

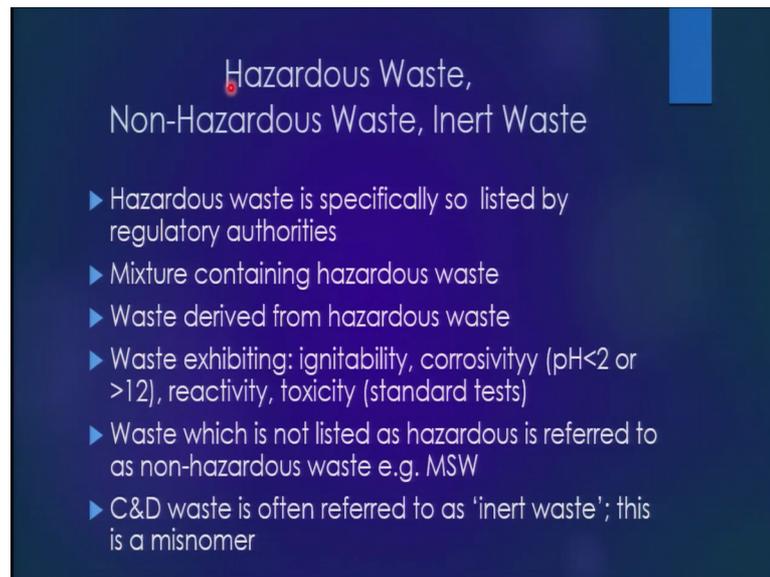
**Geoenvironmental Engineering (Environmental Geotechnology): Landfills, Slurry  
Ponds and Contaminated Sites**  
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**Lecture – 03**  
**Waste – Soil Interaction**

So good day to everybody, we are on lecture 3 in the course Geoenvironmental engineering and today, we will cover waste soil interaction to briefly recapitulate in lecture one we did introduction we defined what is your environmental engineering and we said what is it that we will cover the scope of the entire subject and in the next lecture that is lecture 2 we talked about sources and impact that is one of the sources which are causing ground contamination and subsurface contamination and how do we get an idea of the impact they make and we said the larger the source the shorter the pathway and the greater the number of receptors the greater is the impact from any waste disposal facility be it solid waste disposal facility or a waste pond.

So, today we like to talk about waste soil interaction and to begin with I remember somebody asking me this question is all waste hazardous. So, we will first address that question today. So, when you dispose when you dispose waste on ground if this could be solid waste or liquid waste it has to interact with the soil beneath it and that is what we are going to cover today.

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Hazardous Waste,  
Non-Hazardous Waste, Inert Waste

- ▶ Hazardous waste is specifically so listed by regulatory authorities
- ▶ Mixture containing hazardous waste
- ▶ Waste derived from hazardous waste
- ▶ Waste exhibiting: ignitability, corrosivity (pH<2 or >12), reactivity, toxicity (standard tests)
- ▶ Waste which is not listed as hazardous is referred to as non-hazardous waste e.g. MSW
- ▶ C&D waste is often referred to as 'inert waste'; this is a misnomer

And to begin with we like to address the issue what is hazardous waste what is non hazardous waste and what is inert waste. So, all waste is not hazardous that waste is rejected material waste is material which has which is of no use to us if in the waste there is material which is of use to us then we should reuse that material and the rejects after the reuse of the material would then be waste.

So, I told this last time that hazardous waste is specifically listed by the regulatory authorities and it is a huge list; it is not something which is you know 10 chemicals or 100 chemicals it may be thousand and it is an ever expanding list as man makes more and more complex compounds these are not necessarily natural compound which will be decaying with time or degrading with time. So, we are having the list expanding.

Once you have hazardous waste if you mix anything with it that also gets classified as hazardous and if you take out anything from it suppose you got a large amount of waste you say alright I will fractionate it I will do screening and I will take out the waste which is minus 10 mm sieve size, but this is waste which is derived from hazardous waste and unless you can prove it otherwise this will also be treated as hazardous waste.

So, there are other than this if you have a new material then; how do you say whether the waste is hazardous or not. So, there are 4 tests ignitability corrosivity reactivity and toxicity. So, these are standardized tests these are written in codes of practice. So, if you

have a new type of waste you will do these tests on it and then there are limits which are prescribed which will tell you whether it is hazardous or not hazardous.

So, all these first 4 points cover hazardous waste now if a waste is not listed as hazardous it is normally referred to as non hazardous waste if you suspect that this is a new material and it could be hazardous then you are supposed to do these ignitability corrosivity reactivity and toxicity tests, but otherwise it would be treated as non hazardous. So, municipal solid waste for example, does not come under the list of hazardous wastes. So, it is treated as non hazardous non hazardous does not mean inert non hazardous does not mean that it will not contaminate hazardous means it is proven to be harmful to health there is a direct link between the waste or the contaminant inside the waste and human health and its impact on the ecosystem non hazardous means that there is no direct link there is no direct link.

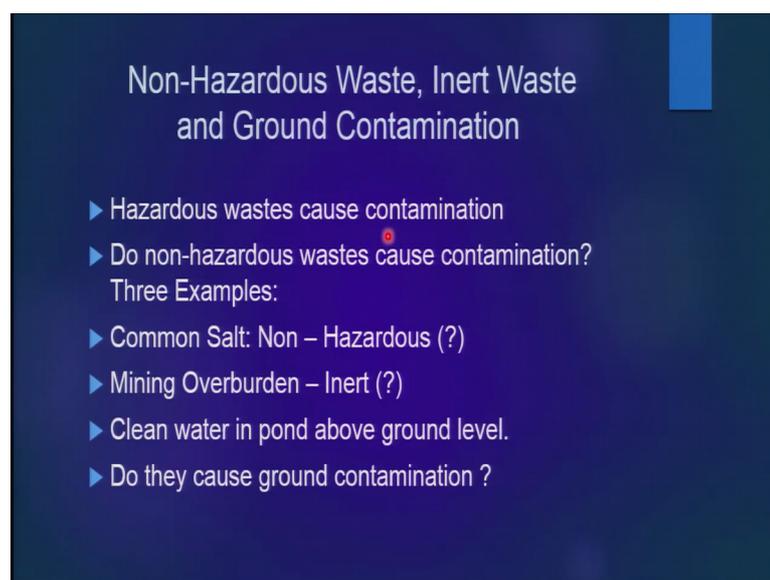
However the constituents can accumulate and the concentrations of the contaminant can increase because of accumulation and finally, you may have something coming out which is above the acceptable limit let me take an example you know ash in the fields we spread ash we burn wood if you look at the farmers in their stoves they will burn the woods and they will spread the ash on the ground because you find that it helps the growth of the next crop, but if the same ash is now accumulated in a mound which is 10 meters high at the same place it may have a different effect it may have some deleterious salts which with water would come down and because it is 10 meters thick as it comes down there will be an accumulation and those accumulated salts which were earlier within the limits would now be exceeding the permissible limits and it can cause contamination.

Construction and demolition waste is often referred to as inert waste now inert waste is something which is in its purest definition should not be chemically active should not be biologically active and should not be physically active the 3 things you need to have to become an inert waste again I say not chemically active not biologically active and not physically active now construction and demolition waste is all that we have we have breaking down right and if we are breaking down a building then its concrete its brick, but it is also wires it is also the paint its all the rebar; the reinforcement bars.

So, untreated C and D waste or unprocessed construction and demolition waste is definitely not inert right then the next step is you can process the waste and remove you can do magnetic separation to remove the metals you can do other kinds of separations to remove some of the other constituents then you get what is called processed construction and demolition waste, it is difficult to remove paint format and paint itself has some properties which are bothersome. So, still it is not inert waste.

However if I was to completely take a brick and crush it then I might be tempted to say that this brick was produced by a process of baking and its nicely burnt it is made from soil. So, maybe it is inert, but crushed material is not physically inert if you crush something you get dust out of it you get suspended solids out of it. So, the term inert which we seem to suggest that it should not be chemically and biologically active should also include that it is not physically active and that is a rare waste to get almost all natural materials undergo erosion the only one which are not going to undergo erosion in our what is the design life of our facilities 50 to 100 years. So, maybe some of the things should not in under hazardous 50 to 100 years will be boulders and rocks they will remain for 50 to 100 years wherever they were and may be physical and chemical weathering will take much longer thousands of years or more. So, maybe they can be termed as inert, but really otherwise calling C and D waste as inert waste is the misnomer.

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### Non-Hazardous Waste, Inert Waste and Ground Contamination

- ▶ Hazardous wastes cause contamination
- ▶ Do non-hazardous wastes cause contamination?  
Three Examples:
- ▶ Common Salt: Non – Hazardous (?)
- ▶ Mining Overburden – Inert (?)
- ▶ Clean water in pond above ground level.
- ▶ Do they cause ground contamination ?

