Environmental Remediation of Contaminated Sites
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Lecture – 14
Remediation of Contaminated GW by Pump and Treat-II

Hello everyone. So again welcome back to the latest lecture session. Again a quick recap of what we have been up to. So in the context of remediating contaminated ground water, we have been looking at extracting the ground water or pumping the ground water out and then treating it. So in that context, we looked at the ideal case scenario as in what is obviously the ideal case scenario, I would be able to finish my pumping or extracting the relevant contaminant, let us say, when I pump out just the contaminated plume, let us say, or the contaminated ground water.

But as we have looked at in the previous class, we know that there are different phases and thus different sources of contaminant. So in pump and treat or in extraction of the relevant plume, I am only pumping the ground water out. As in only that contaminant in the aqueous phase or in the ground water will be removed, right. So obviously if the contaminant is adsorbed on to the soil or the organic fraction of the soil or is present in its own phase as non-aqueous phase, let us say, obviously they are going to act as reservoirs of this particular contaminant.

So as I remove the contaminant from the ground water, let us say, again contaminant from these particular or 2 reservoirs that we have talked about or the phases, they are going, what do we say, either desorb or, let us say, through diffusion change phase into the aqueous phase and again you are going to have concentrations of these contaminants above the relevant cleanup standards, I guess, right.

That is something we looked at and we looked at a few other aspects too as in stratification, right. As in I have sand, clay and gravel and so on. So obviously the ground water flow velocities through these particular layers is going to be different, right. And thus, let us say, only that contaminant that is in that particular zone where the hydraulic conductivity and thus the ground water flow velocity being relatively high, right.

Only that will be or that will be removed first. And again, you need to have equilibrium as in the contaminant in the clay layer needs to diffuse into the sand layer and then it is going to be removed. So obviously pump and treat might not work well if you have stratified layers. And also the contaminant has, what do we say, reached the equilibrium between the different strata here, right. So that is one particular case we looked at.

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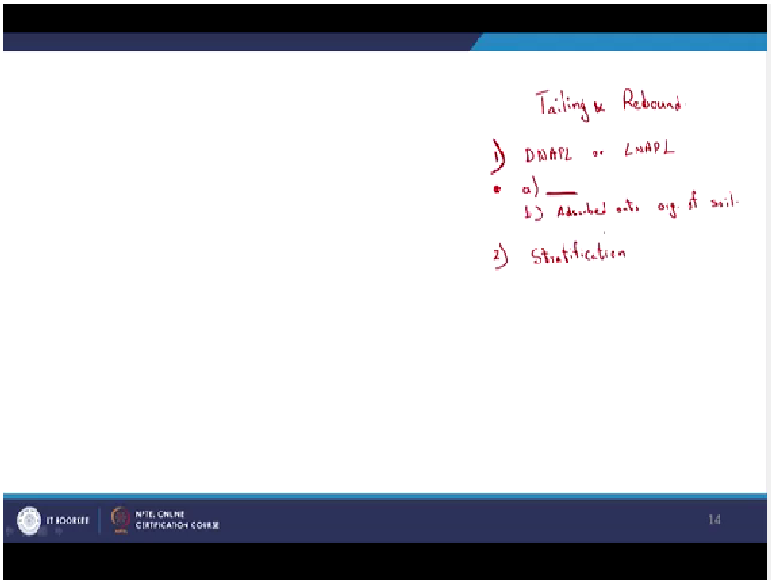

Tailing & Rebound

1) DNAPL or LNAPL
- a) ___
  b) Adsorbed onto org. of soil.

2) Stratification

And what have we looked at until now? We have looked at issues with respect to tailing and rebound, right. And in that context, what are some of the cases or causes, let us say. We know that the presence of the DNAPL or LNAPL can act as reservoirs, let us say. And in that context obviously we know that it can be present in its different phase or adsorbed on to the relevant, what we say, organic fraction of soil, right.

And then also we have different strata or stratification, that is something we looked at, right. So let us just continue this particular discussion for a couple of minutes and then move on to calculating, let us say, the time required or estimating the time required for this particular, removing this particular contaminant, right. So let us look at what we have?

