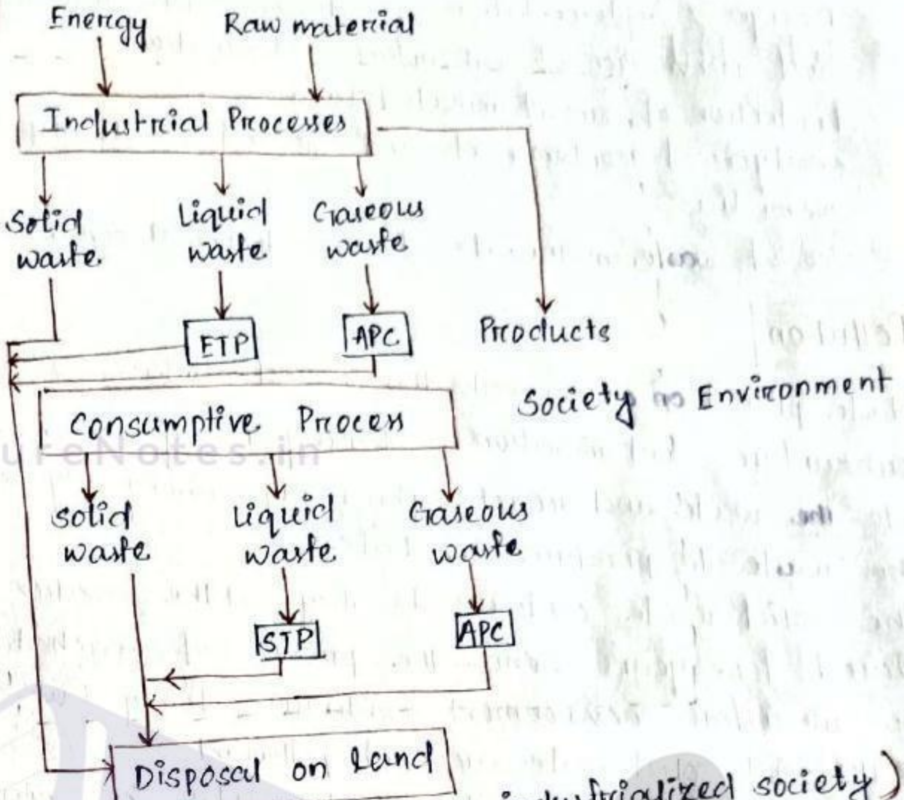
Environmental Geotechniques

1.1 Introduction

* ETP – Effluent treatment Plant

* STP – Sewage treatment plant

* APC – Air pollution control device



(Solid waste generation & disposal in an industrialized society)

Industrialization

- 1990s – rapid industrialization & excessive urbanization.
- 1 million tons of municipal solid waste occupies 1 million sq. mts of area or 1 km² land when the waste spread uniformly with a thickness of 1 mt.
- Waste ⟶ Problems
  - (i) Disposal (Land occupy)
  - (ii) Source of pollution
  - (iii) Contamination of land & ground water.

- Problems due to disposal of solid waste & subsurface contamination –
  - industrial waste-water & mine tailings that are slurry-type liquid wastes are so disposed off (ponding or impoundment of liquid wastes on ground surface)
  - Leakage from storage of liquids in underground tanks (underground petrol storage tanks, septic tanks etc.)
  - leakage from pipeline that transport liquids (sewage lines)
  - accidental spills of toxic liquids
  - application of fertilizers, pesticides on large agricultural areas.

- 4 types of Geoenvironmental Engineering –
  - Design & implementation of solutions for detection, control, remediation and prevention of subsurface contamination.
  - Protection of uncontaminated land
  - analysis of contaminants and ground in transportation through geomedia
  - Use of waste materials for geotechnical construction.

1.2 Pollution

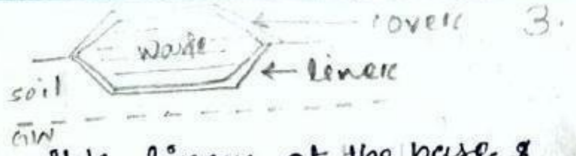
- Waste placed on or beneath the ground surface & the source of subsurface contamination, during rainy season water infiltrates into the waste and reacts physically, chemically & biologically with the waste to produce leachate.
- The solid waste continues to stay at the location where it is placed for years hence the process of leachate infiltration into the subsurface environment continues slowly but surely for several years. All solid wastes are not pollutants.
  Ex- waste from construction & demolition has negligible impact
- Liquid wastes also seep or leak into the sub-surface and the contaminate the subsurface and the ground water, but their impact is less as compair to solid waste.

Inorganic		Organic		Biological
MSW	ISW	MSW	ISW	
Chlorides	Lead	Acetone	Benzene	Coliform bacteria
Sulphates	Zinc	phenol	Toulene	
Nitrates	Copper			

Control and remediation

- Controlling the spread of pollution by vertical barriers. (cut-off wall)
- Remove source of contamination
- Excavating the affected soil (in case of small volume of soil)
- Pumping out contaminated ground water (pump and treat method)
- Pump out pore gas & allow air to soil through injection well.
- Bio remediation by micro-organisms
- Thermal treatment (incineration)

- **Subsurface contamination : control strategies**



1. Solid waste – provide impermeable flexible liners at the base & covers on top to minimize leachate formation.
2. Slurry waste – provide storage in pond & impoundments & embankment & impermeable flexible liner at the base.
3. Liquid waste – provide storage in ponds with impermeable layer.
4. Underground liquid storage – provide double walled tank with leakage detection system.

- **Scope of Geoenvironmental Engineering –**

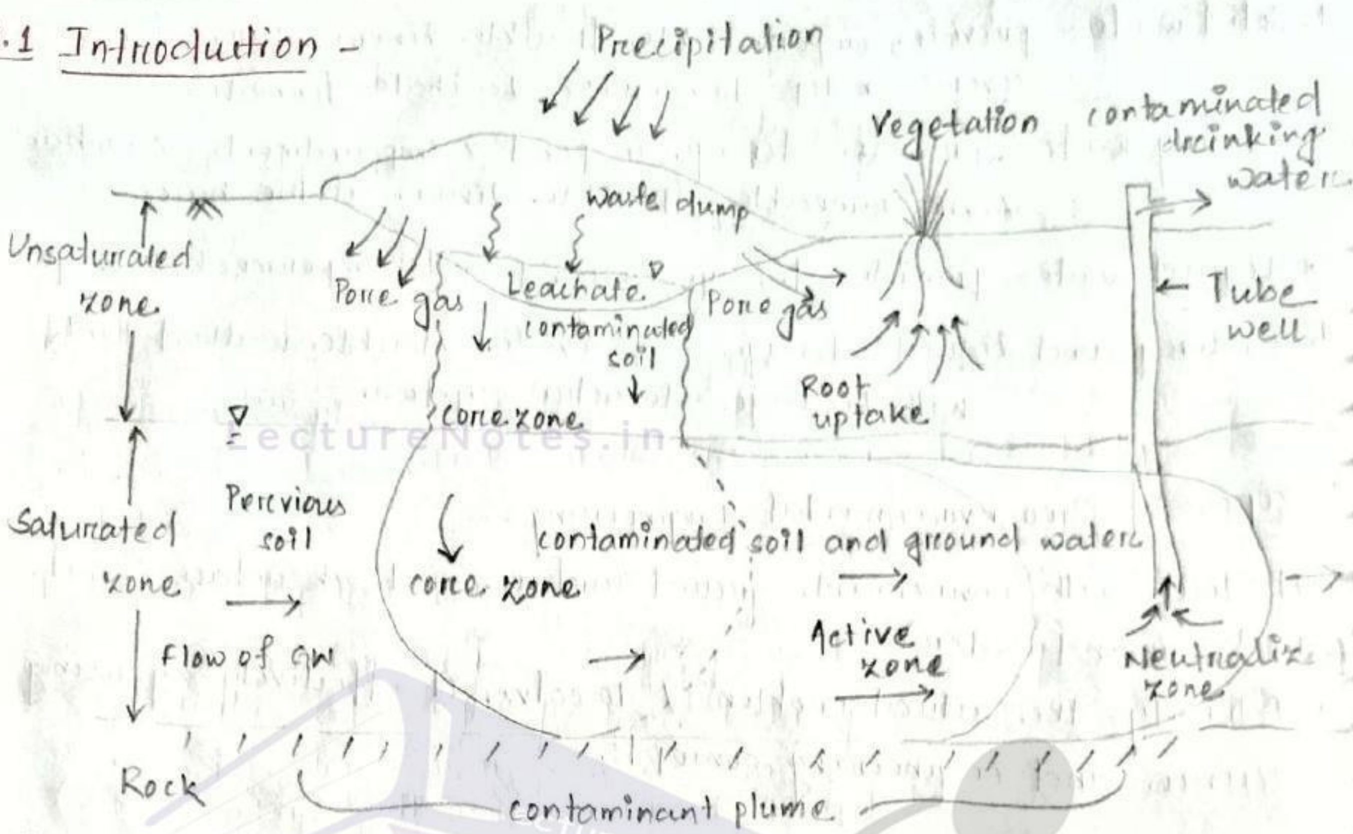
- it deals with environment, ground surface and subsurface (soil, rock, ground water)
- Identify the actual problem & to solve it effectively by using science and engineering concepts.

Note

1. Attenuation capacity of soil – When soil interact with contaminants it results immobilization & retardation of some contaminants. it acts as geochemical trap / Geochemical filter. it is (↑) in clay, (↓) in sand and gravel.

2. Surface Contamination

2.1 Introduction –



[Contaminant plume beneath waste dump]

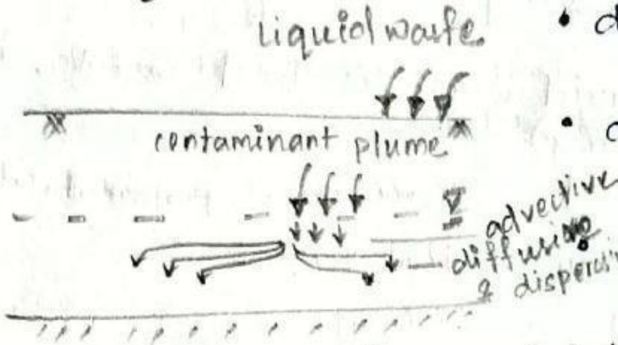
* contaminants are → Liquid & Gas

- Flow of organic or inorganic contaminants to subsurface by gravity flows it is possible when the infiltration capacity of a ~~wat~~ unsaturated soil is less & the fluid moves downwards through void space of soil.
- Contaminants reached upto groundwater and spread in saturated soil and they travel as plume.
- Different source of contamination — Solid waste dumps
  Buried waste
  Liquid ponds
  Underground storage tank

2.2 Contaminant Transport

- Flow of leachate depends upon (in unsaturated soil zone) – Hydraulic gradient
  Permeability of soil
  Initial water content of soil
  Infiltration capacity

• Process of contamination transfer in saturate zone —
• advective process (flow under hydraulic gradient)
• diffusive process (flow under concentration gradient)
• dispersive process (flow under variable velocity)
• coupled process (combination of 2 processes)



* Rate of travel of contaminant plume – 1 mt per year
10 mt per year

1. Advective flow,

$$\boxed{J_A = vC = n v_s C}$$

J_A = Advective mass flux

C = concentration of contaminant in liquid phase
$= \frac{\text{mass of contaminant}}{\text{unit vol. of sol.}}$

v_s = seepage velocity $= \frac{v}{n}$

$\boxed{v = ki}$ from Darcy's law

n = porosity

2. Diffusive flow,

$$\boxed{J_D = -D' n\left(\frac{\partial c}{\partial x}\right)}$$

J_D = Diffusive mass flux

D' = Effective diffusion coefficient
$= \frac{\text{Length}}{\text{time}}$

$\left(\frac{\partial c}{\partial x}\right)$ = concentration gradient

3. Dispersive flow,

$$\boxed{J_M = -D_M n\left(\frac{\partial c}{\partial x}\right)}$$

J_M = Mass flux due to mechanical dispersion

D_M = mechanical dispersion coefficient
$= \frac{\text{Length}}{\text{unit time}} = f(v_s)$ (v_s (↑) D_M (↑))

$$\boxed{J_T = J_A + J_D + J_M}$$

J_T = total flux

* Clay → v_s (↓) J_M (↓)
Gravel → v_s (↑) J_M (↑)

- Gas contaminants → methane & carbon dioxide etc.
  - → Unsaturated soil – travel as pore gas above ground water table
  - → Saturated soil – travel as liquid when dissolved inside it (carbon dioxide)

* Permeability of gas inside soil is more than permeability of water so it passes faster than ~~w~~ ~~H~~ water.

