

2a) Waste generated in a residential community can be classified as Municipal solid waste (MSW) and Municipal waste water.

Municipal solid waste can be further classified as non-hazardous waste & Hazardous waste. The method of disposal is landfilling, incineration or specialist treatment may depend on this classification.

Municipal waste water is usually collected and treated separately from MSW, normally at a sewage treatment plant. [10%]

b) Hazardous waste can be up to 1% of all the MSW collected from residential areas. If the community has certain type of commercial outlets this can be even higher. Examples of hazardous waste in MSW include

- i) Abrasive scouring powders, Aerosols, Bleach
- ii) Furniture polish, Drain openers, Silver polish
- iii) Anti freeze, Car batteries, Kerosene, Gasoline, Paint etc [10%]

c) i) when the landfill has been closed by a well designed top cover layers, the reactions within the waste can be

- 1) Biochemical Reactions,
- 2) chemical reactions.

Biochemical reactions consist of converting complex organic compounds into simpler compounds, for

example, converting insoluble solids into water soluble substances. Soon after placing the top cover aerobic reactions take place converting organic matter into nitrates, sulphates, CO_2 & water. Once the free air is exhausted anaerobic reactions occur producing methane, ammonia, CO_2 , H_2S etc.

Chemical reactions can be classified as neutralisation reactions, precipitation reactions and reduction reactions.

1c ii) When the waste comes into contact with the clay liner along the side slopes or base of the landfill it interacts with clay minerals. Kaolinite, Illite or Montmorillonite. The main concern is that the contaminant can alter (often increase) the hydraulic conductivity of the clay liner by several orders of magnitude. The clay structure may change due to cation exchange or by replacement of water by percolating or organic fluids. Na, K, Ca & Mg ions can be attracted to the clay minerals sorbing preferentially and there by changing the clay structure. This leads to a change in the hydraulic conductivity of the clay liner.

[30%]

Q1d) Solution

Year	Population	Waste/week	Total Waste (tons)	Hazardous Waste (tons)	Non-Hazardous Waste (tons)
2012	25000.00	30	39000.00	4333.33	34666.67
2013	26500.00	30	41340.00	4593.33	36746.67
2014	28090.00	30	43820.40	4868.93	38951.47
2015	29775.40	20	30966.42	3440.71	27525.70
2016	31561.92	20	32824.40	3647.16	29177.25
2017	33455.64	20	34793.87	3865.99	30927.88
	Sum		222745.08	24749.45	197995.63

1d) i) Unit Weight= 7.5 kN/m³
 Volume= 258714.29 m³
 Size = 150 m x 100 m x 20m

300000 > 258714 m³ So OK

1d) ii)

Non Hazardous Waste Revenue =	£5,543,878
Hazardous Waste =	1,534,466.12
Total=	7,078,343.72

1d) iii)
 Landfill tax revenue

Non Hazardous Waste Revenue =	989,978.14
Hazardous Waste =	371,241.80
Total =	1,361,219.95

SPG.M

2 a) Thickness of geomembrane = 6 mm
 Consider a 1m wide strip

$$\begin{aligned} \text{Weight/Mass of geomembrane/m}^2 &= 24 \text{ kg/m}^2 \\ &= 235.2 \text{ N/m}^2 \end{aligned}$$

$$\therefore \text{Weight of 1m wide strip} = W = \frac{10}{\sin 45^\circ} \times 1 \times 235.2$$

$$W = 3.326 \text{ kN/m}$$

Tensile stress in the geomembrane

$$\sigma_T = \frac{W \sin \beta - F}{l \times t}$$

where F is the frictional force

$$F = W \cos \beta \cdot \tan \delta_p$$

$$= 3.326 \cos 45^\circ \tan 12^\circ = 0.5 \text{ kN/m}$$

$$\therefore \sigma_T = \frac{3.326 \sin 45^\circ - 0.5}{0.006 \times 1} = 308.6 \text{ kPa} \quad \text{or } 0.31 \text{ MPa} \quad [15\%]$$

2 b) Down drag stress.

