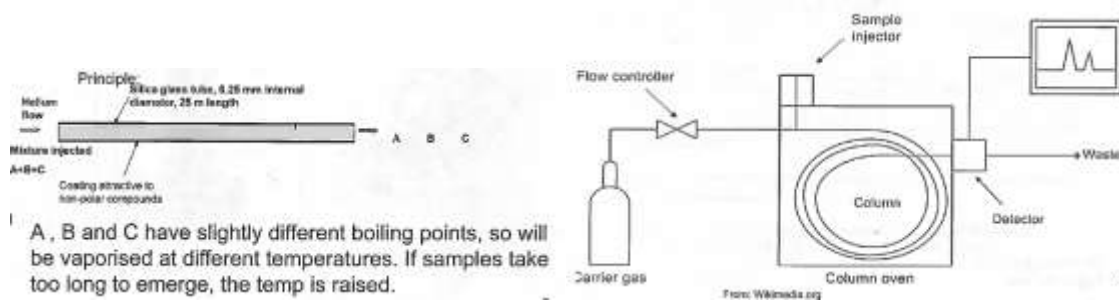
- (i) Aerobic reaction: oxidation leading to complete degradation: $C_6H_{14} + 9.5 O_2$ forming $6CO_2$ and $7 H_2O$.
- (ii) Nitrate reduction to nitrogen
- (iii) Iron reduction – iron III to iron II
- (iv) Sulphate reduction to hydrogen sulphide
- (v) Methanogenesis – carbon dioxide reduction to methane

[20%]

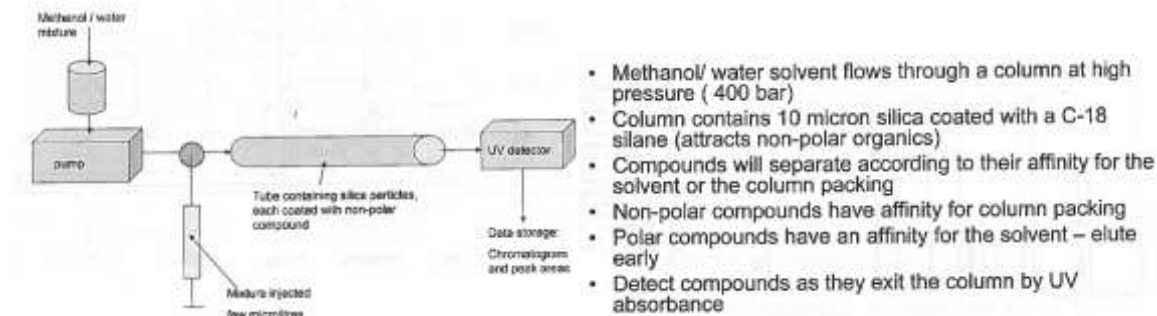


(c) The two analysis methods could be gas chromatography and liquid chromatography as described below:

Gas chromatography:



Liquid chromatography:



[30%]

(d) Present the pros and cons generally of each set.

(i) Combined SVE and air sparging. Typically used for such contamination, which is mainly organic and hence SVE aims to volatilise the lighter weight groups and air sparging the heavier and water soluble groups. The extent of the plume spread will need to be defined so that the extraction can be controlled. Emissions will need to be highly managed given the occupancy of the site. Could be a relatively rapid process depending on the extent of the contamination and the spread.

(ii) This is likely to be the most cost effective option than the former. Extent to which ex-situ bioremediation could be used depends on the volume of the contamination. Again technique suitable as contaminants mainly hydrocarbons for which bioremediation is generally effective. In-situ bioremediation will depend on the ground conditions, environmental conditions etc...

(iii) Monitored Natural Attenuation might be the best option, especially if the site is to remain operational. Again MNA is suitable for this type of contamination and provided that the hydrological, chemical, biological and sorption related properties are favourable, this could be a good option. Again it all depends on where the receptors are: the site workers would require separation from the contamination. Any other receptions outside the site will also need consideration.

Best way to decide on the most appropriate technique is to conduct a cost-benefit analysis taking into account all the relevant requirements in terms of cost, timescale and remediation objectives and targets and then perform a multi-criteria analysis, and cost-benefit analysis if feasible, to compare the monetary, environmental and wider economic and societal impacts. [30%]

Examiners comments: This is a reasonably popular question on LNAPL and DNAPL transport in ground with good students producing excellent descriptions of transport of hydrocarbons, the factors that influence the transport distances and compounds that will be formed under aerobic and anaerobic conditions. Most candidates however produced very poor quality sketches in part a) and b) but could explain the relative merits of using various clean up strategies in part d). Part c) was done rather poorly by many candidates with insufficient descriptions of gas/liquid chromatographic methods.