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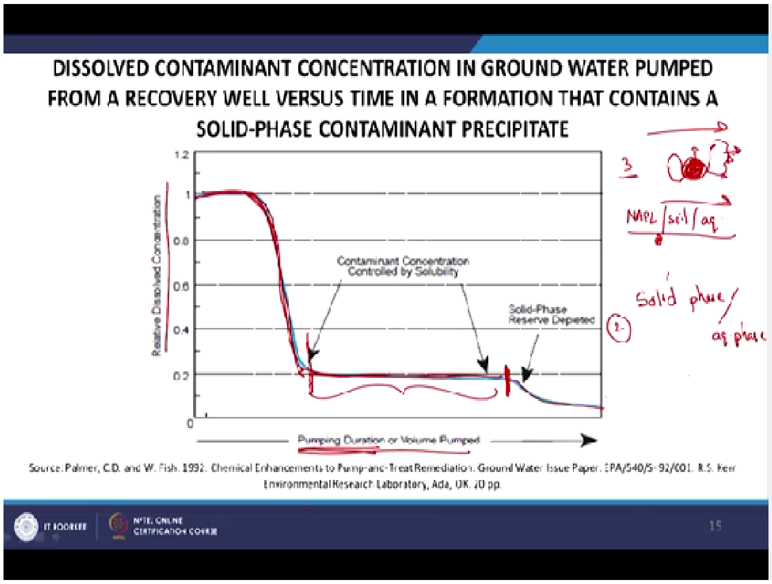

DISSOLVED CONTAMINANT CONCENTRATION IN GROUND WATER PUMPED FROM A RECOVERY WELL VERSUS TIME IN A FORMATION THAT CONTAINS A SOLID-PHASE CONTAMINANT PRECIPITATE

Source: Palmer, C.D. and W. Fish. 1992. Chemical Enhancements to Pump-and-Treat Remediation. Ground Water Issue Paper. EPA/540/S-92/001. R.S. Kerr Environmental Research Laboratory, Ada, OK. 20 pp.

So similar to what we had earlier, let us say, when we had a non-aqueous phase liquid, let us say, in between soil particles. Let us say, this is the non-aqueous phase liquid and this is the soil, right. And again compound adsorbed on to the soil and this is the ground water here. So 2 sources as in from the non-aqueous phase liquid and also from the soil, let us say. Here, let us say, we have another case as in where we have a solid precipitate, let us say. As in different forms of Chromium, let us say, they can precipitate out, let us say, right.

As in the contaminant can either be in the aqueous phase or in the solid phase by itself. So here, let us say, if I have a case where it is in the solid phase, right. And here that is what I have. So here I have, let us say, this is the case when I had all the 3 phases earlier. So here obviously it is not non-aqueous phase liquid but I have the solid phase here. Solid phase and the aqueous phase, right.

Earlier it was the case of non-aqueous phase liquid phase, soil, adsorbed on to the soil and the aqueous phase. There I had 3 phases and here I have 2 phases, right. But the principles are similar as in that. Instead of partitioning between the non-aqueous phase liquid and the water or the aqueous phase, right. The compound from the non-aqueous phase liquid will, what do we say, diffuse into the water, right.

So here now I have a solid particle, let us say, or the solid contaminant, contaminant in its solid phase. And that again will dissolve, right, precipitation and dissolution. So obviously let us say if the soil particle is out here and if I have ground water surrounding this, let us say. And obviously depending upon solubility, solubility will give me an idea about the maximum concentration that that particular contaminant will be present in in that solution, let us say.

So, let us say, equilibrium has been reached and the solution around the soil particle, let us say, has the maximum solubility or the solubility pardon me or is it the solubility concentration, right. And obviously now if I remove this water, let us say, and now I have fresh water around this particular soil particle, not soil particle pardon me, solid phase of the contaminant. Now again I am going to have dissolution of this particular solid phase, right. Why is that?

Because the water surrounding this particular solid phase of the contaminant does not have any, what do we say, contaminant, right. So the equilibrium has not been reached. So now again the system is going to change or move in such a direction that there will be equilibrium between the solid phase and the aqueous phase, right. So the compound is going to dissolve from the solid phase into the aqueous phase and that is what we see here, I guess.

So initially, let us say, I keep pumping out all the water in the aqueous phase. And here I have pumping or pumping duration or volume pumped obviously and relative concentration here. So initially I pump it out here, right. And thus I see a drop in the relevant concentration here. But relevant concentration of the compound as in, so I might presume that I am done with my particular cleanup here.

But I see that it does not reach 0 though. It continues at a particular, the concentration does not drop below a particular value here for a considerable period of duration or period of pumping now. Why is that? So initially I see a tailing, not tailing pardon me, rapid decrease in the concentration. That is when all the, let us say, compound in the aqueous phase has been removed.

But then for a considerable portion of this particular pumping, let us say, or even after particular or considerable volume of the relevant ground water has been removed, I see that, I am talking about this phase. The concentration does not change, right. Why is that? Because we have a solid phase and there you see the relevant precipitation, not precipitation pardon me, dissolution of the solid phase into the aqueous phase right.