Assumptions: 1) The shear strength in the waste does not contribute to a reduction in down drag stress (conservative)

2) The area above the down slope region contributes to the down drag of the geomembrane

$$\begin{aligned} \text{Weight of the waste} &= \left[\frac{1}{2} \times 10 \times 10 + \frac{1}{2} (10 + 1.34) \times 15 \right] \times \gamma \\ &= 945.35 \text{ kN/m} \end{aligned}$$

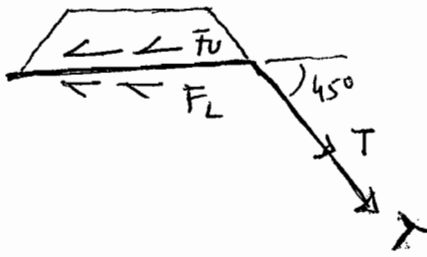
$$\begin{aligned}
 (\sigma_T)_{\text{down drag}} &= \frac{W_{\text{waste}} \cos \beta \cdot \tan \delta_u}{1 \times t} \\
 &= \frac{945.35 \times \cos 45^\circ \tan 5^\circ}{1 \times 0.006} \\
 &= 9747.2 \text{ kPa} = \underline{9.747 \text{ MPa}} \quad [25\%]
 \end{aligned}$$

\therefore Total tensile stress in geomembrane

$$\begin{aligned}
 &= (\sigma_T)_{\text{self weight}} + (\sigma_T)_{\text{down drag}} = 0.31 + 9.747 \\
 &= 10.057 \text{ MPa} < 13.8 \text{ MPa} \\
 &\quad \text{(Yield stress of geomembrane so OK)}
 \end{aligned}$$

iii) Design of Flat bed anchor

$$\begin{aligned}
 \text{Tensile Force in geomembrane / m} &= 10.057 \times 10^6 \times 0.006 \\
 T &= 60342 \text{ N or } \underline{60.342 \text{ kN}}
 \end{aligned}$$



Force on upper surface of geomembrane

$$\begin{aligned}
 F_u &= \sigma \tan \delta_u = 14 \times 1 \times \tan 5^\circ \times 1 \\
 &= 1.225 \text{ kN}
 \end{aligned}$$

Force on lower surface of geomembrane

$$F_L = (14 \times 1 + T \sin 45^\circ) \tan 12^\circ$$

$$\begin{aligned}
 \therefore F_L &= (14 + 60.342 \sin 45^\circ) \tan 12^\circ \times L \\
 &= 12.05 L
 \end{aligned}$$

From equilibrium consideration

$$T \cos 45^\circ = F_u + F_L$$

$$60.342 \cos 45^\circ = 1.225 + 12.05 L \Rightarrow \underline{L = 3.44 \text{ m}}$$

Use an anchorage length of 4 m. (> 3.44 OK) [20%]

Q b) Volume Balance method

i) Receptor stratum porosity $n = 0.4$; Thickness = 12 m

$$\left(\frac{V_{22}}{V}\right) = 0.4$$

$$\therefore V_{22} = 0.4 V$$

Ignoring well radius, $V = \pi \times 50^2 \times 12$
 $= 94247.8 \text{ m}^3$

Volume of voids $V_{22} = 94247.8 \times 0.4 = 37699.1 \text{ m}^3$
 $= \text{Fluid volume injected} = 37699.1 \text{ m}^3$ in 5 hours

$$\therefore Q = \frac{37699.1}{5 \times 60 \times 60} = 2.09 \text{ m}^3/\text{s} \approx \underline{\underline{2.1 \text{ m}^3/\text{s}}} \quad [20\%]$$

ii) Correction for diffusion

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

$$r = 50 \text{ m} \quad r' = 80 \text{ m}$$

$$\therefore 80 = 50 + 2.3 \sqrt{D_d \cdot 50}$$

$$D_d = 3.4 \text{ m}$$

\therefore Co-efficient of diffusion D_d for receptor stratum = 3.4 m.
In the absence of any ground water flow, and no further pumping
this is approximately equal to the coefficient of dispersivity. [20%]