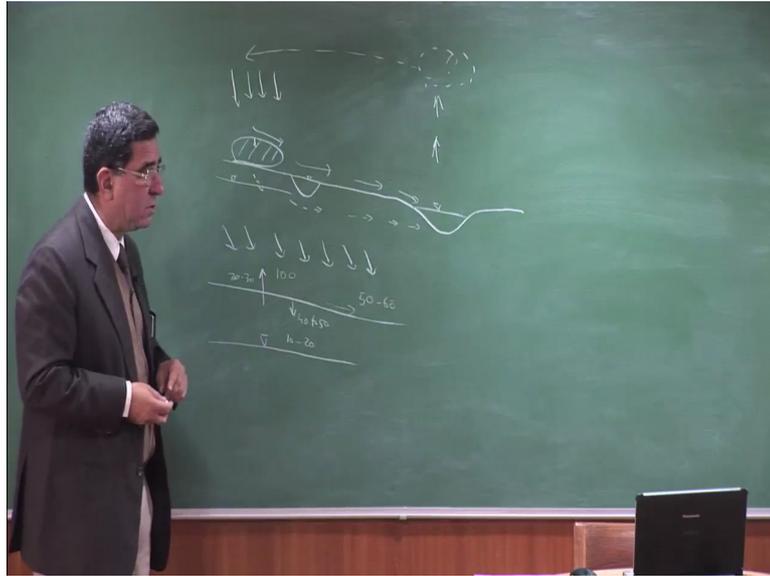
So, the question is we know that hazardous wastes cause contamination because there is a direct link if any contaminant comes they do non-hazardous wastes cause contamination that is the next question; do non-hazardous wastes cause contamination and we look at 3 examples toward the end of this lecture the first example is I am going to put common salt on ground its common salt hazardous sodium chloride we eat it it is not classified as hazardous. So, if I take a 100 tons of common salt and put it on the ground what happens we will examine it at the end mining overburden we talked is just excavated soil and rock is termed as inert again a misnomer sometimes, but nevertheless does it cause contamination.

I take clean water in the pond I create a pond by making an embankment and app store clean water in a pond above the ground level the water is clean. So, its non hazardous the material you missed made the pond off is embankments of natural soil is it contaminating the ground we will look at these 3 questions towards the end of this lecture.

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So, let us understand that I have been drawing the diagram almost every day; I put some waste; I put some waste on the ground when I put waste on the ground solid or liquid, it becomes a part of the hydrological cycle, unless I have designed it not to become a part of the hydrological cycle you cannot do anything about it which means you put out waste in the open and rain will fall on it. So, if the waste was not there; where is the rainwater going its becoming surface runoff and partly it is recharging the groundwater is it right.

So, when rain falls on the ground bulk of it recharges the groundwater or bulk of it is surface runoff.

Student: (Refer Time: 12:03).

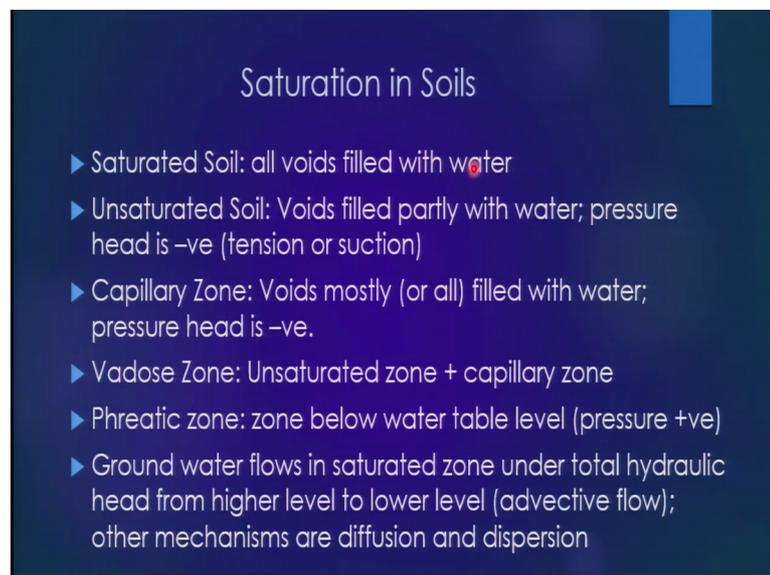
So, a bulk of the rain which falls on the ground does not go into the ground because the ground normally has grass or has a natural slope. So, infiltration into the ground is low most of it is surface runoff it goes to a local rain the local rain goes to a river the river goes to the ocean and therefore, the water goes like this and maybe some of it goes like this and what happens this goes to the ocean then what happen it evaporates becomes clouds it comes back and rains again.

So, really the hydrological cycle is. So, we now and then we have monsoons where are the monsoons coming from the moisture laden clouds where is the moisture coming from someplace where the water evaporated and when that cloud comes to a cold region it

falls rainfall. So, this cycle is going on every year and our waste has knowingly or unknowingly become a part of the cycle [FL], right. So, we are looking at waste soil interaction and the first important thing to realize when you place something in the open we are making it a part of the hydrological cycle if we had flow if I placed if the place the waste in a shed you know shed which had a proper roof and walls and those closed wall around then what would happen then the waste should not become a part of the hydrological cycle because the rain would fall on the roof the roof would put the rainwater aside and we would prevent this waste from becoming a part of the hydrological cycle, but till the time it happens till the time that happens we are looking at this phenomenon we looking at the phenomenon of some waste being on the ground rain falling on it rain percolating through it and going into the groundwater.

So, I have used some terminologies which you might be aware of Vadose zone saturated zone capillary rise, but we will take a quick recap on this what you want to know is in waste soil interaction what is happening when the water passes through the waste and what is happening when it passes through the Vadose zone and what is happening when it is into the saturated zone that is what we want to really know.

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The slide is titled "Saturation in Soils" and contains a list of six bullet points defining different soil zones and groundwater flow mechanisms. The background is dark blue with a lighter blue vertical bar on the right side.

- ▶ Saturated Soil: all voids filled with water
- ▶ Unsaturated Soil: Voids filled partly with water; pressure head is -ve (tension or suction)
- ▶ Capillary Zone: Voids mostly (or all) filled with water; pressure head is -ve.
- ▶ Vadose Zone: Unsaturated zone + capillary zone
- ▶ Phreatic zone: zone below water table level (pressure +ve)
- ▶ Ground water flows in saturated zone under total hydraulic head from higher level to lower level (advective flow); other mechanisms are diffusion and dispersion

So, just let us quickly go back to those definitions saturated soil is all voids filled with water below the groundwater table a saturated soil above the groundwater table saturated or unsaturated.

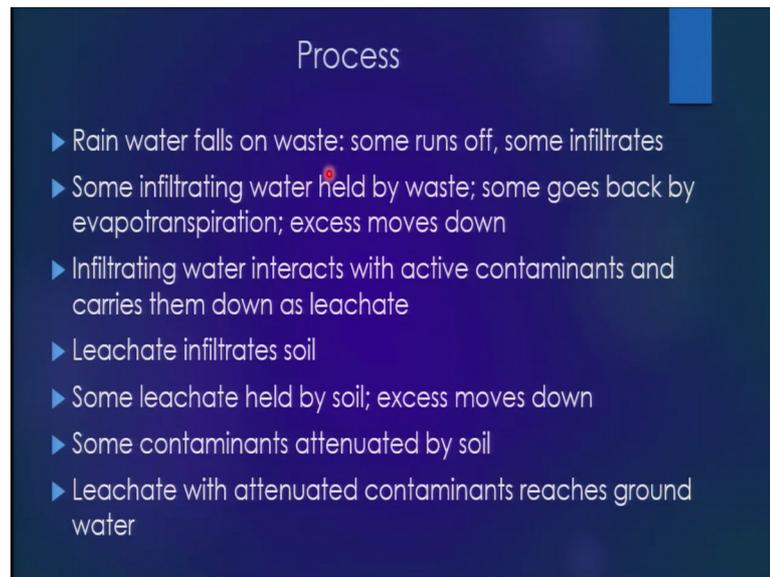
Student: (Refer Time: 15:01).

Partially saturated or unsaturated, but unsaturated soil voids filled partly with water and the pressure head inside is negative because of surface tension effects. So, you have suction or a negative pressure in the partially saturated soil.

But there is a capillary zone above the ground water is that saturated yeah the capillary is zone saturated, but the pressure inside the capillary zone is negative because the capillary action is making the capillary rise. So, the Vadose zone the word Vadose zone which we have used it covers both the unsaturated soil and the capillary rise and the capillary zone truly the saturated zone is below the water table.

So, Phreatic zone is the zone beneath the water table now we start to get positive pore water pressure and ground water flows in the saturated zone under total hydraulic head from higher level to lower level this is called advective flow we all done this the Darcy's law is valid  $q$  is equal to  $k i a$  that is the mechanism by which the water is flowing in the saturated zone we have not done how the water flows in the unsaturated zone will briefly visit that here the other mechanisms once the groundwater is contaminated with something; that means, the concentration in the groundwater of a particular constituent the concentration of the of a particular constituent in the Leachate is higher than in the groundwater. So, there is a concentration gradient. So, over and above the advective flow you have the other mechanisms which are diffusion and dispersion we will discuss that very briefly later this is not a course on groundwater contamination transport these are processes there are huge softwares which can simulate diffusion and dispersion ours is a course on design; design of waste containment facilities design of slurry ponds and remediating contaminated sites.