* **Effects of subsurface contamination :**

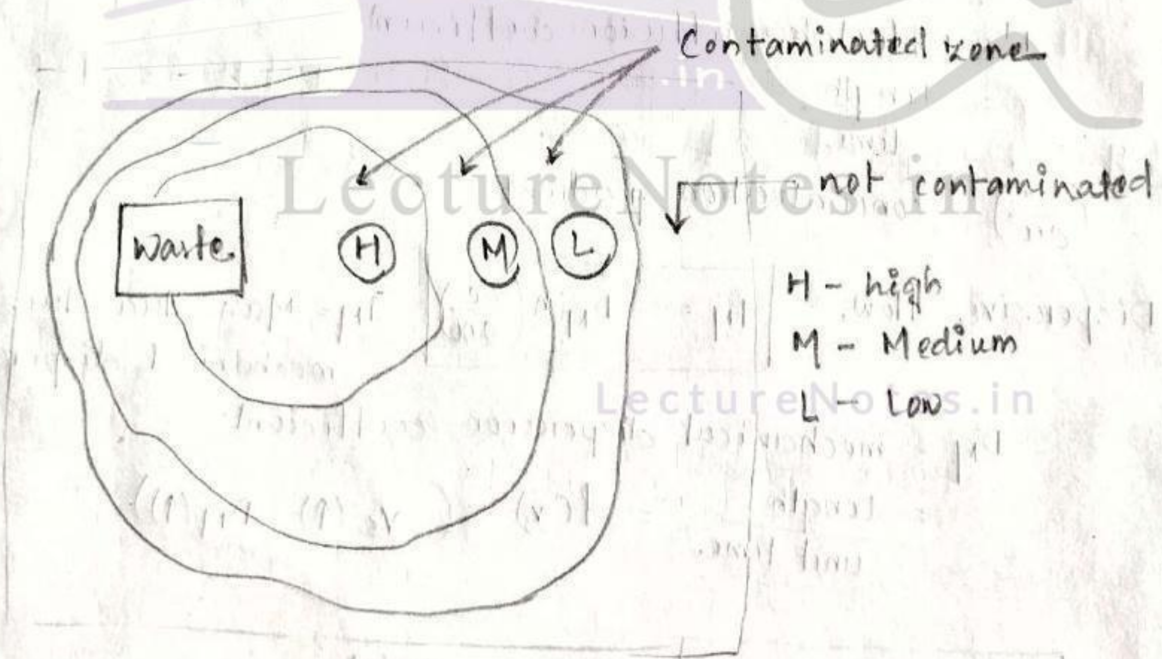
- impact on human health (drinking water)
- intake of contaminated water by plant root (fertility of soil(↓))

* **Detection of polluted zone –**

→ Geophysical method (Electro magnatic survey) – 10mt depth.

→ Drilling and sampling (time taking & required depth)

- sample dia. smaller than 25 mm
- sampler with non-reactive material
- Drilling fluid are not allowed
- Prevent the entering of oils & grease ~~from~~ inside drill hole

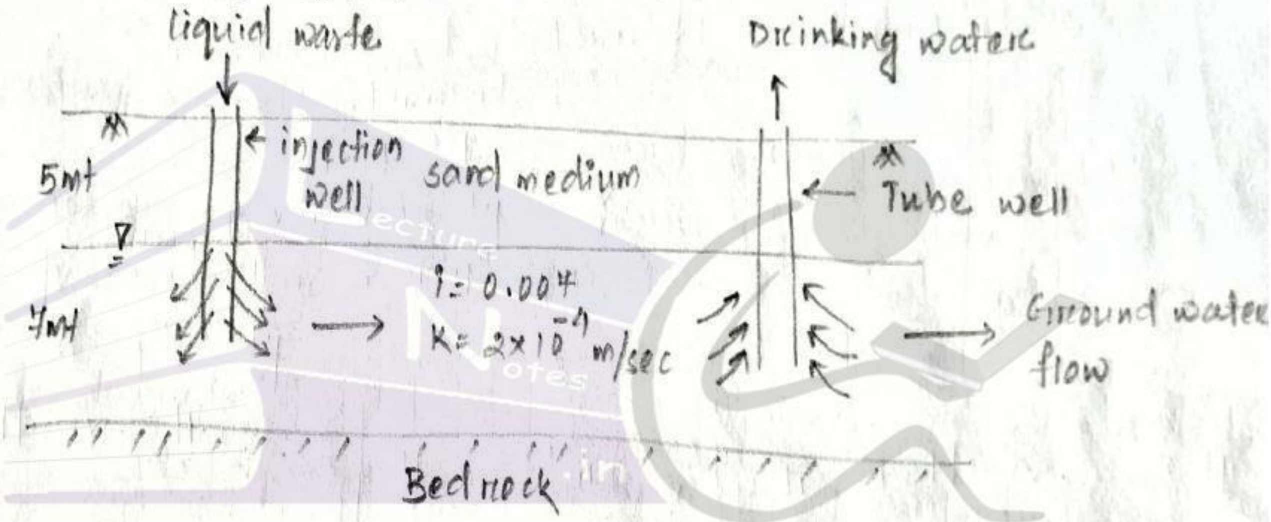


(contours of constant conductivity in plan)

Example - 1

Liquid waste is being discharged into a shallow injection well, the subsoil consists of medium sand with $K = 2\times10^{-4}$ m/sec and porosity of 35%. The GWT is located 5mt below the ground surface and hydraulic gradient causing ground water flow is 0.007. A drinking water tube well is located 1.5km away from injection well on the downstream side as shown. Once the liquid waste percolates vertically down to the ground water table how much time will it take for the liquid waste to reach the drinking water tube well? Consider advective flow and assume 1D horizontal flow condition.

Ans -



$$v = Ki = 2\times10^{-4}\times 0.007 = 14\times10^{-7}\ \text{m/sec}$$

$$v_s = \frac{v}{n} = \frac{14\times10^{-7}}{0.35} = 4\times10^{-6}\ \text{m/sec}$$

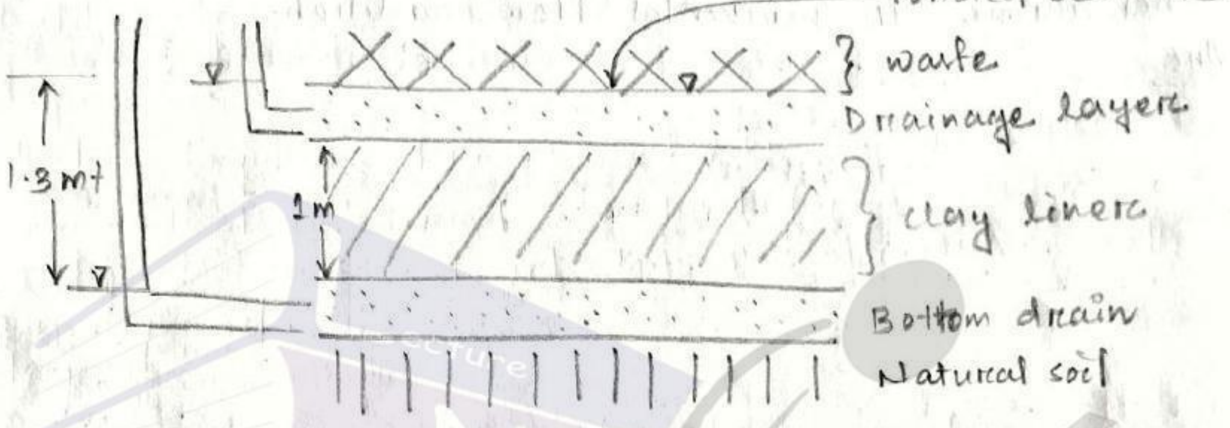
$$t = \frac{L}{v_s} = \frac{1.5\times10^{3}}{4\times10^{-6}} = 3.75\times10^{8}\ \text{sec} = 12\ \text{years}.$$

Hence the liquid waste will reach the tube well in 12 years but due to draw-down by tube well the hydraulic gradient close to drinking water tube is greater than existing hence it will take less than 12 years.

Example - 2

Calculate the total mass flux of chloride ions for flow through a horizontal clay liner shown in fig.. Conc. of chloride in leachate is 1500×10^3 mg/mt^3. The chloride conc. beneath the liner is 200×10^3 mg/mt^3. Permeability of the clay is 10^{-7} m/sec and effective diffusion coefficient is 0.5×10^{-9} m^2/sec for chloride ions that is a non-reactive contaminant. Porosity of clay is 0.4. Assume one dimensional steady state flow conditions exist for advective & diffusive flow. Dispersion may be neglected.

Ans –



$$J_T = J_A + J_D$$

$$J_A = -k\,i\,c$$

$$= -(10^{-9}\ \text{m/sec}) \times \left(\frac{-1.3}{1}\right) \times 1500 \times 10^3\ \text{mg/mt}^3$$

$$= 1.95 \times 10^{-3}\ \text{mg/m}^2\ \text{sec}$$

$$J_D = -D'n\,\frac{\partial c}{\partial x}$$

$$= -(0.5 \times 10^{-9})(0.4)\left(\frac{200-1500}{1.0 \times 10^3}\right)$$

$$= 2.6 \times 10^{-4}\ \text{mg/m}^2\ \text{sec}$$

$$J_T = 2.21 \times 10^{-3}\ \text{mg/m}^2\text{sec}$$

Again, $J_T = 2.21 \times 10^{-3} \times (3.15 \times 10^7)$ mg/m^2 year

$= 69.6$ g/m^2 year

Hence chloride enters naturally at a rate of 69.6g per sq. mt of linear area per year.

3 Geosynthetics

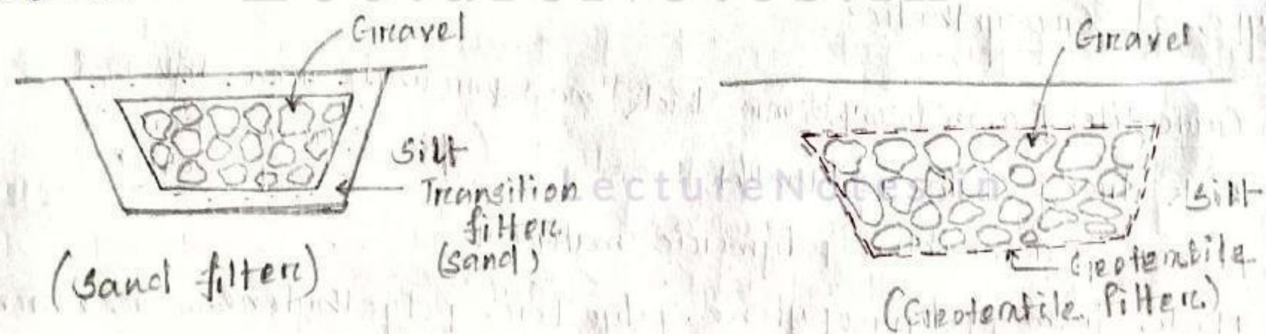
3.1 Introduction –

- Geosynthetics are man made products. They are flexible and planar. They are manufactured from synthetic polymeric material and sometimes from natural materials.
- Five groups – Geotextiles
  Geomembranes
  Geogrids
  Geonets
  Geocomposites
- These are used as separators, filters, drains, reinforcement, hydraulic barriers, protectors and erosion control systems etc. some examples are given below –

(i)

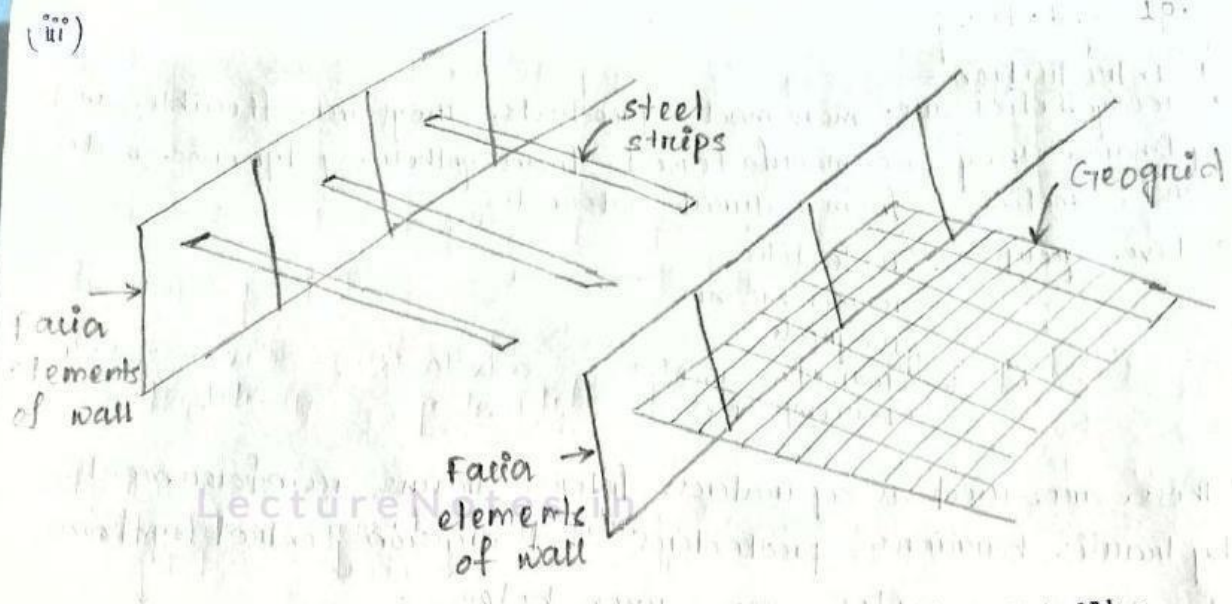
Water storage tank, impervious barrier is required to prevent loss of water. Previously clay liner is used & now 'geomembrane' is used ~~to~~ as seepage barrier & it is flexible hence not affected by subsoil settlement.

(ii)



Trench drain is constructed at the toe of an earthdam to carry away seepage and runoff water which required a transition filter placed in between surrounding soil and the gravel used in trench drain. This process can be done by using 'Geotextile filter' it can reduce the screening & mixing cost as well as it will ~~reduce~~ ~~meet~~ the requirement of filter.

(iii)



Geosynthetics together form a mesh like or grid like stiff 'Geogrid' to reinforced a vertical faced wall or a steep sloped structure to interlock the structure with surrounding soil.

** Advantage –**

- As manufactured so high uniformity & quality
- light weight, 3 to 6 mt wide & long, transportation is easy
- easy and rapid installation.

3.2 Type of Geosynthetics –

1. Geotextile [0.25 to 7.5 mm thick mass per unit area 150 to 2000 g/m²] gsm (gsm – grams per sq. meter)

- Thick strong cloth or blanket
- planar, permeable, polymeric material
- Made from – polypropylene, polyester, polyethylene, or normal fibers like jute
- it may be woven, non-woven or knitted.

Woven – weaving/interlacing at right angle of 2 or more set of fibres.

Non-woven – mechanical bonding / needle punching of randomly oriented fibers.