SPGM

3. Cut-off low permeability walls (LPW) vs permeable reactive barriers (PRB):

(a) their function illustrated with a sketch as appropriate,

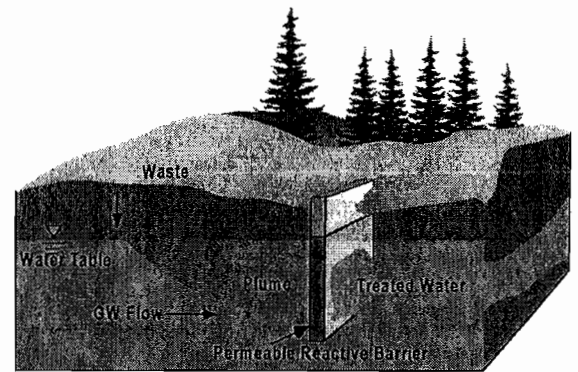
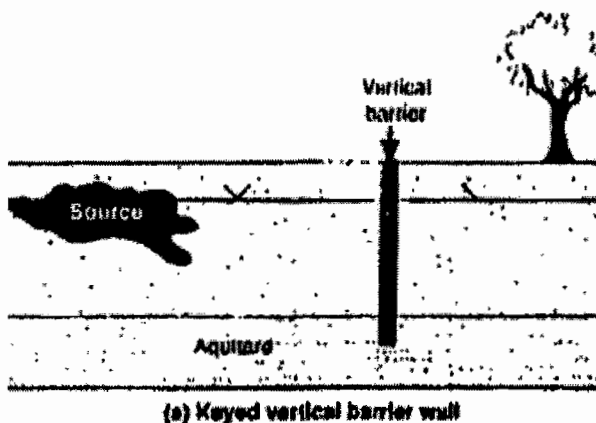
20%

LPW:

- The walls are designed to have a very low permeability hence physically isolating, prevents or limits migration of contaminants to the surrounding environment.
- Hence they interrupt the flow of groundwater out of and into the site.
- They are a containment-based remediation approach.
- An example of pathway management.

PRB:

- The walls are designed to have a permeability similar to that of the native soil, hence cause no interruption to the flow of groundwater.
- They are a treatment based approach to destroy, remove or detoxify the contaminants contained in soil and groundwater.
- Constructed permanent, semi-permanent or replacement units across the flow path of a contaminant plume. As contaminated groundwater moves passively through PRB the contaminants are removed by physical, chemical and/or biological processes including precipitation, sorption, oxidation/reduction, fixation or degradation
- An example of pathway management.



(b) the type of materials used and how their performance mechanism

20%

LPW:

- Sheet piling
- Slurries, mixtures of cement and bentonite clay, or soil and bentonite clay, to which polymers are sometimes added to improve performance
- Geomembranes

Performance of all material used is as a low permeability physical barrier.

PRB:

- Sorption barriers: Contaminants are removed from groundwater by physically trapping them as they pass by absorbent fillings e.g. zeolites, activated carbon. The contaminants remain unchanged
- Precipitation barriers: Contaminants react with treatment matrix and precipitate out. The precipitates are left trapped in the barrier and clean groundwater flow out the other side e.g. lead-saturated battery acid can be treated through a precipitation barrier filled with limestone which neutralises acid and causes lead to change to solid form and is trapped in barrier, Chromium (VI) can be reduced to immobile Chromium (III) which is trapped in the barrier
- Degradation barriers: Contaminants are broken down into to less toxic or non-toxic products as they pass through the barrier e.g. zero valent iron: iron filings are used to

degrade various VOCs via redox (oxidation-reduction) reactions. Degradation barriers may also be biologically mediated. Placement of oxygen and nutrients in PRBs can enhance microbial degradation activities

(c) their design requirements

20%

LPW:

- Design usually based on:
 - Permeability of 10^{-8} m/s or lower
 - Strain at failure, sufficient to prevent cracking
 - Durability to resist chemical attack from contaminants.
- Must be designed in the context of local hydrogeological, hydrological and climatic conditions
- For walls to be effective, they must either be keyed into a naturally occurring layer of low permeability material in the soil which in term is continuous or into an artificially created horizontal barrier
- Can be combined with hydraulic measures to control groundwater levels as part of a long-term remediation strategy

PRB:

- Must be designed in the context of local hydrogeological, hydrological and climatic conditions
- **Reactivity:** A medium that provides faster degradation time is preferred
- **Environmental compatibility:** Materials should be compatible with subsurface environment, not causing any adverse chemical reactions of by-products when reacting with contaminants – reactive materials needs to be well characterised and understood
- **Stability:** Materials should persist over a long time i.e. should not be readily soluble or depleted in reactivity – Difficult to investigate in real time - understanding of reaction mechanisms could provide indication of future behaviour
- **Availability and cost:** Material should be readily available at low to moderate cost
- **Hydraulic performance:** Material should not restrict groundwater flow – hence should not have very small particle size

(d) the techniques employed for their construction

20%

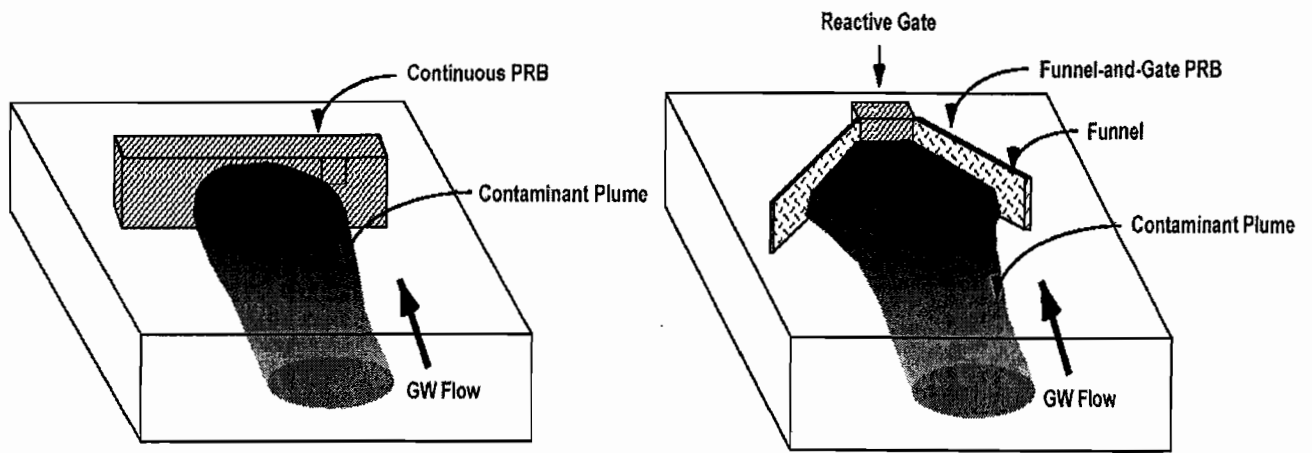
LPW:

Three implementation approaches

- Displacement – e.g. pushing in sheet walls
- Excavation and infilling – e.g. to produce a slurry wall e.g. using trenching system of soil mixing system
- Manipulation of the subsurface e.g. by freezing it

PRB:

- Continuous walls: Reactive media is placed across entire plume in excavated trenches across aquifers so that all contaminated groundwater should flow through the barrier
- Funnel and gate: Groundwater flow is manipulated using containment measures ‘the funnel’ to channel the flow towards small treatment zones ‘the gate’ The concept of gate encompasses the use of removable cassettes
- See sketches below



(e) **their long-term effectiveness including potential failure mechanism** 20%

LPW:

As wall is a physical barrier, main transport mechanism through the wall is either by diffusion (through the cement/bentonite based material) or through physical failure of the wall material i.e. physical damage e.g. cracking and deterioration. This is likely to occur in the long term but the long-term effectiveness has not been proven yet.