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Process

- ▶ Rain water falls on waste: some runs off, some infiltrates
- ▶ Some infiltrating water held by waste; some goes back by evapotranspiration; excess moves down
- ▶ Infiltrating water interacts with active contaminants and carries them down as leachate
- ▶ Leachate infiltrates soil
- ▶ Some leachate held by soil; excess moves down
- ▶ Some contaminants attenuated by soil
- ▶ Leachate with attenuated contaminants reaches ground water

So, let us look at the process the rainwater falls on the waste some runs off some infiltrates. So, how much will runoff and how much will infiltrate will depend on how the waste has been placed if the waste is properly compacted it has a convex upwards shape it is got a layer of soil on it then most of the water which will fall will run off on the convex shape; however, if it is a waste dump with nobody is managing and the surface is like that undulating surface then the water tends to stick on that undulating surface it will form small small puddles and that water tends to go down more. So, rain water falls on the waste some runs off some infiltrates this infiltrating water will it reach the ground my question is some water enters the waste will it reach the ground.

Student: (Refer Time: 18:06).

So, let me go back to the slide and let us try and simulate this on the board as I said some will run off and someone infiltrate.

So, if 10 units fell if 10 units of rain fell and let us say 7 units ran off; that means, a good convex shaped thing then 3 units maintain well now will the 3 units reach the ground surface that is the first question?

Student: (Refer Time: 18:42).

Pardon.

Student: the line is not a (Refer Time: 18:44).

No, there is no lining, this is just a waste dump it is just a waste dump which seems to have a convex shape if it done have a convex shape 3 will run off 7 will coming right the question I am asking is the 7 units were here will there be 7 units here because where will they vanish?

Student: decomposition.

Decomposition of what; of H<sub>2</sub>O?

Student: entering still site solution.

(Refer Time: 19:16) that chemically react. So, what; some materials will go into solution and still come down.

Student: is (Refer Time: 19:23)

So, first let us assume that the waste is not reactive then will all the water which fell on top come down?

Student: may be (Refer Time: 19:31) below the fall use one (Refer Time: 19:33) come part of the (Refer Time: 19:34).

So, you will fill up the void it will little come down. So, what you are trying to articulate is that if the waste is inert and x units went in some maybe held by the pore space I am not sure whether it will be held or not, but if you have fine pores then by capillary action alone you will hold water only excess water we come down.

So, if x units come in here something less or more than x can come how will it be more maybe the waste itself is also squeezing out liquid if you take municipal solid waste put it in a plastic bag and just you know hang it like that after sometime [FL] squeeze that is the squeeze do water or the decomposition water which is coming down. So, the x is not going to be equal to the y which reaches the ground and if it is inert; what will reach the ground will be less than x because some water will be held in the matrix of the pores and balance will reach here.

Now, if it is I said this is if the waste is inert, but if it is a waste which is not inert then chemical reactions will also take place as the water goes down mostly there will be dissolution some salts will dissolve and form a solution, but there can be all kinds water will cause biodegradation it may be anaerobic it may be aerobic. So, all kinds of complex interactions can take place as the water goes down.

So, rain water becomes Leachate and it reaches the bottom, but if Leachate is going to be held in the pores you may have less water reaching the base than the water which was coming in from the top then what happens now our Leachate encounters the soil now in the soil also there is a distinctly saturated zone and the unsaturated zone. So, when the when the leach it goes into the soil what will happen again some of it will be held because the unsaturated zone maybe this dry soil . So, you add 1-2 percent of water it is not going to flow it is going to be held because there is a field capacity of the soil.

Then the excess water will come down then the excess water will come down the other thing is will there be a chemical reaction now between the soil and the Leachate which is coming in what do you think maybe yeah. So, intense interaction between the water and the waste and it can be 2 way it may be dissolving something and going down and precipitating it at a lower level we cannot predict the complexities of this, but we can model them then you hit the soil and its soil inert why not its sand inert well let us not talk about physical physically inert, but is it chemically and biologically inert soil.

Sand; so, you said soil may not be inert, but sand may be inert is that is that a correct statement why will soil not be inert.

Student: So;

It is a mixture of.

Student: of caring (Refer Time: 23:19) them self.

What is typical organic content of soil now you only started the discussion that it what was said was soil is not [in/inert] inert because it is a mixture of organic and inorganic typically if I take a soil when you do soil mechanics do you is organic content at a normal test which you do yes or no, no, because why organic content is very higher or very low.

Student: very low;

Very low; so, in the surface on the surface of the soil for the agronomist in the agricultural engineers there is plant growth there are roots. So, let us say for the first half a meter you will have organic content because of biological activities. So, you are right there could be biological activities, but you think you will have biological activities 10 meters we know the ground no maybe they will be some microorganisms who can live without oxygen I would done it, but the organic content of soil will normally not be more than a how much.

Student: 10 percent.

Half a percent one person maybe less than that so, the organic content of soil is typically very low, but there are a lot of microorganisms in the soil typically in the upper zone. So, if there is sand pure sand will there be grass on it unlikely because pure sand is does not promote growth of that. So, you have to have silt in it which will hold the water which will hold the nutrients will allow the root growth to take place. So, sand and gravel typically gravel is easier to understand than sand gravel is definitely not going to have any interactive properties both biologically and chemically mostly.

So, when the Leachate hits the ground and most of the soil is not pure sand and pure gravel it will be silty sand, sand is not like Delhi. So, there is grass which is growing on it. So, it is active and if you have clay silt; silty clay that will be active clay particles are inert, why is it not inert?

Student: (Refer Time: 25:34).

Clay particle they have a negative charge. So, there are they are electrically lot of negative charge on the surface of clay particles. So, they are totally different from sand in any case Leachate will interact with the soil.

Even if the sand grains are inert there may be some interaction of precipitation from the water onto the sand grains suppose your solution is coming down the waste and it is picking up chlorides or carbonates when it comes to the soil it suddenly becomes supersaturated with respect to chlorides and carbonates very different pore size different environment all together it might want to where the temperature changes right maybe the

municipal solid waste at a temperature of 40 degrees and the soil at a temperature of 15 degrees. So, maybe what was solubility at 60 degrees was high and at 15 degrees is low. So, something will come out of solution.

You may have inert grain. So, there is interaction between the Leachate and the soil and the balance Leachate which is over and above the holding capacity of the soil goes into the groundwater and that interaction continues because there the soil matrix in the groundwater also, but now the groundwater is moving this moisture nothing is moving here, but when you come to the groundwater it is moving under a hydraulic head from higher ground to lower ground.

So, consequently contaminate begins to move in the groundwater. So, that is the process that is the process at every stage there is interaction and all kinds of interaction. So, for a civil engineer it is boggling; the mind boggling, but it is very simple, it is too complex. So, and what is the worst design condition worst design condition is Leachate is coming into the waste the waste the Leachate is going into the soil the soil is becoming saturated and then it is getting a saturated connect with the groundwater that is the worst condition because partially such saturated soil the permeability of partially saturated or unsaturated soil is more than of saturated soil or less than a saturated soil.

Student: (Refer Time: 27:55).

Why less; wide space [FL] same[FL].

Student: (Refer Time: 27:59) such as the saturated form.

So, one is the issue of matrix section and second water will only travel through the water film. So, if you have a wide space in which 50 percent of it is water then water will only travel to the that water film and therefore, the pathway the cross sectional area is slow. So, partially saturated soil will have low permeability to water as saturation increases permeability to water where increase and when it is saturated it will become the highest low value. So, critical design condition is everything is saturated. So, we make this building this building is made for its self weight, but it is made for critical design loads which is what earthquake wind tsunami cyclone.

So, similarly when you design something for waste it is. So, the critical condition it is not for the intermediate condition right. So, let us summarize what we have talked about the process rain water falls on waste some runs off some infiltrates; some infiltrating water is held by the waste some goes back by Evapotranspiration. So, water is going down, but this also going back by Evapotranspiration excess water moves down this excess water interacts with the active contaminants and carries them down as Leachate; Leachate infiltrates the soil some Leachate is held by the soil excess moves down.

Some contaminants are attenuated by the soil attenuated means they retard the conduct some of the contaminants are held by the soil concept of rapid sand filter you; your Leachate will interact with the soil and maybe the net negative charge of the clay particles will hold back calcium calcium ions. So, that is called attenuation or retardation Leachate with attenuated contaminants reaches the groundwater and then flows with the groundwater, but the interaction continues in the groundwater with the soil with the soil.

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Process:  
Waste – Water – Soil Interaction

- ▶ Physical interaction: TSS
- ▶ Chemical & Biochemical Interaction: Ion exchange, reaction, sorption – desorption, dissolution – precipitation, volatilization, biodegradation, others
- ▶ Affected by temp, pH, presence of oxygen, moisture content, others
- ▶ Complex phenomena

So, what kind of interaction occurs; this physical interaction as the rainwater goes down in a waste dump; total suspended solids will go down, the fines may travel with the;

Student: (Refer Time: 30:37).

With the water as it goes down. So, there is a tendency if you have heterogeneous municipal solid waste the fines tend to come down with time because as the water goes through with it the fines come down with it a lot of chemical and biological interactions ion exchange reaction sorption and desorption dissolution precipitation volatilization biodegradation another lots of I mean I cannot predict what is going to happen which is the predominant reaction which is going to take place and these are affected by the temperature the pH the presence of oxygen or the lack of oxygen the moisture content in situ and other factors. So, this whole thing is like a biochemical factory biochemical factory this is going on and that is waste first interacts with the water the water that interacts with the soil and then it reaches the ground water.