2. Geomembranes – [0.25 to 3 mm thick & 250 to 3000 gsm]

- Thick flexible plastic sheet & smooth surface
- impermeable polymeric sheet
- Manufactured by high density polyethylene (HDPE), very flexible polyethylene (VFPE), polyvinyl chloride (PVC)

3. Geogrids – [5 to 15 mm thickness & 200 to 1500 gsm]

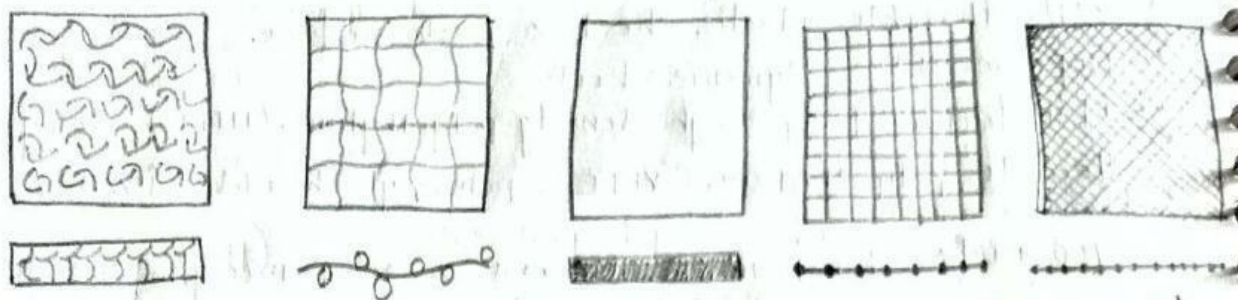
- Mesh like or grid like geosynthetics with sq. or rectangular shape, plastic meshes used in garden fences.
- planar polymeric material of regular open network of connected tensile element (ribs) with sq. or rectangular openings
- Manufactured from HDPE, polypropylene, polyester
- %age open area = 40 to 95%.
  width of opening = 10 to 100 mm
  rib thickness = 5 to 15 mm

4. Geonets – [property similar to geogrids]

- Thin member & ~~regular~~ angular apertures not sq. or rectangular
- planar polymeric material, parallel sets of ribs overlying & integrally connected to similar sets of ribs at various angles
- width of opening – 5 to 15 mm
  rib thickness – 3 to 10 mm

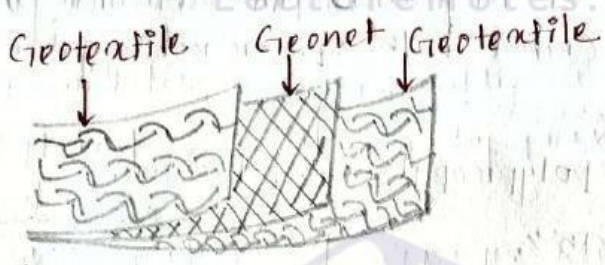
5. Geocomposites –

- multilayered geosynthetics,
- Ex – clay / bentonite is bonded to geotextile to yield a geocomposite known as geosynthetic clay liner.



(a) Non-woven geotextile (b) Woven geotextile (c) Geomembrane (d) Geogrid (e) Geonet

(--------) (--------) (———) (•—•—•—•) (xxxxxx)



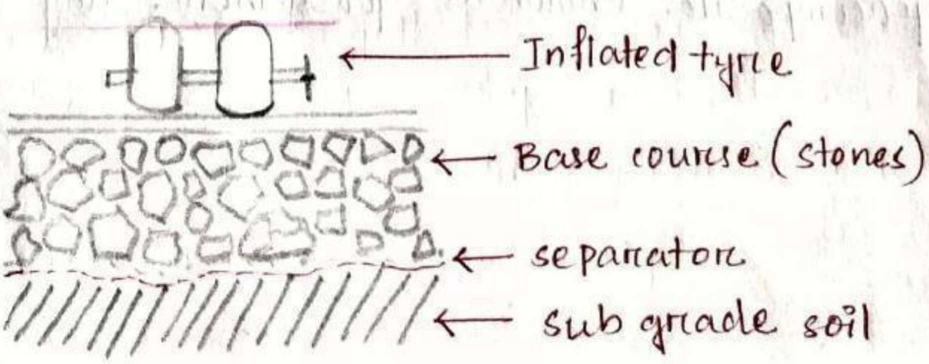
(Geocomposites)

Functions of Geosynthetics –

1. Separation–

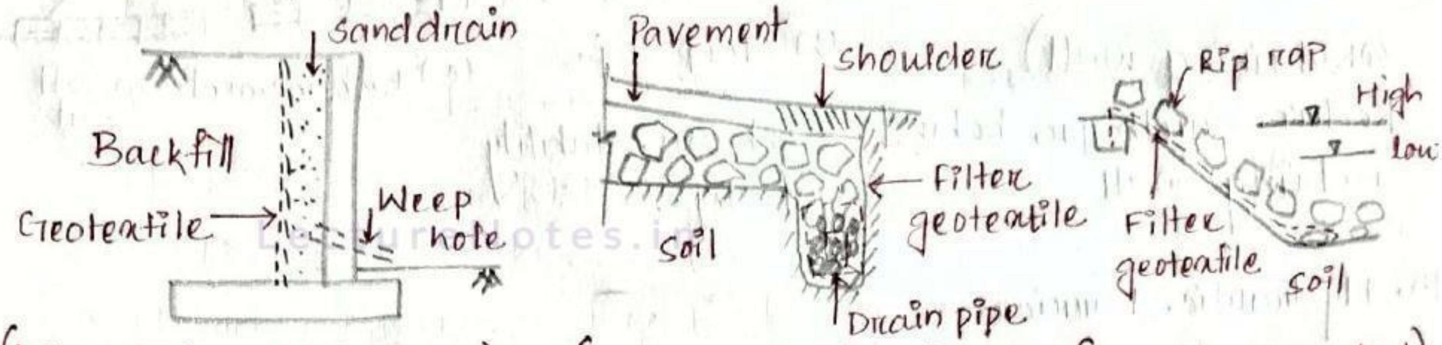
- Provide b/w a different layers of ~~sand~~ soil to keep them separate
- Ex-(i) road pavement consist of base course material as gravel size placed directly over subgrade soil. Due to traffic load the gravel may penetrate in to the weak subgrade soil layer, so to prevent mixing we can use geosynthetic to increase the performance also.

(ii) similarly in Railways also we can use.



2. Filtration

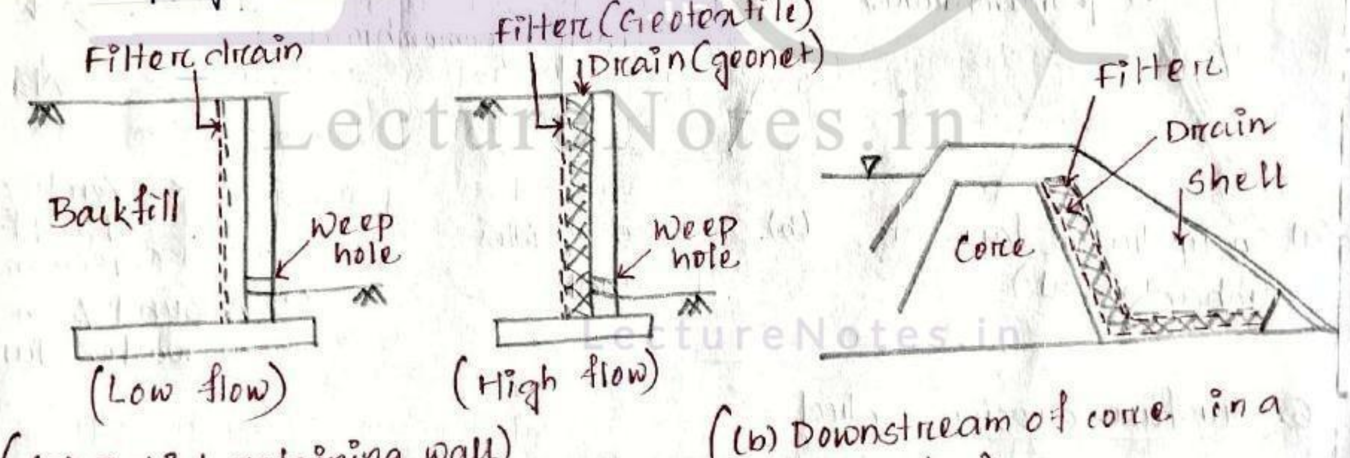
- Porous geosynthetic placed b/w FG soil layer & CG soil layer.
- Transition filter to make the water flow/pass through it.



(a) Behind retaining wall) (b) Edge drain below road shoulder) (c) Erosion control)

3. Drainage -

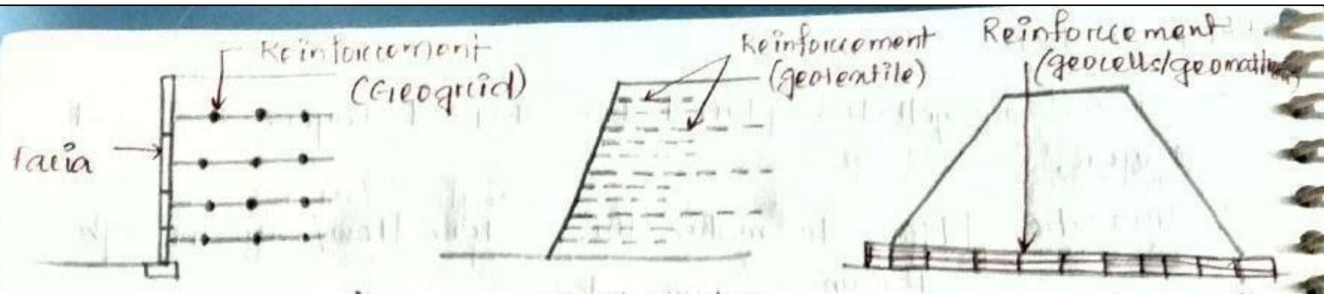
- Porous geosynthetics with high in-plane permeability placed within a soil mass for rapid flow of water in plane direction without migration of fines.
- Ex- seepage water intercepted behind retaining wall



(Low flow) (High flow)
(a) Behind retaining wall) (b) Downstream of core in a dam)

4. Reinforcement -

- High tensile strength perform the fn of reinforcement in a soil so geosynthetic is provided in single or multiple layers to improve engineering property of soil. (Bearing capacity)
- soil is good in compression & weak in tension.



(a) Retaining wall) (b) Steep slope (c) Embankment on soft soil

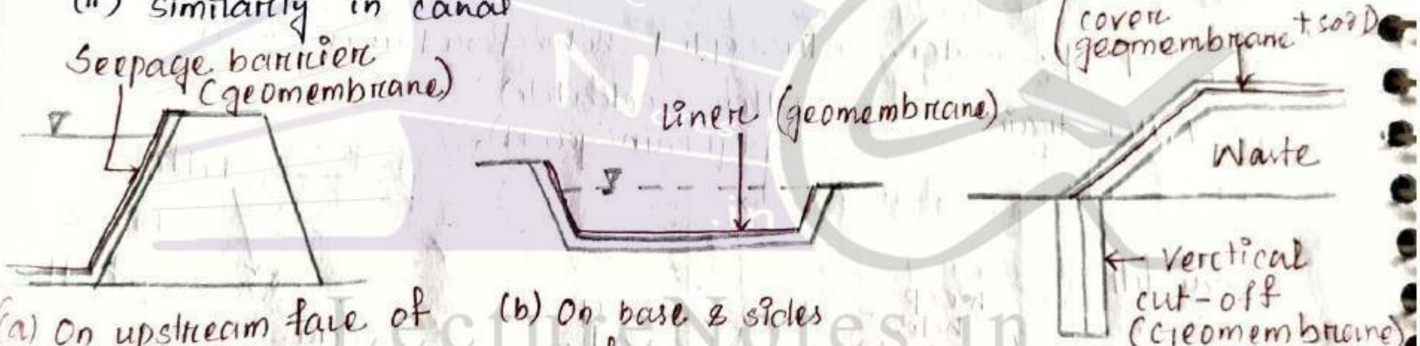
- Reduce earth pr. behind retaining wall
- enhance stability of slope

5. Hydraulic Barriers –

- Geosynthetic is impermeable in the cross-plane & in-plane dirn & placed in a soil mass by preventing seepage of water through soil mass.

Ex-(i) elimination of seepage water through a water retaining embankment is achieved by placing an impervious geosynthetic on the upstream slope of the embankment

(ii) Similarly in canal



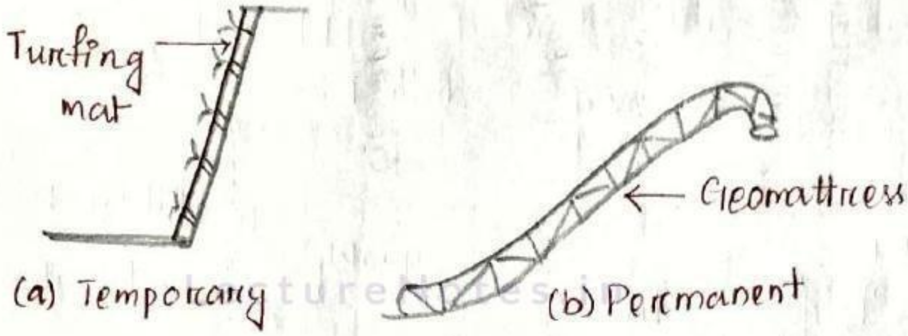
(a) On upstream face of embankment) (b) On base & sides of canal (c) Around & on top of waste dump

6. Surface erosion control –

- Temporary or permanent erosion control measures along with side slopes.
- Temporary erosion control geosynthetics comprise of natural biodegradable fibers, eg- jute. They spread in the form of grids or mats prevent erosion until vegetative growth occu
- Geomattresses – cover the slope permanently

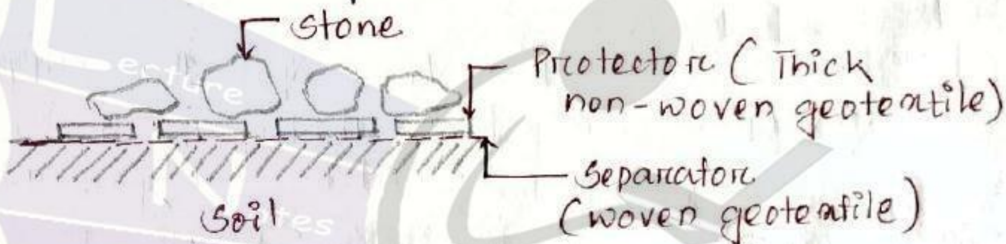
7. Encapsulation / Containment -

- It is used to encapsulate soil / sediments & prevent the loss of material.