PRB:

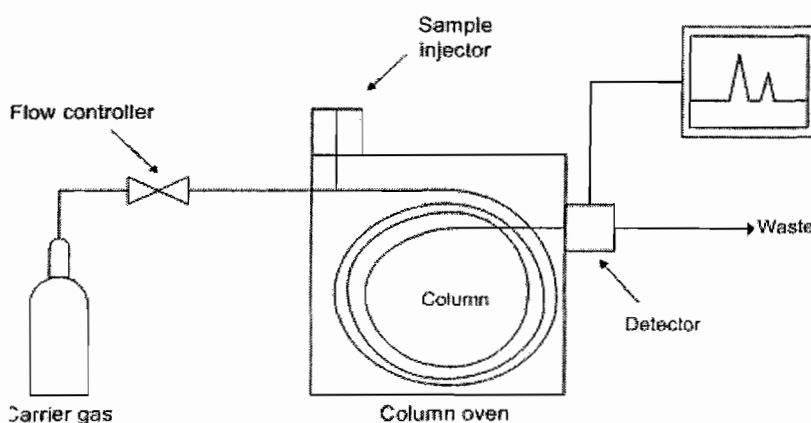
The effectiveness in the long term is linked to the effectiveness of the wall material. Typical problems are likely to be: saturation of the wall material, desorption of contaminants, change of environmental conditions leading to change in the performance of the material, non-uniform distribution of the material within the wall leading to preferential paths through the wall. The long-term effectiveness of PRB walls is not proven yet.

4. (a) Laboratory-based analytical techniques for contaminants.

[30%]

For Organics:

Gas chromatograph. Can use diagram such as:



Or description:

- ◆ A gas chromatograph separates compounds according to their volatility, (or boiling point). Samples are typically extracted from water using a solvent, or if quite volatile, just collect the vapour (the headspace) above a sample of water from the site.
- ◆ A sample is injected into a flowing stream of helium gas. It is heated and passed into a thin tube called a capillary column which has the wall coated with a material attractive to organics.

(b) Heavy metals

Metal plating industry

Mining activities

Former coal gas manufacturing

Lead compounds were once used as a gasoline additive, so petroleum industry sites.

~~(c and d)~~ ^{mark} **Three treatment methods and type of contaminants treated by each**

Vitrification

15%

- Vitrification processes use high temperature (1600 - 2000°C), by electrical melting, to form solid glassy monolith mass from contaminated soil, material is hence encapsulated within matrix. Hence highest temperatures of three thermal treatment methods.
- Technology works by melting aluminosilicate minerals present in the soil
- Both in-situ (using electrodes inserted in the ground) and ex-situ methods have been developed
- Off-gas from the heating is collected by emission control system
- Has limitations:
 - Maximum allowable concentrations of most organics of 5-10%
 - Moisture content of soil will significantly affect costs
 - Presence of large metal objects could short the electrodes
 - Large amount of combustible materials could lead to underground fire and excessive volumes of off-gases
 - Depth of treatment limited to around 6m
 - Extended time period required for monolith to cool to ambient temperature
- Inorganic contaminants incorporated into ceramic-like matrix, Typical inorganics treated by vitrification: Volatiles (Hg), semi-volatiles (As, Cd, Pb) and non-volatile (Cr, Cu, Ni, Zn)
- Organic contaminants volatilised or destroyed by incineration, Typical organics treated by vitrification: Pesticides, volatiles (fuel oil, toluene), non-volatiles (PCBs, Dioxins). Particularly suitable for radioactive waste.
- Generally there is substantial decrease (up to 30%) in volume of treated soil

Incineration:

15%

- Temperatures of 870 to 1200°C are used to volatilise and combust (in the presence of oxygen) halogenated and other organics. Intermediate temperatures of three thermal treatment systems.
- Treatment processes are ex-situ
- Treatment residue or end product is usually ash or slag, which needs to be dealt with.
- Most common for treatment of soils contaminated with organics. Can also be used to treat asbestos (decomposition at 900°C), but not applicable for most other inorganics.

Thermal desorption:

20%

- Physical separation process in which wastes are heated to desorb (from soil) and volatilise organic contaminants.
- Not designed to destroy contaminants.
- Vapour and gases are collected and treated.
- Treatment processes ex-situ.
- Uses the lowest of three thermal treatment methods.
- High temperature thermal desorption heats waste to 320 to 560°C & targets SVOCs, PAHs, PCBs, pesticides & high boiling point petroleum products
- Low temperature thermal desorption heats waste to 90 to 320°C and targets nonhalogenated VOCs & low boiling point petroleum products
- Treatment residue or end product is usually soil-like.