Again one may tend to think let us say I have soil lets go to original ground and 100 units of rain are falling on this original ground and let us say out of these 100 units 50 units run off 50 to 60 units are running off surface on off then what is going down 60 to 50 you know this will be held some of it will be held right because if the soil on the ground surface is dry the water table is somewhere deep below or few meters below.

So, order this 60 to 50 due to a rapid transformation 20 to 30 may go up. So, what is going down even 10?

Student: 10.

So, maybe now these are all hypothetical figures, but if you at look at India as a whole and take the major river basins the following is what is observed and about 60 percent of all the rain goes to the river streams it becomes stream flow 60 to 50 percent become stream flow groundwater recharge is only 10 percent or less.

So, ground water recharge from directly precipitating rain is not very high and the balance is evaporation and Evapotranspiration first what accumulates on the surface is evaporated and then the flag roots also take it off.

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So, very if little amount reaches, but if I put a waste dump now in position for you a badly maintained waste dump badly maintained waste dump what is happening this 50 to sixty falls to 10 to 20 or 20 to 30 right 80 goes it.

Now, in a waste dump there are no grass growing vegetation growing it is a miniscule solid waste number, it is a hazardous waste dump. So, what happens is their transportation route no is there an operation yes if some of the water holds on the top it will evaporate back. So, maybe 10 will go back 70 is still going through now that comes the model into play out of the 70 maybe 30 should be held by the waste maybe.

But what if the waste has preferential flow channels vertical preferential flow channels if you sometimes go to a waste dump you will see vertical cracks. So, what happens through that it will go very fast it will go very fast? So, this whole concept that this is the homogeneous soil mass does not exist for waste worst waste is a heterogeneous soil mass. So, if it was to go usually formally everywhere then maybe 30 to 60 would be held back, but it does not and you may have vertical path and you may horizontal I mean any kind of high permeability zones.

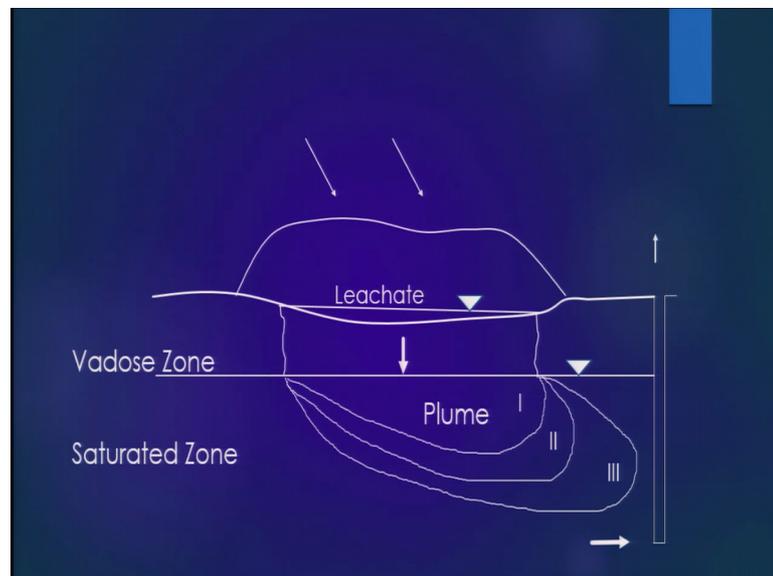
And then it comes on sits at the ground surface and the ground surface is horizontal waste is typically placed where in horizontal ground or low lying areas.

Student: (Refer Time: 35:46).

I told most of the time wasters puts to start within the low lying area. So, low lying area means that you had. So, all the things will come and accumulate in that low lying area and the fines have come down anyways. So, and will it now will this go back up no there is no evaporation possible it is all covered. So, a larger amount of Leachate tends to come down; however, if you start doing calculations in the Leachate by using the holding capacity of soil or equivalent soil mass you tend to show a lot of water is held in the waste which may get help or which may not depending on the vertical preferential flow path.

And if you go to a waste dump you will find perched water table why fines came down and settled at one level fines came down and settled at another level. So, there may be high permeability zones and there may be impervious zones as well. So, when you are excavating those you know that there is no water table, but you find little puddles of water inside the wastes because fines are coming down they do not reach the base when you have a 30 meter high dump fines will come down [FL] artificial [FL] finds gets [FL] then on that the first water table get form.

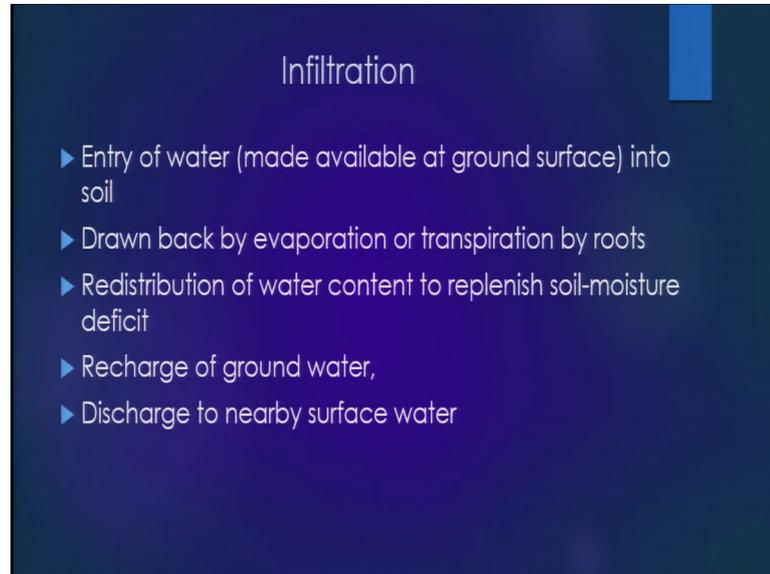
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So, when the Leachate accumulates here it is stay there because it is a low lying area it does not go back because its covered the sunlight is not reaching it is not going to evaporate back and there is no Evapotranspiration which is going to take place the

contaminates come the contaminants interact here they also interact here the water is moving in this direction the groundwater. So, contaminant plume is formed.

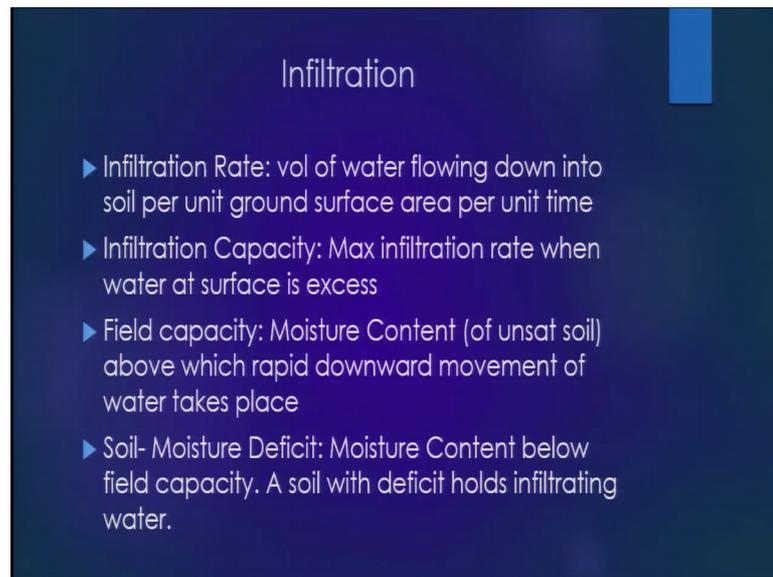
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And this contaminant plume travels in the direction of flow of the groundwater. So, infiltration entry of water made available at the ground surface into the soil that is it terminology drawn back by evaporation or transpiration by the roots after it is drawn back redistribution of water contained to replenish the soil moisture deficit you have the moisture inside the soil natural moisture content and then you have the field capacity that is the moisture content beyond which water will flow down. So, the difference between the field capacity and the natural water content is the soil moisture deficit. So, if there is a deficit the water will continue to be held only when it is more than that will it go down then you may discharge to nearby surface water or you may recharge the groundwater. In fact, this should be up you may recharge the groundwater and the groundwater may discharge into the nearby surface water.

Should I quickly change it yeah discharged to nearby surface water there is some terminologies I just want you to quickly brush them you might have done that we all done them with the in undergraduate level.

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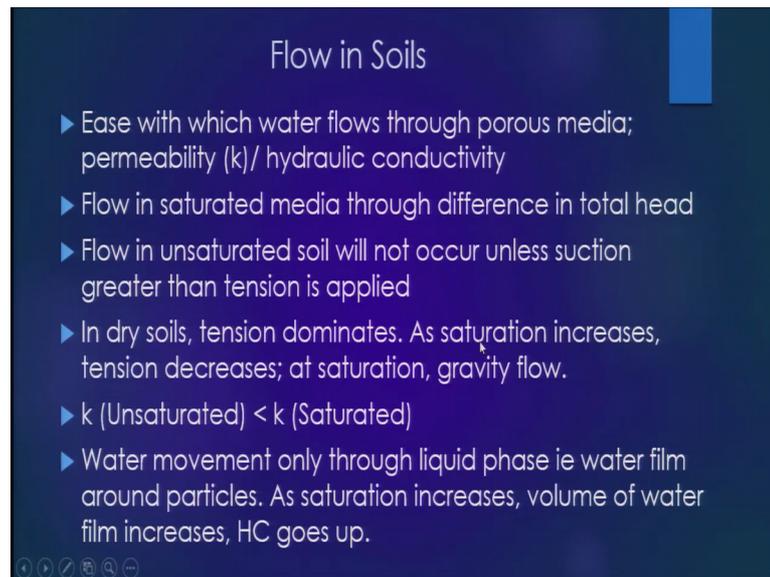
### Infiltration

- ▶ Infiltration Rate: vol of water flowing down into soil per unit ground surface area per unit time
- ▶ Infiltration Capacity: Max infiltration rate when water at surface is excess
- ▶ Field capacity: Moisture Content (of unsat soil) above which rapid downward movement of water takes place
- ▶ Soil- Moisture Deficit: Moisture Content below field capacity. A soil with deficit holds infiltrating water.