8. Protection -

- Geosynthetics are used to prevent an underlying layer from damage ~~from~~ occur due to presence of angular materials (gravel & stone) above the layer.



* Property of Geosynthetics -

Properties	Parameters
1. Physical	Thickness, sp.grvt., gsm, porosity, ~~pore~~ percent open area, apparent opening size
2. Chemical	Polymer type, filler material, carbon black percentage, plasticizer
3. Mechanical	Tensile strength, compressibility, elongation, burst strength, seam strength, anchorage in soil.
4. Hydraulic	Permittivity (cross-plane permeability), transmissivity (in-plane permeability) clogging potential
5. Endurance Degradation	installation damage potential

Function	Primary Requirements	Type of Geosynthetic used
1. Separator	• Tensile strength (↑) • Allow water flow • Tear/impact/puncture resistance (↑)	Geotextile
2. Filtration	• small pore size • Low clogging potential	Geotextile
3. Drainage	• Filtration in cross plane dirⁿ • High inplane permeability	Geotextile / Geocomposite sheet
4. Reinforcement	• Tensile strength (↑) • elongation (↓) (high stiffness) • (↑) shearing resistance along soil reinforcement interface	(Geotextile) / (Geogrids)
5. Barrier	• (↑) imperviousness • Leakproof welding along seams • no slippage	Geomembranes

Remediation

→ Principle
→ Planning, source control
→ Soil-gas extraction
→ Soil washing
→ Bioremediation

1.1 Introduction :-

Soil is contaminated by various sources like, industries (chemical, pharmaceuticals, plastic, automobile, biomedical etc). Nuclear industries, biomedical wastes, mining industies, municipa solid wastes etc. So the soil needs treatment.

The remediation porocess can be of two types -
(i) Elimination of pollutant by using any method & treat them
(ii) Removal of contaminated soil & treat it

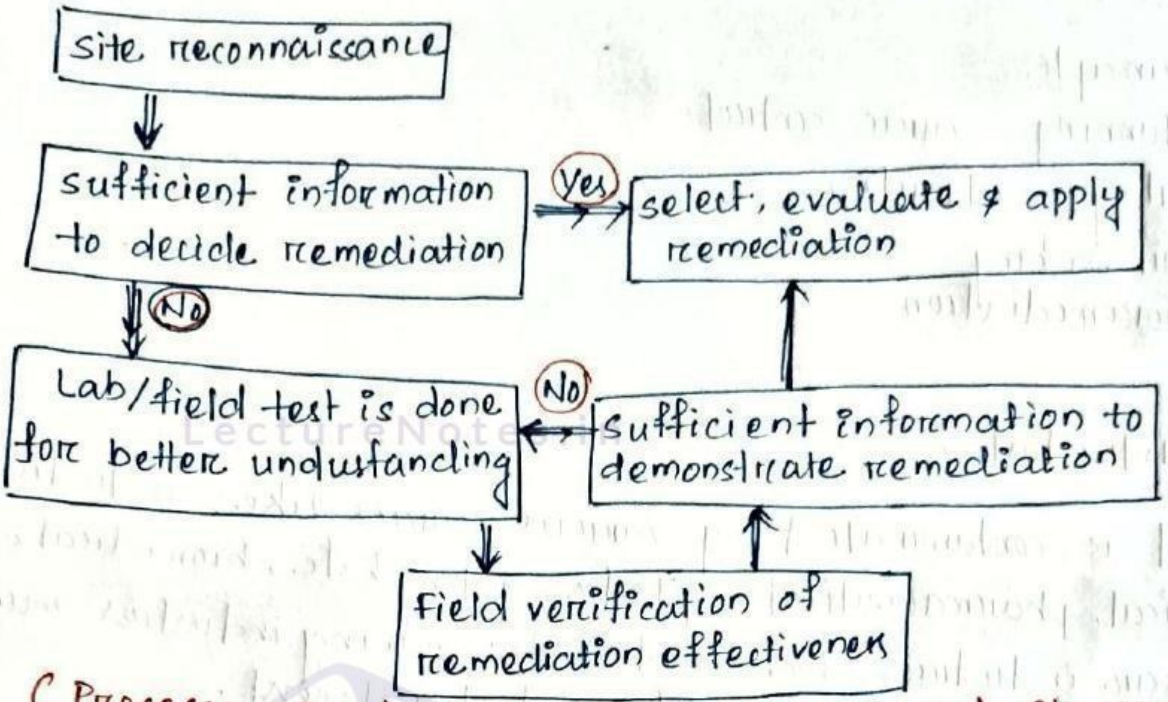
1.2 Characterization of contaminated site :-

→ CSA → Contaminated site assessment
i) Concentration of harmful pollutants
ii) selection of remediation method
iii) Risk to environment & human health

The above analysis is possible only if we know the following details -

1. Source of contamination
2. type & it's form of existance
3. total contaminated area / vol.
4. transportation characteristic of contaminants
5. potential of contaminants

1.3 Planning of Remediation method :-



(Processes involved in deciding contaminated site remediation)

Data	Details	Method of acquisition
1. Site History	(i) Population density within 3km from the contaminated site	Field
	(ii) Proximity to airport, railway, river ..	
	(iii) Ownership of the land	
	(iv) Extent of contamination	
2. Geologic & Hydrologic	(i) Topography	Field
	(ii) soil profile upto bed rock	
	(iii) Information on aquifer	
	(iv) GWT depth & dirn of flow	
3. Geotechnical	(i) soil sampling & classification	Field
	(ii) Permeability of soil	Field
	(iii) Chemical characteristics of soil	Lab
	(iv) soil strength	Lab
4. Waste	(i) Water quality	Field/Lab
	(ii) type of contamination	Field/Lab
	(iii) Concentration	lab
	(iv) extent of contamination	Field/Lab
	(v) ~~Depth~~ of depth "	Field/lab
	(vi) transportation "	lab

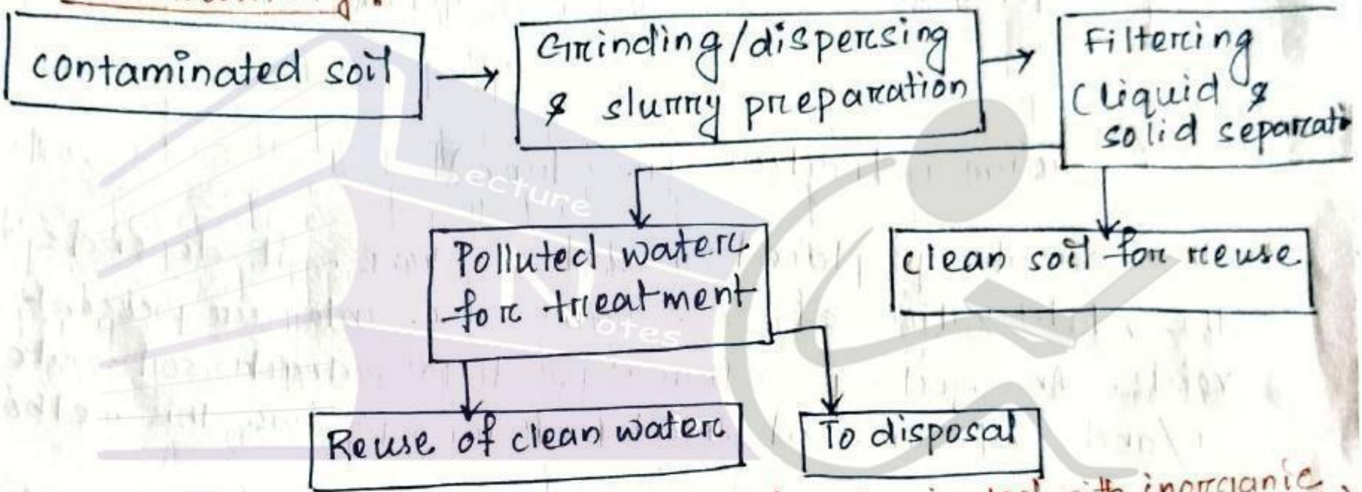
1.4. Method of Remediation :-

Depending upon various factors like toxic level of contaminants, risk to environment and human ~~hed~~ health a suitable remediation method is selected. The remediation methods are classified as follows -

(i) Physico - chemical method
(ii) Biological method
(iii) Electrical method
(iv) Thermal method

1.4.1 Physico - chemical Method -

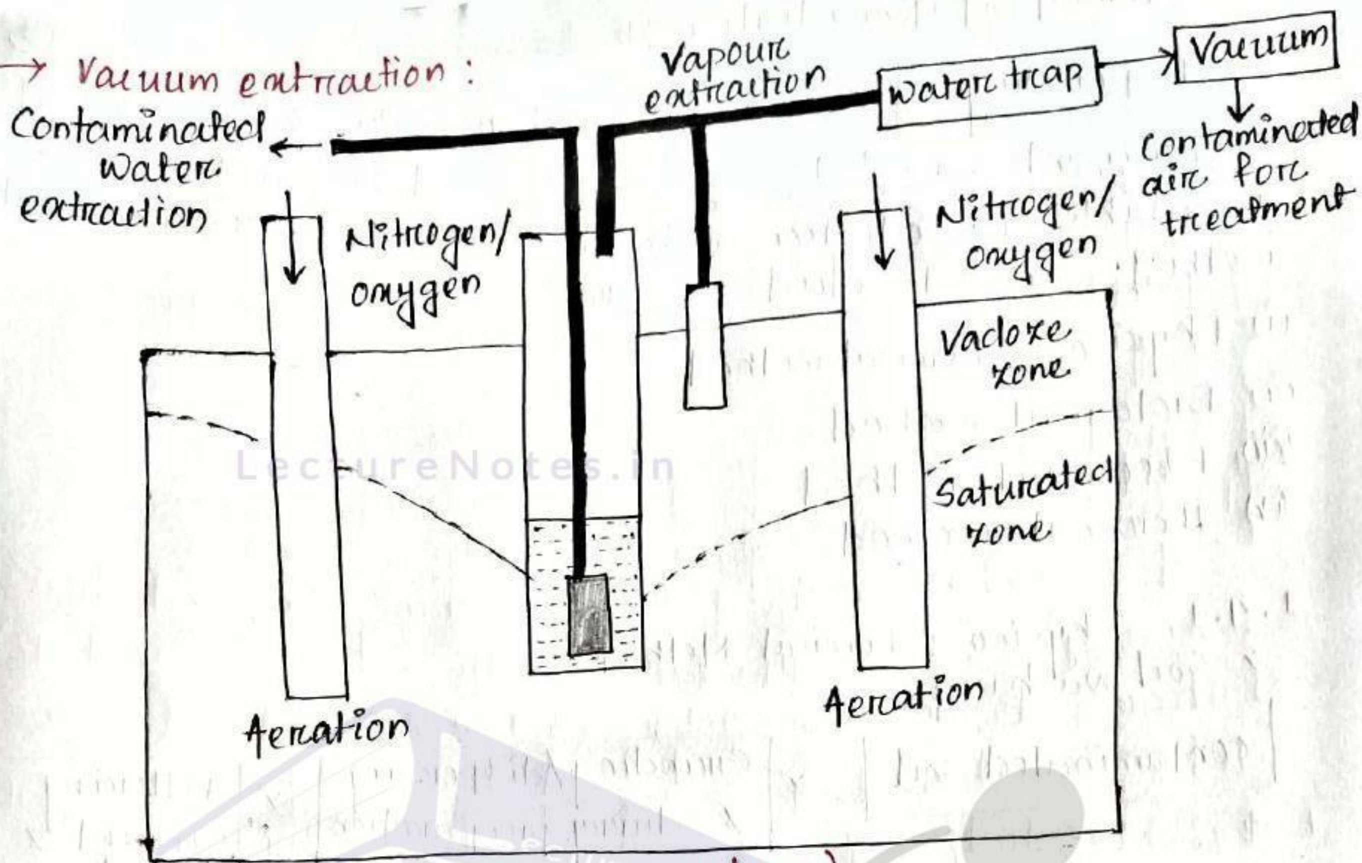
→ Soil washing:



(Soil washing for granular soil contaminated with inorganic pollutants)

- Soil washing process is suitable for granular soil with less clay content & contaminated with inorganic pollutants.
- For clayey soils chemical dispersion agent need to be added to deflocculate & then chemical washing is employed to break the retention of contaminants with the clay surface
- ~~Inclination~~ Inclinaration is suggested for soils contaminated with organic pollutants. Sometimes certain solvents and/or surfactants are used as washing agents. This method is in-situ and directly applied by injection and recovery systems.
- The additives are used to enhance the remediation effect & reduce soil contamination.