Change in phase from the solid phase into the aqueous phase and that is what you see here. And then once all the solid phase has precipitated out, so let us say initially I had bigger chunk of particle let us say and obviously I am not going to have, what do we say, a few millimeter size or diameter particle. My counts are such, let us say, depending upon again the type of, what do we say, conditions there, let us say, the solid particle size can vary from different, from one size to the other, right.

So again if I have a solid particle initially now here and then water out here, I keep removing the water. Again equilibrium keeps shifting and so slowly but surely this particular solid phase, the particle precipitate, right, pardon me dissolve. So then the phase of this or the size of this particle is going to keep decreasing, right.

So that is what I would or one would presume happens out here. And when all the particular solid particle has dissolved, then I am going to see a further decrease of the particular contaminant concentration in the ground water, right. So again, similar to the NAPL or the non-aqueous phase liquid, here we have a solid particle and then the relevant aspects here, right.

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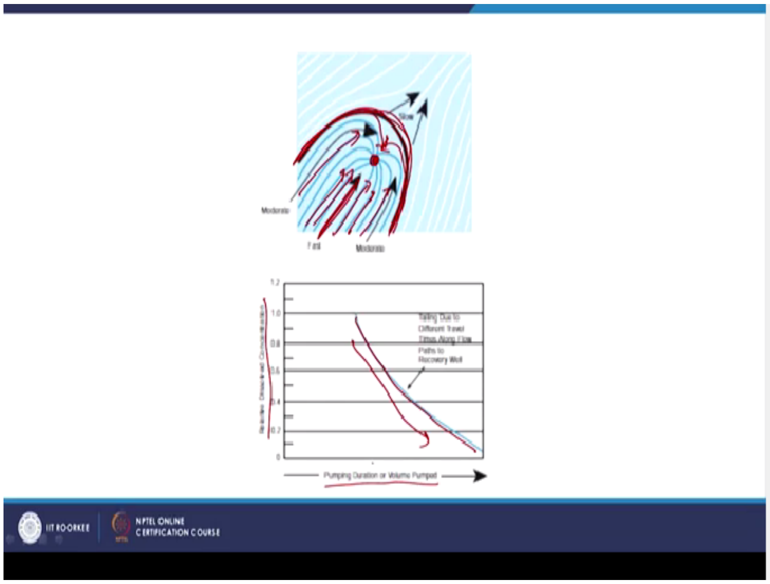

So the other aspect is that when we would have issues with, what do we say, tailing, let us say, is that. I am pumping the water out. This is my location of the valve, right. Let us say, from (()) (09:04) and this is the boundary of my particular flow line for that particular extraction valve, let us say, right. So but as you know though in the center, along center, let us say, the ground water flow or the velocity would be relatively fast and relatively moderate as we move away from that.

And obviously remarkably or relatively slower and also the path that the ground water particle or the aqueous molecule should take would be greater along the periphery obviously, right. So obviously relatively slower at the periphery, let us say, of this particular flow path and moderate and then fast through the center, right. So again this will cause issues with respect to tailing and that is what you see here.

So here I have the relevant dissolved concentration and pumping duration of or volume pumped. So why do I see this tailing now? Because there are different flow velocities within this particular capture plume here, right. Again we have more, what do we say, faster, what do we say, moving ground water in the center and less faster along the periphery.

So obviously the contaminant in the center of the plume will, let us say, be pumped out first. But you still have contaminant along the periphery and that obviously as we see here takes longer to be pumped out. And thus you see this particular behaviour of tailing here, right. And let us move on to the relevant aspects here.

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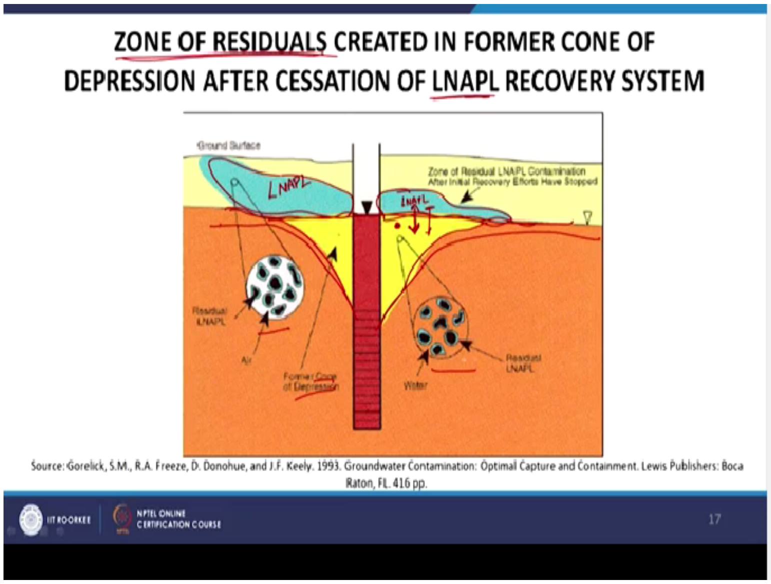