Infiltration rate volume a water flowing down into the soil per unit ground surface area per unit time and infiltration capacity if you flood the surface of the ground what is the maximum rate at which infiltration will take place, so, it is says volume of water flowing down into the soil per unit ground surface area and infiltration capacity.

You seem to want to anyways infiltration capacity is the maximum filtration rate field capacity as I told you moisture content of unsaturated soil above which rapid draw a downward movement of water takes place and soil moisture deficit moisture content the low field capacity a soil with deficit holds infiltrating water.

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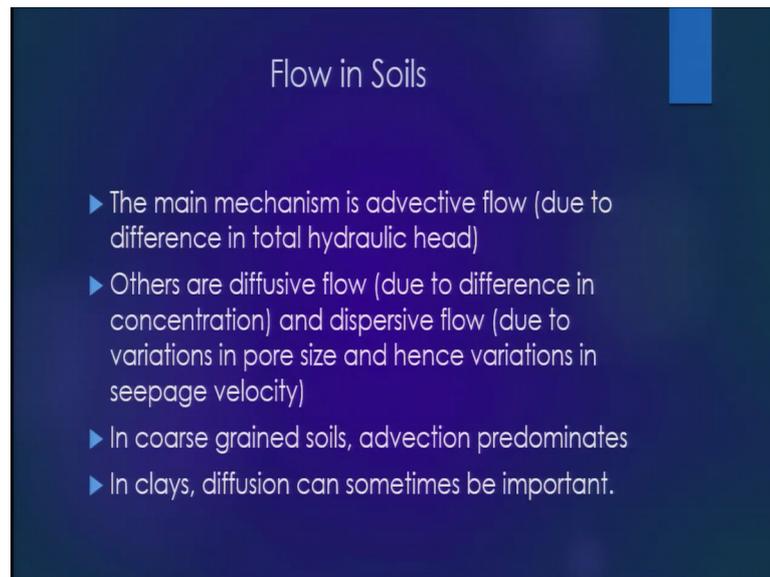
### Flow in Soils

- ▶ Ease with which water flows through porous media; permeability ( $k$ ) / hydraulic conductivity
- ▶ Flow in saturated media through difference in total head
- ▶ Flow in unsaturated soil will not occur unless suction greater than tension is applied
- ▶ In dry soils, tension dominates. As saturation increases, tension decreases; at saturation, gravity flow.
- ▶  $k$  (Unsaturated) <  $k$  (Saturated)
- ▶ Water movement only through liquid phase ie water film around particles. As saturation increases, volume of water film increases, HC goes up.

We all know about flow in soils does is law and vector flow, but let us; we recapitulate the ease with which for water flows through the porous media is reflected by the term permeability you will also find the term hydraulic conductivity written in many books. So, the flow in saturated media is through difference in total head flow in unsaturated soil will not occur unless suction greater than the tension is applied if the water is in tension you have to have a head greater than that. So, typically in dry soils the tension beam is the main dominating factor as saturation increases tension decreases and adds saturation gravity flow occurs.

$K$  of the unsaturated we already said permeability of the unsaturated is less than the permeability of the saturated water movement is only through the liquid phase that is within the water film around the particles as saturation increases volume of water film increases hence hydraulic conductivity or permeability goes up.

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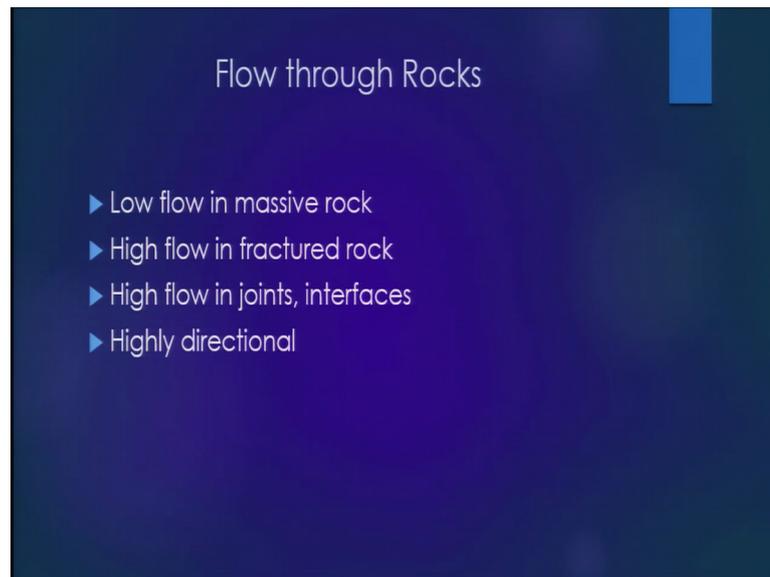
The slide is titled "Flow in Soils" and contains four bullet points. The background is dark blue with a lighter blue vertical bar on the right side.

- ▶ The main mechanism is advective flow (due to difference in total hydraulic head)
- ▶ Others are diffusive flow (due to difference in concentration) and dispersive flow (due to variations in pore size and hence variations in seepage velocity)
- ▶ In coarse grained soils, advection predominates
- ▶ In clays, diffusion can sometimes be important.

The main mechanism is advective flow; that means, when I look at the plume the plume is moving because of the difference in the it is a gravity flow and there is a difference in the total head causing flow from one point to another the other factors are diffusive flow which is due to difference in concentration which will look at when we are doing contaminated sites what is diffusive flow and dispersive flow due to variations in pore size and hence variations in seepage velocity you send a water along channel and suddenly the pore sizes change. So, there will be dispersion in the flow because of the fact that there is a kind of a tortuosity the seepage velocity in the fine poor will increase. So, it is not the same thing as everything traveling along one line and that is the dispersive flow.

In coarse grained soils advection predominates it is more than diffusion by many orders of magnitude. So, diffusive flow and dispersive flow are not of any consequence it may be a 100, 2000 to 10000 times larger advective flow; that means, flow at the gravity why because the coefficient of permeability is very high in clays with low permeability sometimes diffusion can also become significant. So, by and large and soils by and large in soils diffusion is very small, but in clays diffusion can be of the same order of magnitude and this can become important when we see performance of liners when we see performance of liners this can become somewhat important.

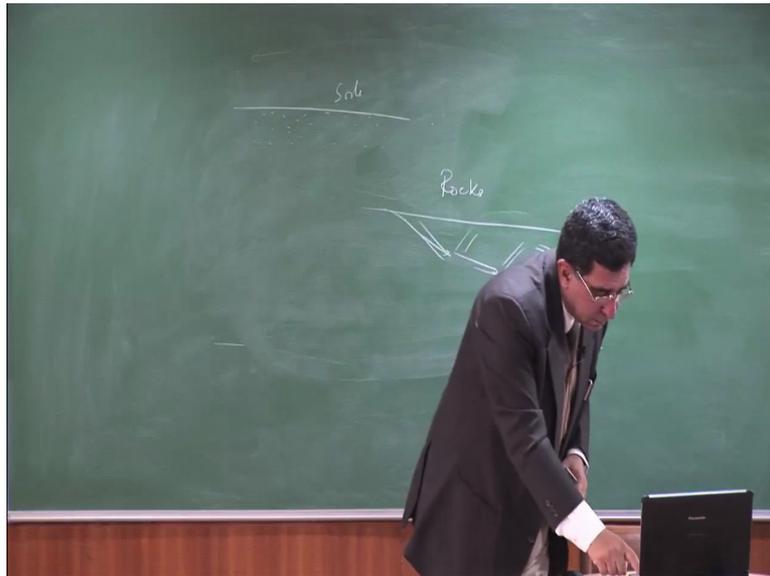
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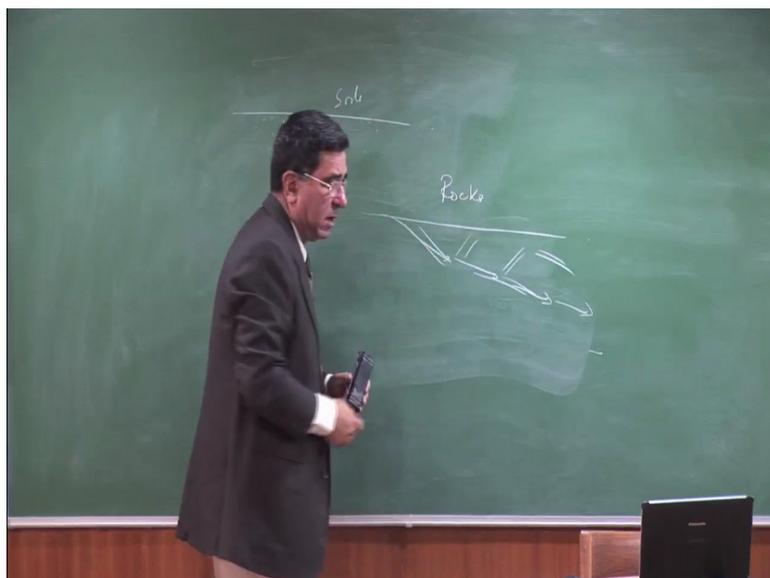
Flow in rocks is different from flow in soils; soils are typically treated as homogeneous isotropic though horizontal permeability in soils is usually larger than the vertical permeability because of the depositional effect. So, if you have a lugal soils; lugal soils will deposit in layers and there will be a some anisotropy and horizontal permeability of lugal soils maybe more than the vertical permeability, but in rock it is all about fissures and joints and fractures. So, mostly if you have solid rock flow is not going to take place, but if you have fissures and joints flow will take place and it is highly determined by the direction of the fishes in the joints is highly determined by the direction of the fishes and the joint.