→ Vacuum extraction :

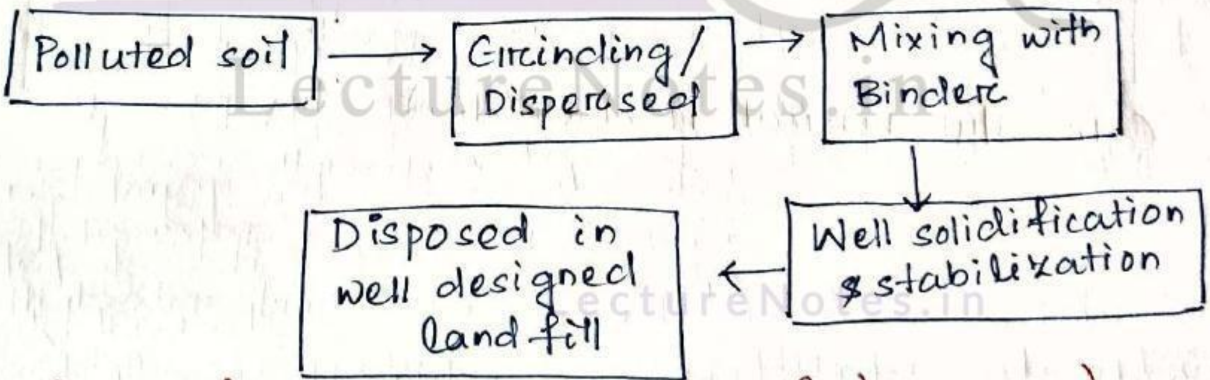


(Vacuum extraction procedure)

- This is always placed at vadoze zone. It depends on the volatilization of VOC from water into air present in voids. An injecting medium is used to extract soil-water or/and soil-air. Soil structure is also imp. for this method.
- When oxygen is used instead of nitrogen as the injecting medium, it enhances aerobic biodegradation.
- Granular soils provide better passage of fluid & gas.
- Organic matter provides high retention leading to less volatilization.
- High density & water content also minimize transmissivity and the property of VOC also influence extraction process.

→ Solidification & stabilization :

- It is the process of im-mobilixing toxic contaminants sothat it's effect is eliminated temporally & spatially. This process is performed in a single step or in two steps.
- In case of single step, the polluted soil mixed with a special binder sothat the polluted soil is fixed and rendered insoluble.
- In case of two step process,
  (i) Polluted soil is made insoluble & non-reactive
  (ii) Solidified that soil.
- This process is suitable for highly toxic pollutants & mostly influenced by the transmissivity characteristics of the soil, viscosity and setting time of the binder.
- Well compacted soil, high clay & organic content soil do not supported in-situ process of stabilization.
- The common binders are, cement, lime, fly ash, clay, zeolites, pozzolonic products etc and organic binders include bitumen, polyethylene, epoxy & resins which is used when organic pollutants are present.



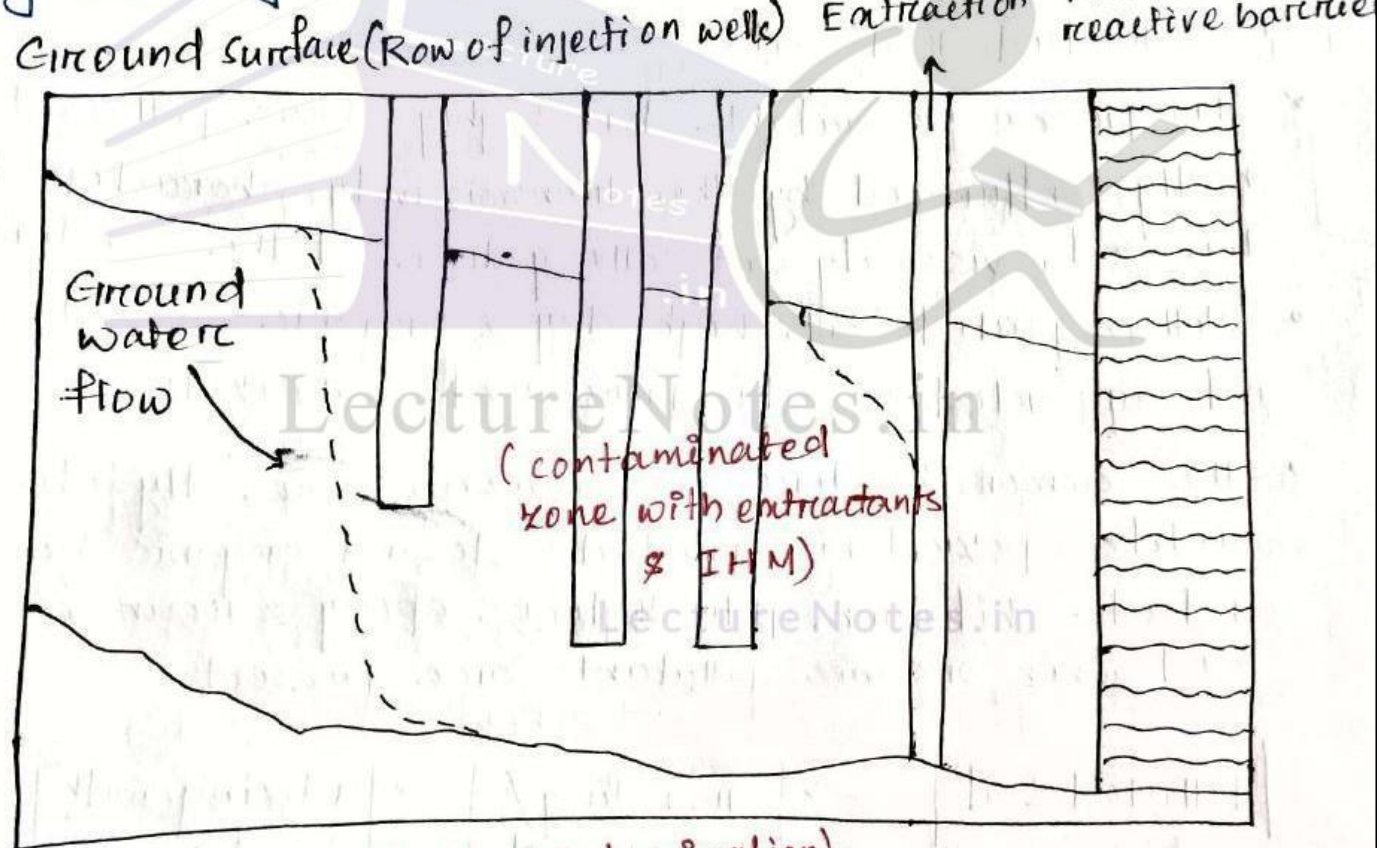
(Solidification & stabilization (ss) process)

→ Chemical Decontamination :

- This method is applicable when the soil has high sorbed contamination of inorganic heavy metals (IHM)
  1. Identify the nature of bonding b/w pollutants & soil surface

(6)

- An extractant is used to reduce the effect of pollutants which have electrolytes, weak acid, complexing agents, oxidizing & reducing agents, strong acid etc. Multiple extractants are used when required also.
- The pore water is pumped out & treat otherwise the pore water is allowed to flow through a permeable reactive barrier & the barrier will retain the IHM by exchange complexation or precipitation reaction.



(In-situ chemical decontamination)

1.4.2 Biological Methods :-

- It is applicable for soil contaminated with organic polutants & the process is also known as Bio-remediation.
- Certain micro-organisms are used to metabolize organic chemical compounds.
- The micro-organisms degrade the contaminants. The natural micro-organisms like bacteria, virus or fungi is not capable of producing enzymes required for this method so genetically produce micro-organisms are used but before that the harmful characteristics of it should be examined.
- The remediation process depend on microbial degradation, hydrolysis, aerobic & anaerobic transformation, redox reaction, volatalization etc.

1.4.3 Electro-kinetic Methods :-

- It is a field method by using electrical principles for decontamination. It is suitable for granular type of soil
- Two electrodes are inserted into the soil mass which acts as anode & cathode & an electric field is established across these electrodes that produce electronic conduction as well as charge transfer b/w electrode & solids in the soil-water system. Low intensify direct current is applied to the electrodes. This result electro-osmosis & ion migration resulting in the movement of contaminant from one electrode to another.
- Sometimes surfactants & complexing agents are used in support of this process.
- This is a costly method of decontamination.

1.4.4 Thermal Method :-

- This Method contains both high & low temp.s and suitable for high volatilization potential contaminants.
- High temp. (>5000C) process involved incineration, electric pyrolysis and in-situ vitrification. (oxidation)
- Low temp. (<5000C) process includes low temp. incineration thermal aeration, infrared furnance treatment. (phase transfer from solid to gas)
- It is an in-situ process in which hot air, water or steam is injecting to form volatization & sometimes vacuum is applied to extract air or steam for further treatment.
- Chemical agents are used to enhanced the method of decontamination. But this method is costly and can't apply for ally type of contaminants so It is not used every time.

- 4 types of Geoenvironmental Engineering –
- Design & implementation of solutions for detection, control, remediation and prevention of subsurface contamination.
- Protection of uncontaminated land
- analysis of contaminants and ground in transportation through geomedia
- Use of waste materials for geotechnical construction.

1.2 Pollution

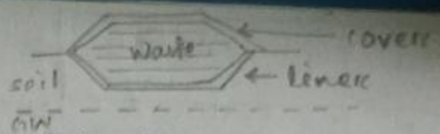
- Waste placed on or beneath the ground surface & the source of subsurface contamination, during rainy season water infiltrates into the waste and reacts physically, chemically & biologically with the waste to produce leachate.
- The solid waste continues to stay at the location where it is placed for years hence the process of leachate infiltration into the subsurface environment continues slowly but surely for several years. All solid wastes are not pollutants.
  Ex- waste from construction & demolition has negligible impact
- Liquid wastes also seep or leak into the sub-surface and the contaminate the subsurface and the ground water, but their impact is less as compair to solid waste.

Inorganic		Organic		Biological
MSW	ISW	MSW	ISW	
Chlorides	Lead	Acetone	Benzene	Coliform bacteria
Sulphates	Zinc	phenol	Toulene	
Nitrates	Copper			

Control and remediation

- Controlling the spread of pollution by vertical barriers. (cut-off wall)
- Remove source of contamination
- Excavating the affected soil (in case of small volume of soil)
- Pumping out contaminated ground water (pump and treat method)
- Pump out pore gas & allow air to soil through injection well.
- Bio remediation by micro-organisms
- Thermal treatment (incineration)

• Subsurface contamination :- control strategies



1. Solid waste - provide impermeable flexible liners at the base & covers on top to minimize leachate formation.
2. Slurry waste - provide storage in pond & impoundments & embankment & impermeable flexible liner at the base.
3. Liquid waste - provide storage in ponds with impermeable layer.
4. Underground liquid storage - provide double walled tank with leakage detection system.

• Scope of Geoenvironmental Engineering -

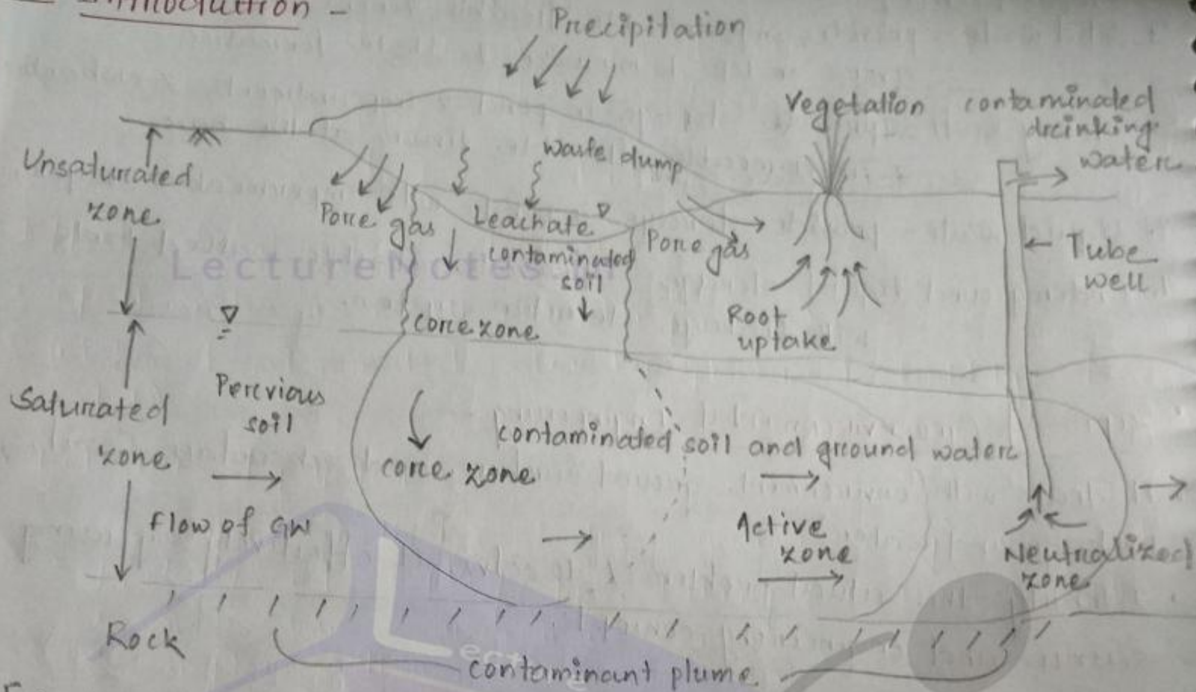
- it deals with environment, ground surface and subsurface (soil, rock, ground water)
- Identify the actual problem & to solve it effectively by using science and engineering concepts.

Note

1. Attenuation capacity of soil - When soil interact with contaminants it results immobilization & retardation of some contaminants. it acts as geochemical trap / Geochemical filter. it is (↑) in clay, (↓) in sand and gravel.