ZONE OF RESIDUALS CREATED IN FORMER CONE OF DEPRESSION AFTER CESSATION OF LNAPL RECOVERY SYSTEM

Source: Gorelick, S.M., R.A. Freeze, D. Donohue, and J.F. Keely. 1993. Groundwater Contamination: Optimal Capture and Containment. Lewis Publishers: Boca Raton, FL. 416 pp.

And again this is one other aspect where we have LNAPL, let us say, right. So we have LNAPL and here we have case of zone of residuals I guess, right. So think of this case LNAPL or light non-aqueous phase liquid, right. It is non-aqueous phase, right. It is present as a non-aqueous phase, let us say. But the case is that it is light or relatively lighter than water, right. It is not denser than water.

So obviously it would float above this particular or stay at the top of this particular ground water table or be in contact with the upper portion of this ground water now. And may be if anything, obviously if it is soluble, some of it will also be soluble obviously, right. So let us say if I detect the concentrations, let us say, of this particular NAPL in the ground water and I start pumping ground water out, right.

And then I have a cone of depression. I pump that water out, okay. And then I see that there is no other or no more concentration with time or change in concentration with time. And thus I stop the pumping, right. And then may be after a couple of months, let us say, I come back, take the concentration of the relevant ground water. I see that again the concentration is now higher. Why is that?

Let us see the case, I guess. So initially let us say the ground water level was somewhere out here, right. And then after pumping has started, the ground water and we have the draw down and this is the draw down and the cone of depression, let us say. And so I pump this water out, let us say, I pump this particular water out, let us say, right. But the key is that, we still have LNAPL in this particular location.

So what have I removed? Only that NAPL that was dissolved in this particular aqueous phase or in this particular ground water was removed. So once I stopped pumping, again the ground water level is going to come back to its original level, right. Again the ground water is going to be in contact with this LNAPL, right. And now again I am going to have equilibrium and thus transfer of, what do we say, the mass of the contaminant from this particular non-aqueous phase to the aqueous phase, right.

Again some of it will be soluble and that is what I see here, right. So again different cases out here. So what is happening here? I can think of the LNAPL as being standard, let us say, right. I am pumping the ground water out, let us say. But again may be due to the, what do we say, capillary action, let us say, or because of surface tension, let us say, your NAPL though is not being pumped out though, right.

It is present as a different phase and it is stranded now. Earlier NAPL was here, ground water here and I pump the ground water out but NAPL was still stuck somewhere out here. And once I stop pumping, the ground water again comes up here in contact with this NAPL and now again I have contamination, right. So these are the relevant aspects or one more aspect where you would expect, let us say, rebound of the relevant contaminant, right. So let us try to summarize what have we have looked at.

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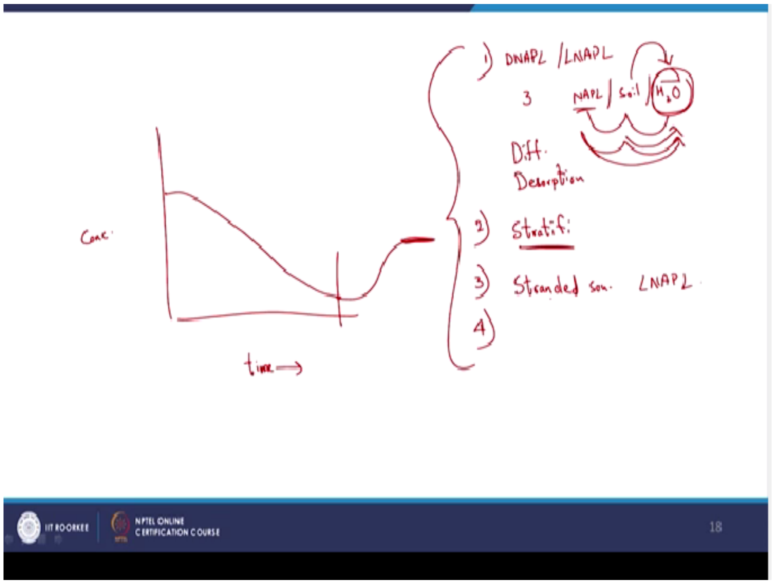

So one is the case when we have DNAPL or LNAPL, right. So we can then have 3 phases, right. And between NAPL, soil and water, right, so then there is an equilibrium between these 3 phases. So even though you pump out the contaminant in this particular water, again you have a new equilibrium and then that is going to be the case again as in the contaminant can be transported from the NAPL into the H2O or again from the soil into H2O and so on and so forth.