And even in the unsaturated zone you may have flow occurring along these fishes and joints in a particular direction this surrounding environment will be all unsaturated, but the water may travel through a connecting fissures and joints. So, it could be vertically downwards it could be horizontal it could be inclined. So, its highly directional and that is the difference that in soils you have granular media which is porous, but which is by large uniform in rocks you will have.

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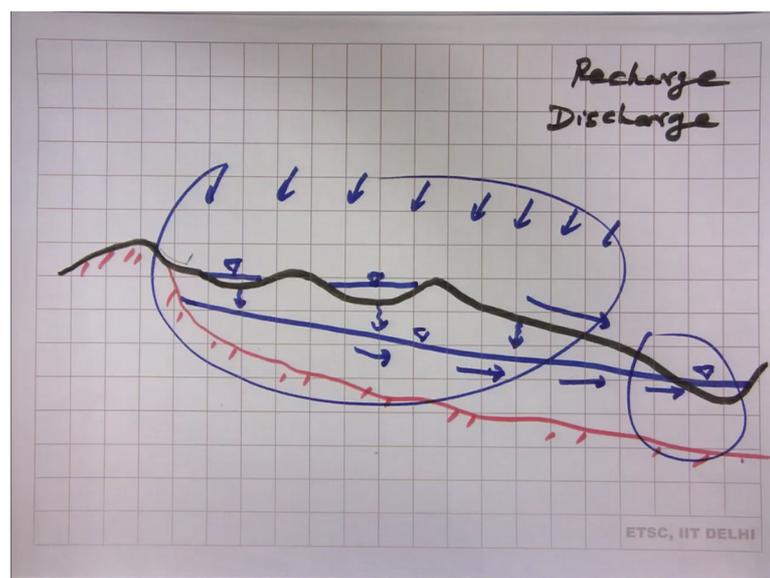
So, you can have preferential flow paths in these joints and fissures. So, you may have flow taking place very fast and many of the contaminated sites is because the waste was dumped on exposed fractured rocks when you have rock typically the ground surface will be more inclined; that means, the gradient is higher and water will traveled during the rains through this fissures and if the contaminant has entered it will travel very fast and reach a well in a particular direction. So, rocks are all governed by the fractures and fissures.

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### Flow Regimes

- ▶ Watershed: area from which water flows to a river basin
- ▶ GW Recharge Areas (predominant)
- ▶ GW Discharge Areas (low)
- ▶ Flow paths: Recharge to Discharge Areas
- ▶ Set of flow paths is a flow regime: Local flow regime and regional flow regime
  
- ▶ Aquifer: Sustain a water supply
- ▶ Aquitard: Not sustain a water supply

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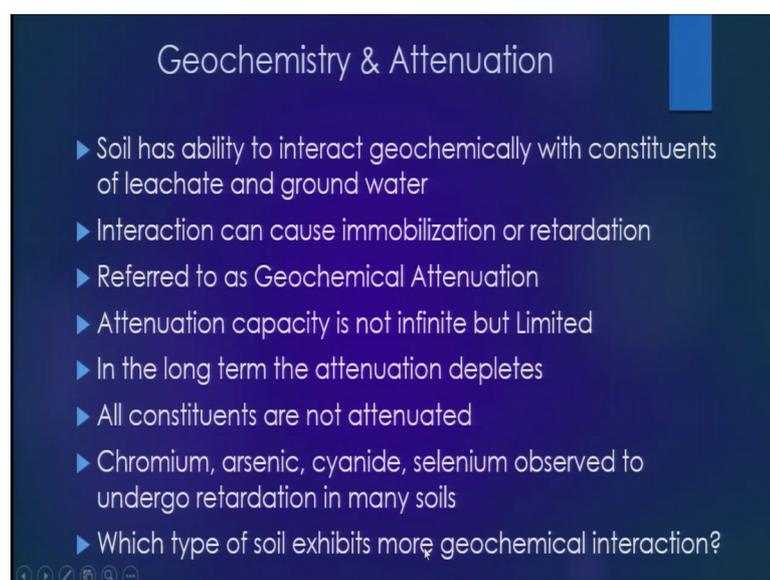
Let us look at flow regimes let me see if I can use the projector now I am just going to introduce you to the issue of the concept of recharge and discharge. So, so if this is the topography of an area water is reaching a stream or a river or a rivulet and that is the ground surface topography. So, what happens when rain occurs this is high ground this is low ground. So, this is the watershed on both sides the water is coming in. So, if I have rain here what will happen its simple for me to say that whatever rain falls here it is going to go down a little bit may come here.

But what happens here it might you may have a small puddle or a pond or you may have a minor rivulet. So, this will then work to recharge and finally, all this way water will go and discharge into the river. So, any ground will have recharge zones and discharge zones and bulk of the area is recharged small amount is discharged see this is the discharge area for groundwater and this is the recharge area for the ground water if I was to attempt to make a rock line I just gave you a ground surface. So, maybe the rock is different ways, but one of the options is maybe the rock or is like that.

So, all this may be a deposited material. So, you have rock you have groundwater and all this groundwater is recharging the groundwater and. So, depending on where you put your waste now you can have a problem of the appropriate nature for example, if you put your waste in this low lying area we have created a real problem why because this is a low lying area and it is recharging the groundwater at that location.

So, let us go back to the slide to resource the watershed is the area from which water flows to the river basin I showed you a watershed one half of it groundwater recharge area is predominant groundwater discharge there is a low flow paths are from the recharge to the discharge how is the groundwater flow taking place from the recharge to the discharge area and a set of flow paths give you flow regime and in this flow paths you can have an aquifer which can sustain water supply or you can have an aquitard; that means, the permeability is not high enough to sustain water supply.

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### Geochemistry & Attenuation

- ▶ Soil has ability to interact geochemically with constituents of leachate and ground water
- ▶ Interaction can cause immobilization or retardation
- ▶ Referred to as Geochemical Attenuation
- ▶ Attenuation capacity is not infinite but Limited
- ▶ In the long term the attenuation depletes
- ▶ All constituents are not attenuated
- ▶ Chromium, arsenic, cyanide, selenium observed to undergo retardation in many soils
- ▶ Which type of soil exhibits more geochemical interaction?

Quickly as we have already discussed this soil has ability to interact geochemically with the constituents of Leachate and groundwater interaction can cause immobilization or retardation of these constituents and this is referred to as geochemical attenuation of the soil attenuation capacity is not infinite, but it is limited please understand this there is an initial attenuation capacity which is high right, but what will happen after some time whatever active deposit would have deposited and the attenuation capacity will go down. So, initial attenuation capacity looks very attractive that soils can withhold contaminant from reaching the groundwater, but if Leachate is coming in every year after year after year this is not going to be infinite capacity.

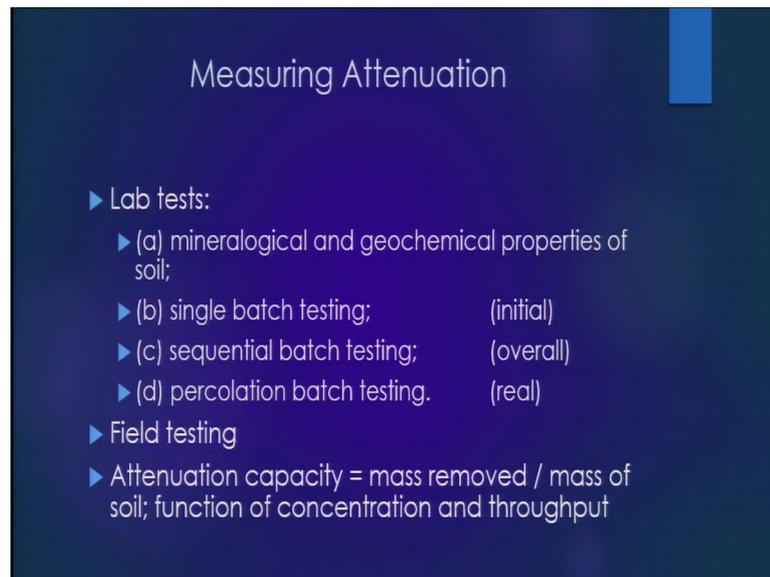
So, in the long term the attenuation capacity depletes all constituents are not attenuated do not think every contaminant will get contaminated typically for example, a chloride ion is  $Cl^-$  negative and the calcium ion is  $Ca^{2+}$  plus what will happen  $Ca^{2+}$  plus can be retarded by clay because it might get attached to the net negative charge in the clay what would happen to chloride  $Cl^-$  minus is not going to be retarded. So, many things will get retarded many will not. So, there are if you look at literature many examples of chromium arsenic cyanide selenium being retarded in many soils, but not infinitely they retard for some time and then a breakthrough occurs and it goes forward.