2. Surface Contamination

2.1 Introduction –



[Contaminant plume beneath waste dump]

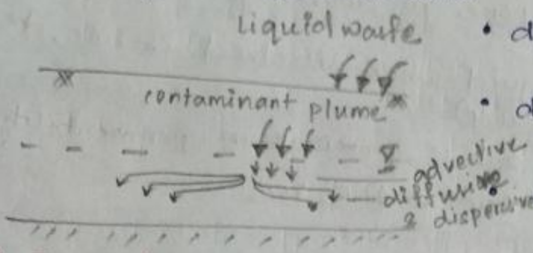
* contaminants are → Liquid & Gas

- Flow of organic or inorganic contaminants to subsurface by gravity flows it is possible when the infiltration capacity of a ~~wat~~ unsaturated soil is less & the fluid moves downwards through void space of soil.
- Contaminants reached upto groundwater and spread in saturated soil and they travel as plume.
- Different source of contamination — Solid waste dumps
  Buried waste
  Liquid ponds
  Underground storage tank

2.2 Contaminant Transport

- Flow of leachate depends upon – Hydraulic gradient
  (in unsaturated soil zone) Permeability of soil
  Initial water content of soil
  Infiltration capacity

- Process of contamination transfer in saturate zone —
  - advective process (flow under hydraulic gradient)
  - diffusive process (flow under concentration gradient)
  - dispersive process (flow under variable velocity)
  - coupled process (combination of 2 processes)



* Rate of travel of contaminant plume — 1 mt per year
  10mt per year

1. Advective flow,
$$\boxed{J_A = vC = n v_s C}$$
J_A = Advective mass flux

C = concentration of contaminant in liquid phase
$= \dfrac{\text{mass of contaminant}}{\text{unit vol. of sol.}}$

v_s = seepage velocity $= \dfrac{v}{n}$

$\boxed{v = Ki}$ from Darcy's law

n = porosity

2. Diffusive flow,
$$\boxed{J_D = -D' n\left(\frac{\partial c}{\partial x}\right)}$$
J_D = Diffusive mass flux

D' = Effective diffusion coefficient
$= \dfrac{\text{Length}}{\text{time}}$

$\left(\dfrac{\partial c}{\partial x}\right)$ = concentration gradient

3. Dispersive flow,
$$\boxed{J_M = -D_M n\left(\frac{\partial c}{\partial x}\right)}$$
J_M = Mass flux due to mechanical dispersion

D_M = mechanical dispersion coefficient
$= \dfrac{\text{Length}}{\text{unit time}} = f(v_s)$ $\left(v_s (\uparrow)\ D_M (\uparrow) \right)$

$$\boxed{J_T = J_A + J_D + J_M}$$
J_T = total flux

* Clay → $v_s (\downarrow)$ $J_M (\downarrow)$
  Gravel → $v_s (\uparrow)$ $J_M (\uparrow)$

- Gas contaminants → methane & carbon dioxide etc.
  → Unsaturated soil – travel as pore gas above ground water table
  → Saturated soil – travel as liquid when dissolved inside it (carbon dioxide)

* Permeability of gas inside soil is more than permeability of water so it passes faster than water.

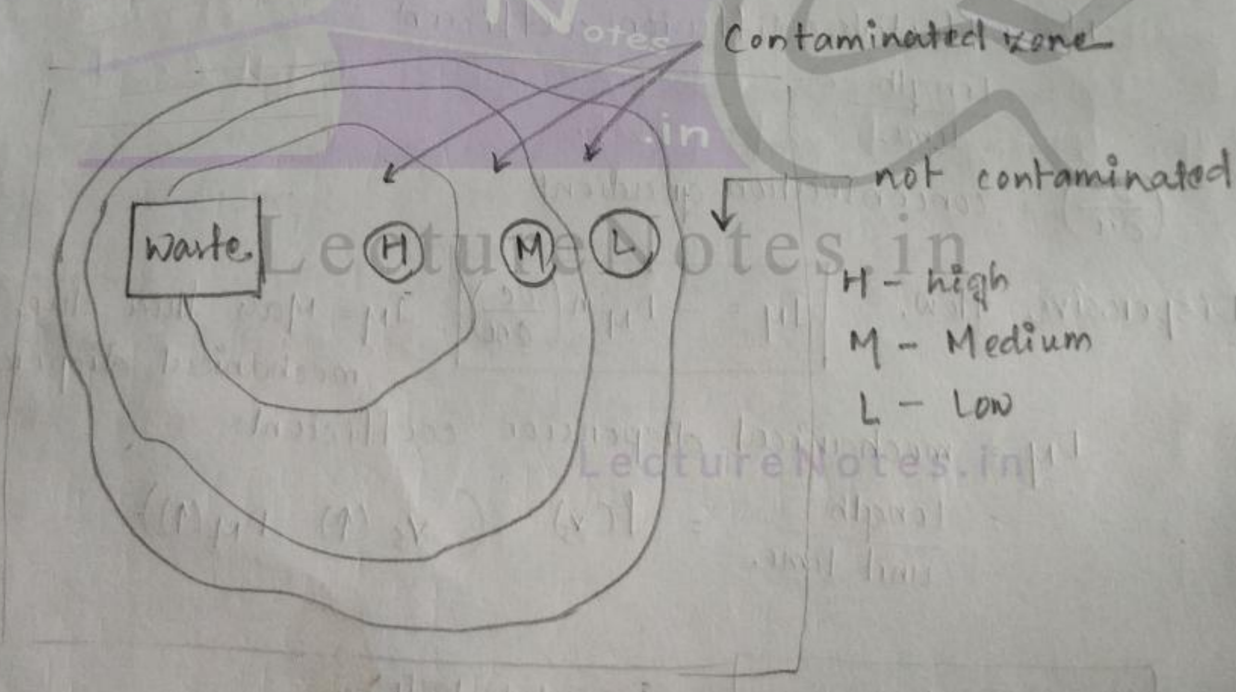
* Effects of subsurface contamination :-

- impact on human health (drinking water)
- intake of contaminated water by plant root (fertility of soil (↓))

* Detection of polluted zone –

→ Geophysical method (Electro magnetic survey) – 10mt depth.
→ Drilling and sampling (time taking & required depth)

- sample dia. smaller than 25 mm
- sampler with non-reactive material
- Drilling fluid are not allowed
- Prevent the entering of oils & grease ~~from~~ inside drill hole

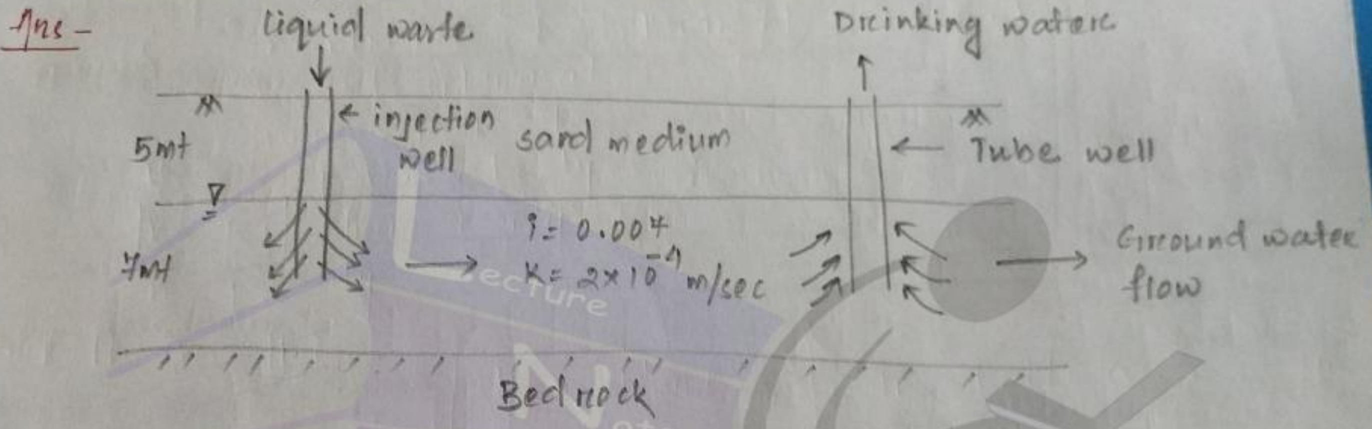


(contours of constant conductivity in plan)

Example - 1

Liquid waste is being discharged into a shallow injection well, the subsoil consists of medium sand with $k = 2\times10^{-4}$ m/sec and porosity of 35%. The GWT is located 5mt below the ground surface and hydraulic gradient causing ground water flow is 0.007. A drinking water tube well is located 1.5km away from injection well on the downstream side as shown. Once the liquid waste percolates vertically down to the ground water table how much time will it take for the liquid waste to reach the drinking water tube well? Consider advective flow and assume 1D horizontal flow condition.

Ans -



$$V = Ki = 2\times10^{-4}\times 0.007 = 14\times10^{-7}\ \text{m/sec}$$

$$V_s = \frac{V}{n} = \frac{14\times10^{-7}}{0.35} = 4\times10^{-6}\ \text{m/sec}$$

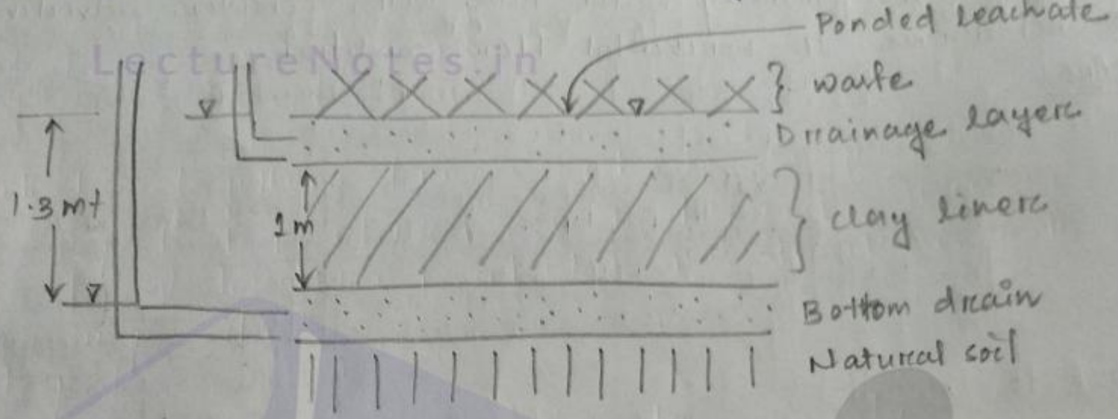
$$t = \frac{L}{V_s} = \frac{1.5\times10^{3}}{4\times10^{-6}} = 3.75\times10^{8}\ \text{sec} = 12\ \text{years}.$$

Hence the liquid waste will reach the tube well in 12 years but due to draw-down by tube well the hydraulic gradient close to drinking water tube is greater than existing hence it will take less than 12 years.

Example - 2

Calculate the total mass flux of chloride ions for flow through a horizontal clay liner shown in fig. . Conc. of chloride in leachate is 1500×10^3 mg/mt³. The chloride conc. beneath the liner is 200×10^3 mg/mt³. Permeability of the clay is 10^{-9} m/sec and effective diffusion coefficient is 0.5×10^{-9} m²/sec for chloride ions that is a non-reactive contaminant. Porosity of clay is 0.4. Assume one dimensional steady state flow conditions exist for advective & diffusive flow. Dispersion may be neglected.

Ans -



$$J_T = J_A + J_D$$

$$J_A = -k\,i\,c$$

$$= -(10^{-9}\ \text{m/sec}) \times \left(\frac{-1.3}{1}\right) \times 1500 \times 10^3\ \text{mg/mt}^3$$

$$= 1.95 \times 10^{-3}\ \text{mg/m}^2\ \text{sec}$$

$$J_D = -D'n\frac{\partial c}{\partial x}$$

$$= -(0.5 \times 10^{-9})(0.4)\left(\frac{200-1500}{1.0 \times 10^3}\right)$$

$$= 2.6 \times 10^{-4}\ \text{mg/m}^2\ \text{sec}$$

$$J_T = 2.21 \times 10^{-3}\ \text{mg/m}^2\text{sec}$$

Again, $J_T = 2.21 \times 10^{-3} \times (3.15 \times 10^7)$ mg/m² year

$= 69.6$ g/m² year

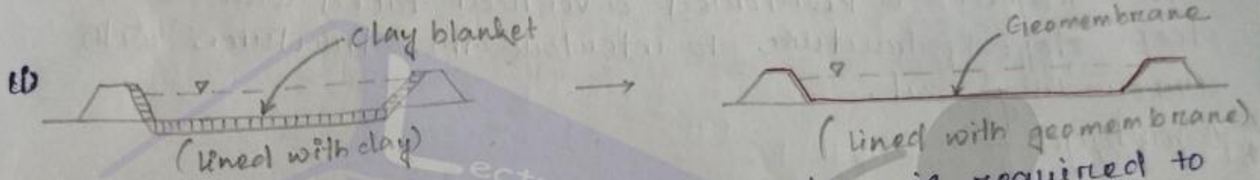
Hence chloride enters naturally at a rate of 69.6g per sq. mt of linear area per year.