So, which type of soil exhibits more geochemical interaction?

Student: yes.

Yeah. So, between core strengths soils and fine grained soils fine grained soils are more geochemical interactive because of the net negative charges on the surfaces also because of the final pore size and more intimate contact of the surface area with the Leachate.

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Measuring Attenuation

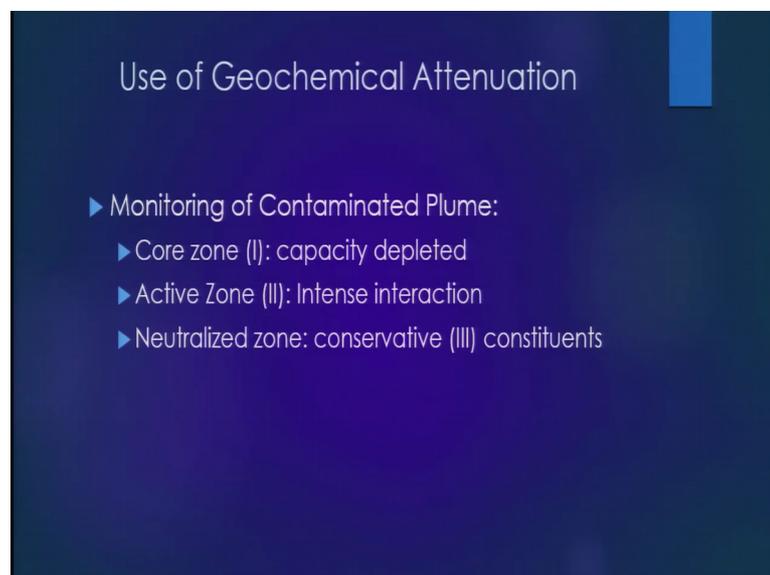
- ▶ Lab tests:
  - ▶ (a) mineralogical and geochemical properties of soil;
  - ▶ (b) single batch testing; (initial)
  - ▶ (c) sequential batch testing; (overall)
  - ▶ (d) percolation batch testing. (real)
- ▶ Field testing
  - ▶ Attenuation capacity = mass removed / mass of soil; function of concentration and throughput

Can we measure attenuation well you can do some laboratory tests first of course, you can do the mineralogical and geochemical properties of the soil if you have larger clay content you can say it will have larger geochemical attenuation capacity, but the simplest test is take some Leachate put some soil in it mix the 2 in some proportion leave it for 20 hour or 68 hours come back take out the Leachate and see whether any chemical has depleted if the concentration has gone down that constituent is being retarded.

In sequential batch testing you do this more often means you take a you take a Leachate you interact it with some soil then take some fresh soil interact the balance Leachate with that and in this way you can get a cumulative figure. So, you can get single batch testing will give you a kind of initially renovation capacity and sequential batch testing will give you a more cumulative attenuation capacity you can read about these details in in the chapter on geochemistry in Daniels; the first book that we had talked about percolation is real life; that means, take a permeameter a falling head permeameter or and percolate the water top to down. So, you put a Leachate at the top and take it out at the bottom this is the kind of a column test initially the attenuation capacity will be high then gradually the attenuation capacity will deplete. So, we can do laboratory tests to get an idea of attenuation and we can also do field testing similar to a field permeability test to understand attenuation.

So, an attenuation capacity is typically mass of the contaminant removed over the mass of the soil and this is again a function of many things throughout the time the concentration the temperature the available oxygen the pH, but you get a value you get a hold of the value from design perspective attenuation is overrated I would like to design assuming the attenuation capacity is depleted I cannot rely that the soil will attack unless you can tell me sir no I have got 30-60 meters thick soil which will attenuate then Leachate and show that for the next 100 years it can attenuate all the contaminants which are going to go down. So, typically geotechnical design presumes attenuation capacities depleted we should not let anything go into the soil.

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Because of this attenuation and everything does not get depleted as I told you we find that in the plume there are 3 zones a core zone or active zone and a neutralized zone in the core zone a attenuation capacity is depleted in the active zone interaction is taking place and the in the neutralized zone conservative constituents means nonreactive constituents I clearly gave the example of chlorides. So, it may be non reactive constituents. So, in the neutralized zone the nonreactive constituent will go forward just imagine a plume what will be in the front of the plume the reactive components; so, the nonreactive. If I have a plume which is traveling downstream along the ground water flow in the very front of the plume what will you get reactive constituents or non reactive?

Student: non reactive.

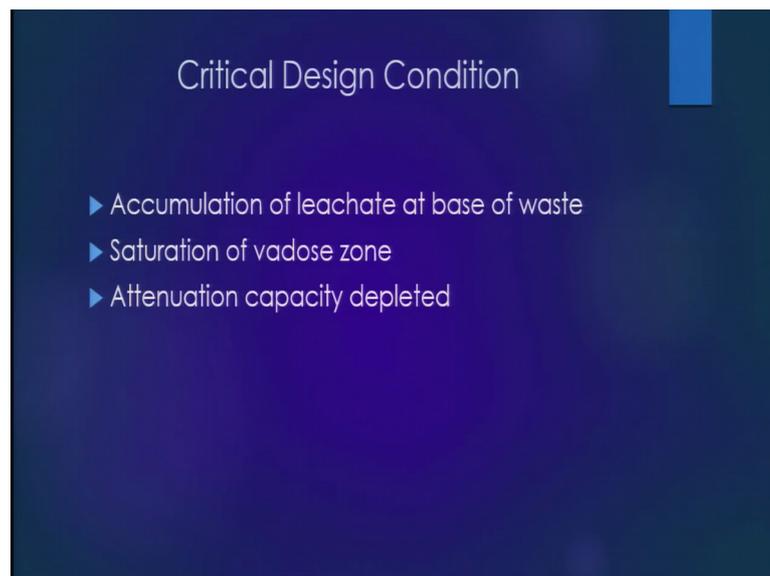
Non reactive because they have escaped all the reactions the reactive components are coming only when the attenuation capacity will get depleted. So, really the non reactive constituents travel the fastest and if you are trying to detect groundwater contamination what is it that you should be looking for?

Student: (Refer Time: 56:38).

Yeah suppose you have 5 or 7 contaminants you are trying to find out what is the spread of contamination. So, you should actually be targeting the non reactive contamination. So, so that was the plume that we had seen and those are the 3 zones.

That is the core zone its completely depleted attenuation capacity is completely depleted very little contaminants are held here attenuation capacity is there reactions are taking place right and here the reactive constituents have not reached only the neutralized conservative constituents are reached. So, here you will find the non reactive contaminants and as I said if you are putting a tube well to detect or if you are using other techniques you are trying to go in to detect the non conservative. So, core active utilized.

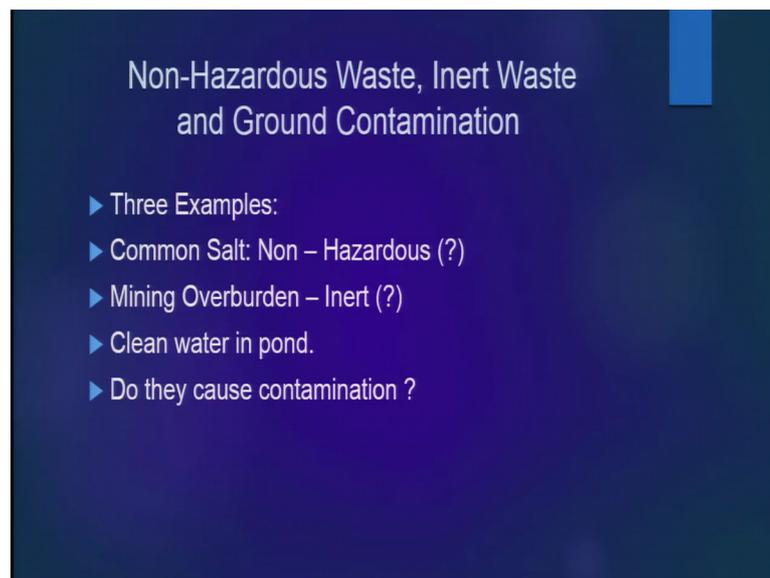
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So, the critical design I have already stated this is just reinforcing we assume accumulation of Leachate at the base of the waste because it is a low lying area. So, there

is a kind of a continuous supply of Leachate either from the squeezing fluid of the waste or from the rain water which has infiltrated we assume that the Vadose zone is saturated and we assume that the attenuation capacity is depleted and our solution must be a design which takes this into account.

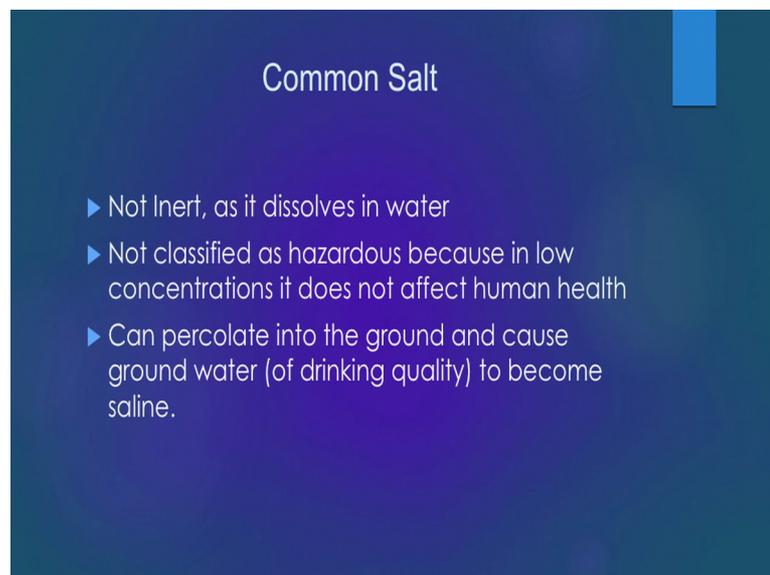
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Non-Hazardous Waste, Inert Waste  
and Ground Contamination

- ▶ Three Examples:
- ▶ Common Salt: Non – Hazardous (?)
- ▶ Mining Overburden – Inert (?)
- ▶ Clean water in pond.
- ▶ Do they cause contamination ?

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Common Salt

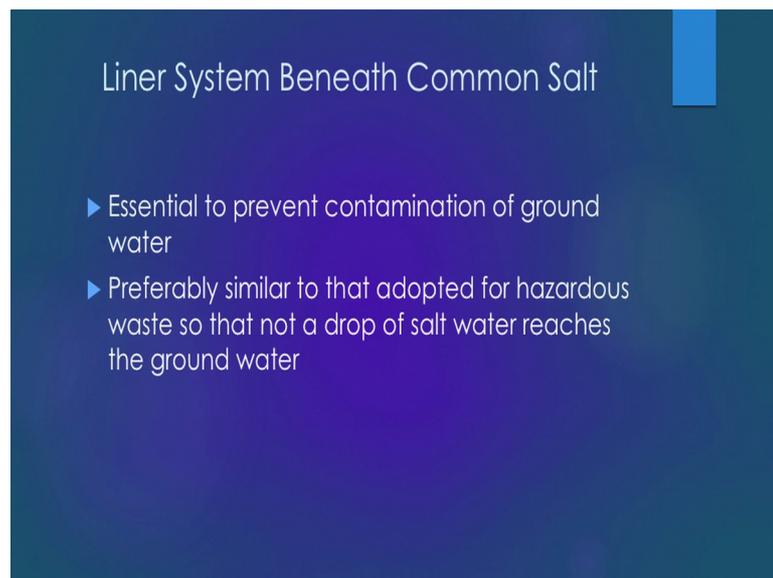
- ▶ Not Inert, as it dissolves in water
- ▶ Not classified as hazardous because in low concentrations it does not affect human health
- ▶ Can percolate into the ground and cause ground water (of drinking quality) to become saline.

Finally we have still to discuss these 3 examples. So, let us examine whether common salt when it is stored on ground should be treated as hazardous non hazardous or inert common salt is not inert because it dissolves in water. So, when rain will come common

salt will dissolve in water and tend to percolate in the ground common salt is not classified as a hazardous material because we eat it and in low concentrations it is not harmful to man.

However if common salt percolates into the ground and reaches the groundwater table it can cause drinking water to become like salt water and not suitable for drinking purposes consequently common salt for the purpose of subsurface contamination can be treated as being harmful to human health and thus depending on the system that we choose we can either designate it as hazardous because excessive intake of common salt can cause high blood pressure in human beings or we can also call it non hazardous like municipal solid waste which means though it may not directly impact the health in low concentrations it; however, renders drinking groundwater not suitable for drinking.

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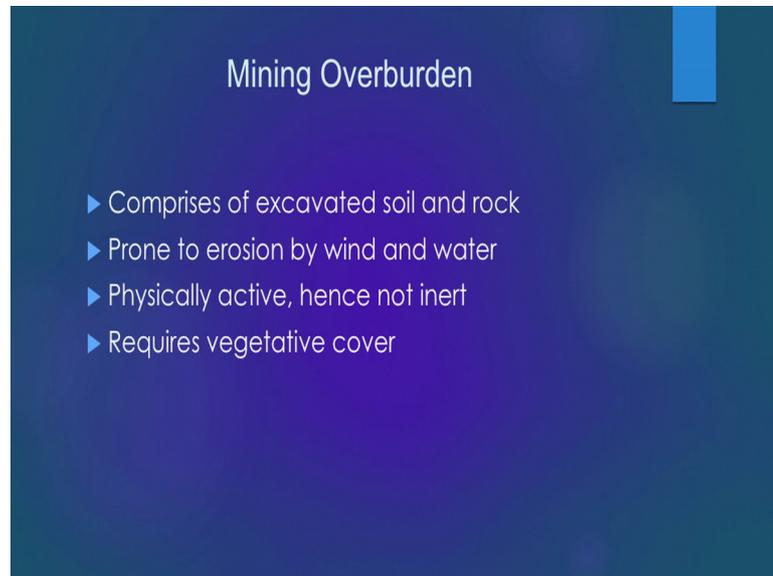


And thus needs a liner or a protective measure to prevent the salt from contaminating the groundwater and the system that would be most suitable would be basically a liner which we use for hazardous waste material because we would not even like even a drop of water having salt going to the groundwater and spoiling the quality of groundwater.

So, what this demonstrates is that depending on the way you look at a particular contaminant or a particular constituent you may treat it as hazardous or non hazardous and even though we eat that constituent such as common salt its percolation into the

ground can have disastrous effect on the quality of groundwater. So, we have to be careful about protecting our subsurface groundwater resources.

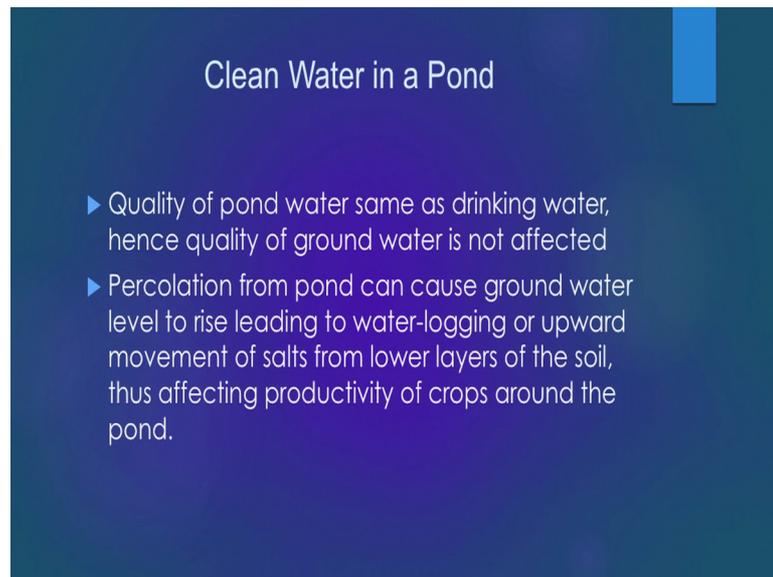
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Mining overburden which is nothing, but excavated soil and rock appears to be material which is inert and therefore, one is tempted to classify it as inert waste; however, please do recall that excavated soil or rock is prone to erosion both by wind and by water. So, during hot dry months you will have fugitive dust emissions from mining overburden and during monsoons you will have erosion gullies being formed on the mining overburden and muddy water going into the rivers.

So, mining overburden is not inert it is physically active and it impacts the environment in the form of fugitive dust or total suspended solids. So, mining overburden 2 can be classified similar to municipal solid waste that is a non hazardous waste which will impact surface water and air quality around the waste.

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### Clean Water in a Pond

- ▶ Quality of pond water same as drinking water, hence quality of ground water is not affected
- ▶ Percolation from pond can cause ground water level to rise leading to water-logging or upward movement of salts from lower layers of the soil, thus affecting productivity of crops around the pond.

Clean water in a pond well clean water is drinking water and if it percolates into the ground it can reach the groundwater; however, since it is drinking water it is not likely to alter groundwater quality; however, if a lot of clean water is stored in a pond in an area which did not have a pond in the past the water may cause the groundwater table to rise as the ground water table rises it can have 2 impacts one the area or the land can become waterlogged or 2 salts from the lower strata of soil can come up to near the ground surface as the water table rises and this can affect the vegetation of the crops which are growing at the ground surface.

So, once again it is important to recognize that clean water may not affect quality, but it can change the ecosystem because both water logging as well as upward movement of salts can affect the quality of vegetation and the quality of the crops which are growing on land adjacent to the pond and hence one has to be careful that we should line the pond with an impermeable material. So, that the water does not go into the groundwater and cause a change in the ground water regime. So, have a good day all the best.