3 Geosynthetics

3.1 Introduction –

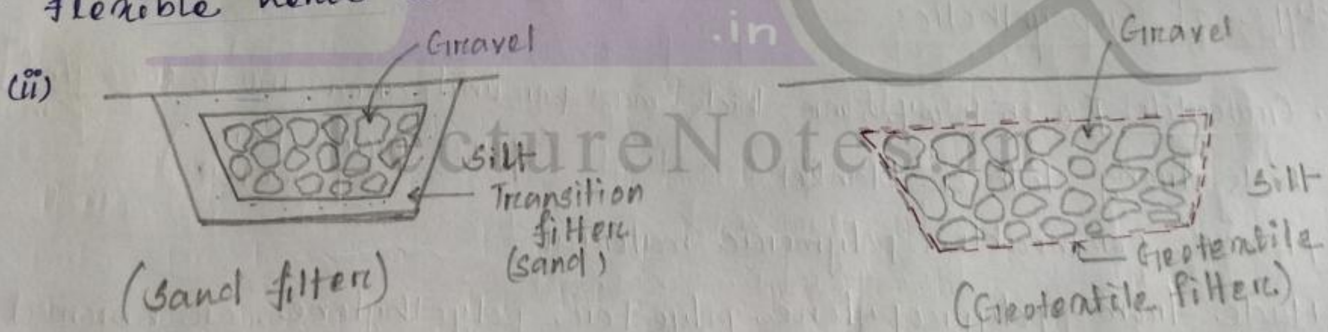
- Geosynthetics are man made products. They are flexible and planar. They are manufactured from synthetic polymeric materials and sometimes from natural materials.
- Five groups – Geotextiles
  Geomembranes
  Geogrids
  Geonets
  Geocomposites
- These are used as separators, filters, drains, reinforcement, hydraulic barriers, protectors and erosion control systems etc. Some examples are given below –

(i)



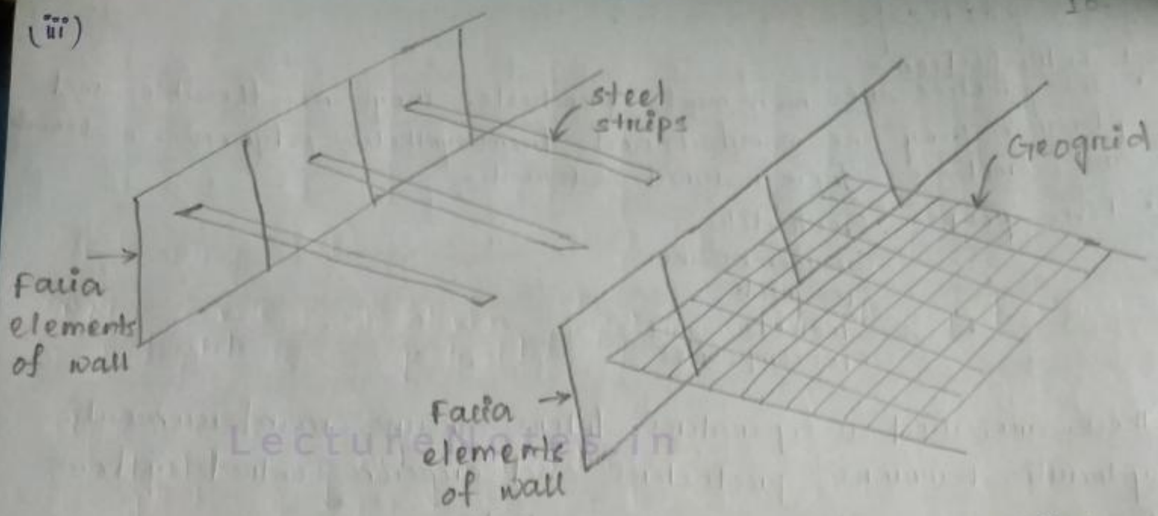
Water storage tank, impervious barrier is required to prevent loss of water. Previously clay liner is used ~~to~~ as seepage barrier & it is now 'geomembrane' is used & it is flexible hence not affected by subsoil settlement.

(ii)



Trench drain is constructed at the toe of an earthdam to carry away seepage and runoff water which required a transition filter placed in between surrounding soil and the gravel used in trench drain. This process can be done by using 'Geotextile filter' it can reduce the screening & mixing cost as well as it will ~~reduce~~ meet the requirement of filter.

(iii)



Geosynthetics together form a mesh like or grid like stiff 'Geogrid' to reinforced a vertical faced wall or a steep sloped structure to interlock the structure with surrounding soil.

* Advantage -

- As manufactured so high uniformity & quality
- light weight, 3 to 6 mt wide & long, transportation is easy
- easy and rapid installation.

3.2 Type of Geosynthetics -

1. Geotextile [0.25 to 7.5 mm thick mass per unit area 150 to 2000 g/m² gsm]
   (gsm - grams per sq. meter)

- Thick strong cloth or blanket
- planar, permeable, polymeric material
- Made from - polypropylene, polyester, polyethylene, or normal fibers like jute
- it may be woven, non-woven or knitted.

Woven - weaving/interlacing at right angle of 2 or more set of fibers.

Non-woven - mechanical bonding / needle punching of randomly oriented fibers.

2. <u>Geomembranes</u> – [0.25 to 3 mm thick & 250 to 3000 gsm]

- Thick flexible plastic sheet & smooth surface
- impermeable polymeric sheet
- Manufactured by high density polyethylene (HDPE), very flexible polyethylene (VFPE), polyvinyl chloride (PVC)

3. <u>Geogrids</u> – [5 to 15 mm thickness & 200 to 1500 gsm]

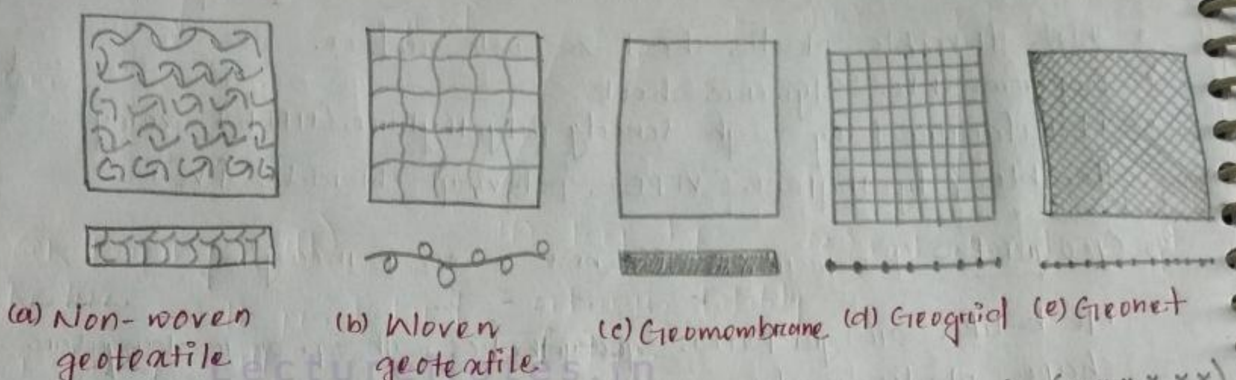
- Mesh like or grid like geosynthetics with sq. or rectangular shape, plastic meshes used in garden fences.
- planar polymeric material of regular open network of connected tensile element (ribs) with sq. or rectangular openings
- Manufactured from HDPE, polypropylene, polyester
- %age open area = 40 to 95%
  width of opening = 10 to 100 mm
  rib thickness = 5 to 15 mm

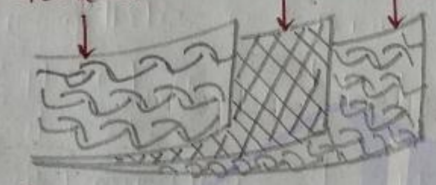
4. <u>Geonets</u> – [property similar to geogrids]

- Thin member & ~~regular~~ angular apertures not sq. or rectangular
- planar polymeric material, parallel sets of ribs overlying & integrally connected to similar sets of ribs at various angles
- width of opening – 5 to 15 mm
  rib thickness – 3 to 10 mm

5. <u>Geocomposites</u> –

- multilayered geosynthetics.
- Ex – clay / bentonite is bonded to geotextile to yield a geocomposite known as geo<u>synthetic clay liner</u>.





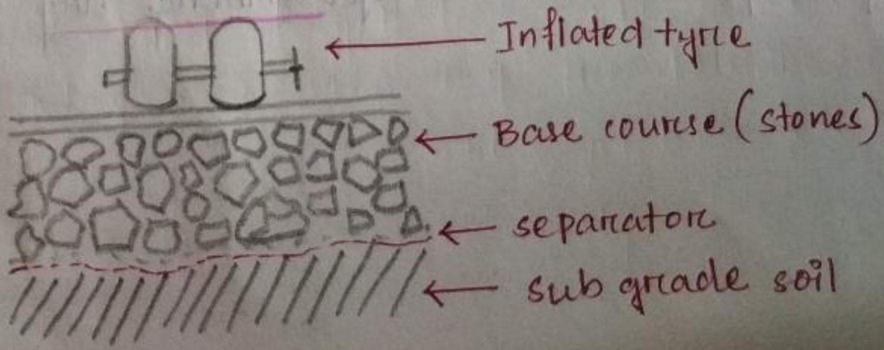
(Geocomposites)

Functions of Geosynthetics –

1. **Separation**–

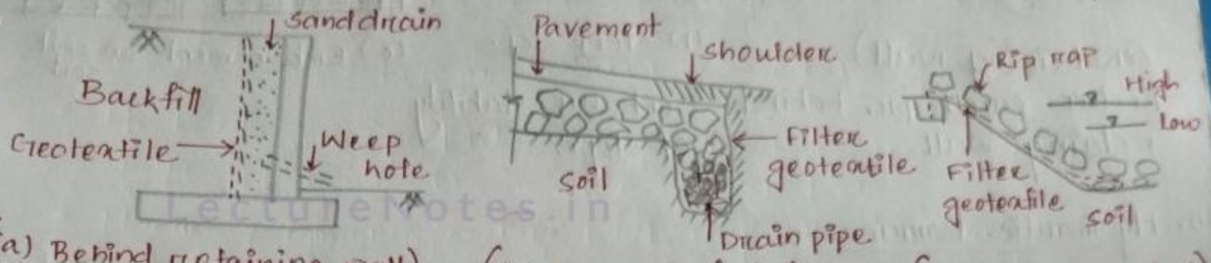
- Provide b/w 2 different layers of ~~sand~~ soil to keep them separate.
- Ex (i) road pavement consist of base course material as gravel size placed directly over subgrade soil. Due to traffic load the gravel may penetrate into the weak subgrade soil layer, so to prevent mixing we can use geosynthetic to increase the performance also.

  (ii) similarly in Railways also we can use.



2. Filtration

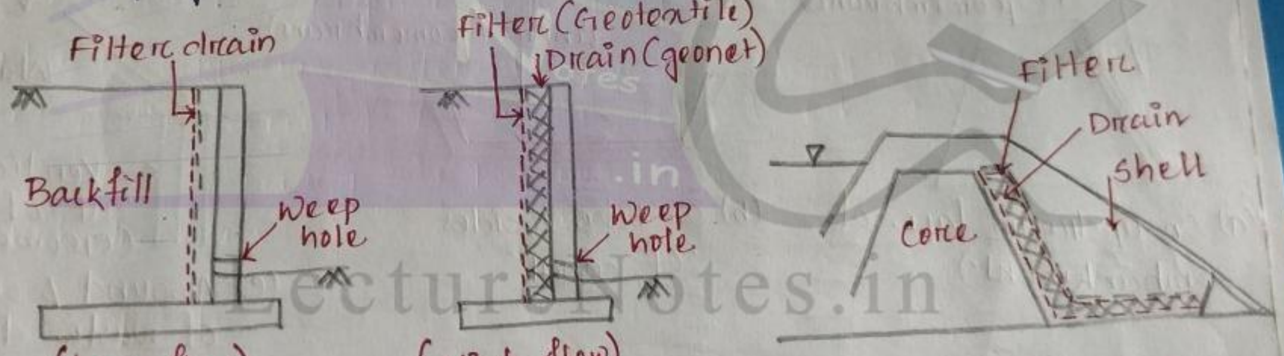
- Porous geosynthetic placed b/w FG soil layer & CG soil layer.
- Transition filter to make the water flow/pass through it.



(a) Behind retaining wall) (b) Edge drain below road shoulder) (c) Erosion control)

3. Drainage -

- Porous geosynthetics with high in-plane permeability placed within a soil mass for rapid flow of water in plane direction without migration of fines.
- Ex- seepage water intercepted behind retaining wall

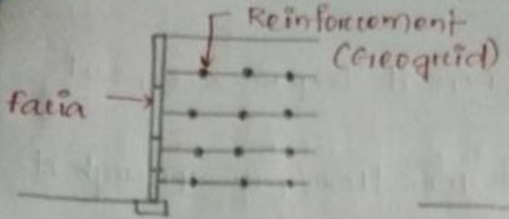


(Low flow) (High flow)

(a) Behind retaining wall) (b) Downstream of core in a dam)

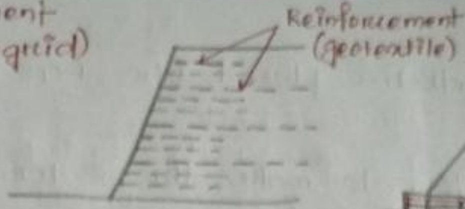
4. Reinforcement -

- High tensile strength perform the fn of reinforcement in a soil so geosynthetic is provided in single or multiple layers to improve engineering property of soil. (Bearing capacity)
- soil is good in compression & weak in tension.



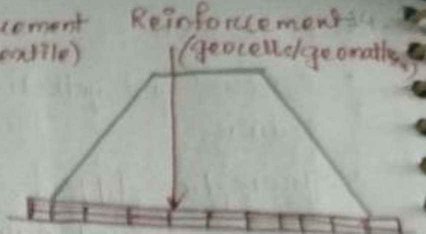
(a) Retaining wall)

- Reduce earth pr. behind retaing wall



(b) steep slope

- enhance stability of slope



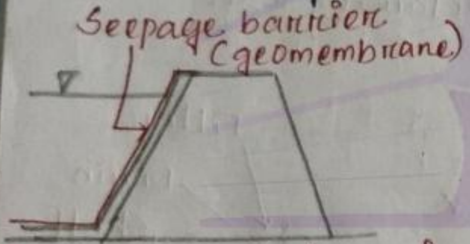
(c) Embankment on soft soil

5. Hydraulic Barriers –

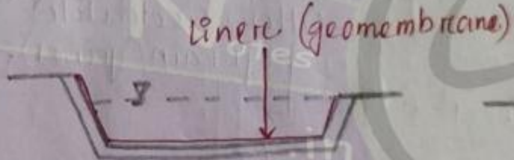
- Geosynthetic is impermeable in the cross-plane & in-plane dirn & placed in a soil mass by preventing seepage of water through soil mass.

Ex-(i) elimination of seepage water through a water retaining embankment is achieved by placing an impervious geosynthetic on the upstream slope of the embankment

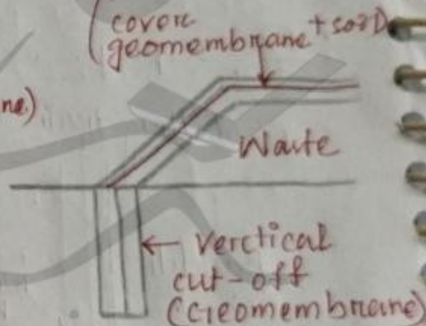
(ii) similarly in canal



(a) On upstream face of embankment)



(b) On base & sides of canal



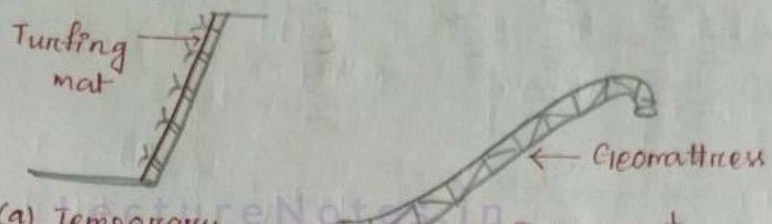
(c) Around & on top of waste dump

6. Surface erosion control –

- Temporary or permanent erosion control measures along with side slopes.
- Temporary erosion control geosynthetics comprise of natural biodegradable fibers, eg- jute. They spread in the form of grids or mats prevent erosion until vegetative growth occurs
- Geomattresses – cover the slope permanently

7. Encapsulation / Containment –

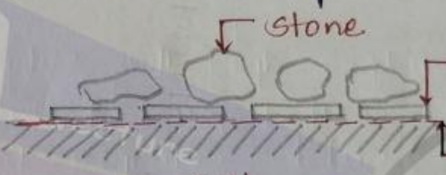
- It is used to encapsulate soil / sediments & prevent the loss of material.



(a) Temporary (b) Permanent

8. Protection –

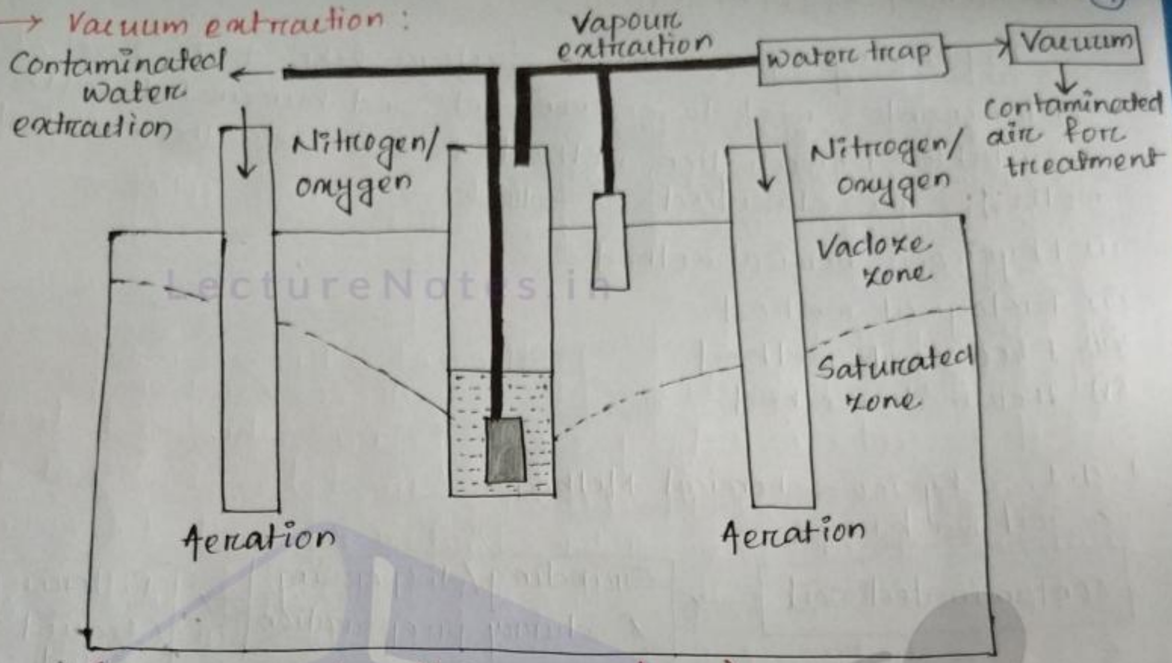
- Geosynthetics are used to prevent an underlying layer from damage ~~from~~ occur due to presence of angular materials (gravel & stone) above the layer.



* Property of Geosynthetics –

Properties	Parameters
1. Physical	Thickness, sp.grvt., gsm, porosity, ~~pore~~ percent open area, apparent opening size
2. Chemical	Polymer type, filler material, carbon black percentage, plasticizer
3. Mechanical	Tensile strength, compressibility, elongation, burst strength, seam strength, anchorage in soil.
4. Hydraulic	Permittivity (cross-plane permeability), transmissivity (in-plane permeability) clogging potential
5. Endurance Degradation	installation damage potential

→ Vacuum extraction :

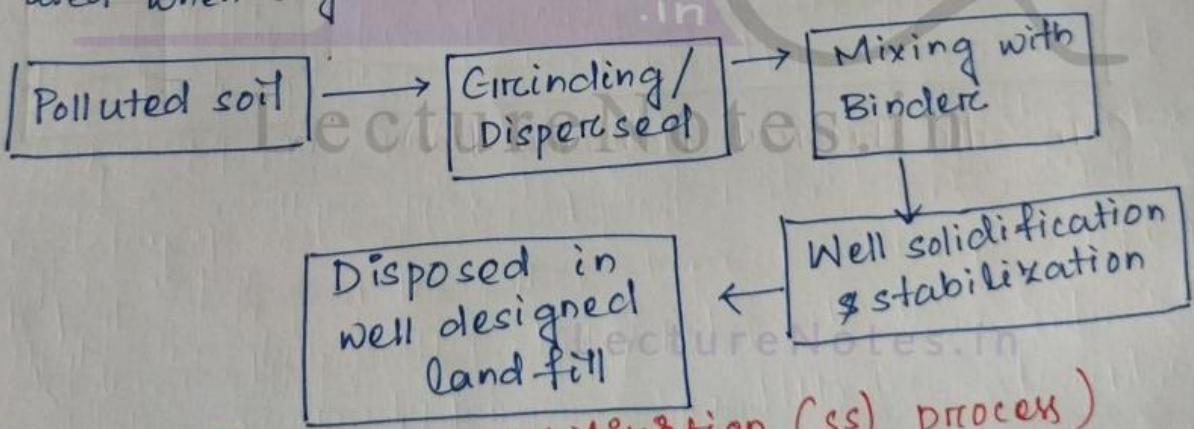


(Vacuum extraction procedure)

- This is always placed at vadoze zone. It depends on the volatilization of VOC from water into air present in voids. An injecting medium is used to extract soil-water or/and soil-air. Soil structure is also imp. for this method.
- When oxygen is used instead of nitrogen as the injecting medium, it enhances aerobic biodegradation.
- Granular soils provide better passage of fluid & gas.
- Organic matter provides high retention leading to less volatilization.
- High density & water content also minimize transmissivity and the property of VOC also influence extraction process.

→ Solidification & Stabilization :

- It is the process of im-mobilizing toxic contaminants sothat its effect is eliminated temporally & spatially. This process is performed in a single step or in two steps.
- In case of single step, the polluted soil mixed with a special binder sothat the polluted soil is fixed and rendered insoluble.
- In case of two step process,
  (i) Polluted soil is made insoluble & non-reactive
  (ii) Solidified that soil.
- This process is suitable for highly toxic pollutants & mostly influenced by the transmissivity characteristics of the soil, viscosity and setting time of the binder.
- Well compacted soil, high clay & organic content soil do not supported in-situ process of stabilization.
- The common binders are, cement, lime, fly ash, clay, zeolites, pozzolonic products etc and organic binders include bitumen, polyethylene, epoxy & resins which is used when organic pollutants are present.

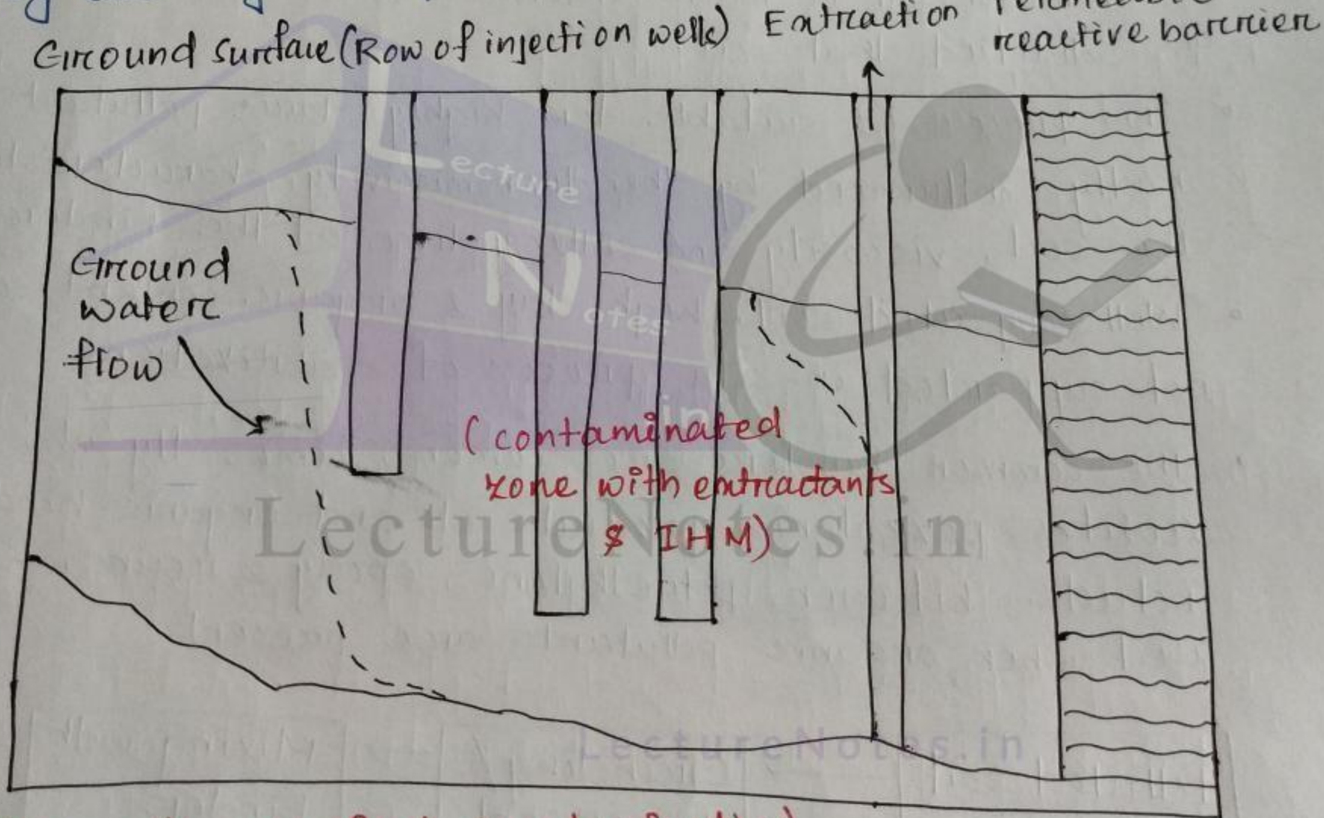


(Solidification & Stabilization (SS) process)

→ Chemical Decontamination :

- This method is applicable when the soil has high sorbed contamination of inorganic heavy metals (IHM)
  1. Identify the nature of bonding b/w pollutants & soil surface

- An extractant is used to reduce the effect of pollutants which have electrolytes, weak acid, complexing agents, oxidizing & reducing agents, strong acid etc. Multiple extractants are used when required also.
- The pore water is pumped out & treat otherwise the pore water is allowed to flow through a permeable reactive barrier & the barrier will retain the IHM by exchange complexation or precipitation reaction.



(In-situ chemical decontamination)

1.4.2 Biological Methods :-

- It is applicable for soil contaminated with organic polutants & the process is also known as Bio-remediation.
- Certain micro-organisms are used to metabolize organic chemical compounds.
- The micro-organisms degrade the contaminants. The natural micro-organisms like bacteria, virus or fungi is not capable of producing enzymes required for this method so genetically produce micro-organisms are used but before that the harmful characteristics of it should be examined.
- The remediation process depend on microbial degradation, hydrolysis, aerobic & anaerobic transformation, redox reaction, volatalization etc.

1.4.3 Electro-kinetic Methods :-

- It is a field method ~~by~~ using electrical principles for decontamination. It is suitable for granular type of soil.
- Two electrodes are inserted into the soil mass which acts as anode & cathode & an electric field is established across these electrodes that produce electronic conduction as well as charge transfer b/w electrode & solids in the soil-water system. Low intensify direct current is applied to the electrodes. This result electro-osmosis & ion migration resulting in the movement of contaminants from one electrode to another.
- Sometimes surfactants & complexing agents are used in support of this process.
- This is a costly method of decontamination.

1.4.4 Thermal Method :-

- This Method contains both high & low temp.s and suitable for high volatilization potential contaminants.
- High temp. (>5000C) process involved incineration, electric pyrolysis and in-situ vitrification. (oxidation)
- Low temp. (<5000C) process includes low temp. incineration thermal aeration, infrared furnance treatment. (phase transfer from solid to gas)
- It is an in-situ process in which hot air, water or steam is injecting to form volatization & sometimes vacuum is applied to extract air or steam for further treatment.
- Chemical agents are used to enhanced the method of decontamination. But this method is costly and can't apply for ally type of contaminants so it is not used every time.