So here it is limited by diffusion from the NAPL into water or by desorption from soil into H2O, right. Again these are relatively slower process, right. And I think we also looked at stratification, right. We looked at stratification where we have different strata and thus different ground water flow velocities. And I think we looked at stranded source, let us say, stranded sources, right.

Especially in the case of LNAPL, that is something we looked at, right. And we also looked at I believe, let us say, when we have ground water flow velocities being different because of the contaminant or the different velocities at different locations of this particular flow path, right. So we looked at different cases when we are going to observe, let us say, tailing and once we stop pumping, again rebound here, right.

Again rebound is because I have different reservoirs of this particular contaminant, I mean this is the concentration of the contaminant and time or volume of the relevant water pumped out here, time of pumping or duration of pumping and here. So the tailing, let us say, again different case of desorption and such or stratification and so on. So these are the cases obviously when pump and treat might not be or will not be feasible or practical conditions, let us say, are going to limit the efficiency.

Obviously for that, you need to understand the type of aquifer you have, let us say, right. Because as you see it depends upon the type of media certainly and also the phase of this relevant contaminant as in is it mostly only in the dissolved phase or aqueous phase or has it been adsorbed on to the soil or is it also present as the NAPL, let us say, or in a different phase, right.

So these are the aspects you obviously need to consider. So once I consider this, let us say, I obviously need to be able to estimate the time required for, let us say, pumping out a particular contaminant, let us say, right. Because only then can I consider I will be getting the relevant resources. So let us try to quantify that. So here let us say I have, I am trying to conduct the mass balance here.

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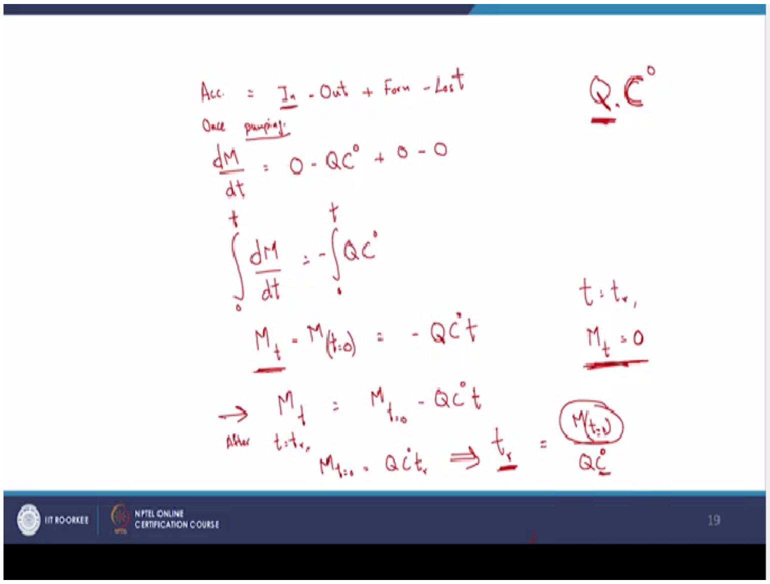

Acc. = $\underline{\text{In}}$ - Out + Form - Lost

$\underline{Q}.C^{0}$

Once $\underline{\text{pumping}}$:

$$\frac{dM}{dt} = 0 - QC^{0} + 0 - 0$$

$$\int_0^t \frac{dM}{dt} = -\int_0^t QC^{0}$$

$$\underline{M_t} - M_{(t=0)} = -QC^{0}t$$

$t = t_r$,

$\underline{M_t = 0}$

$$\rightarrow M_t = M_{t=0} - QC^{0}t$$

After $t = t_r$,

$$M_{t=0} = QC^{0}t_r \Rightarrow \underline{t_r} = \frac{\boxed{M_{(t=0)}}}{Q\underline{C}^{0}}$$

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So the accumulation would be equal to in, compound coming in-compound going out+anything that is formed or lost, right. Again this is just mass balance, right. So that is what I have here. So, let us say, I will have rate of change of mass of that particular compound with time, let us say, is going to be; so once I start pumping, once pumping starts, I am going to assume that no other, what do we say, source of the relevant contaminant exists, so nothing comes in.

So 0-out. How is it being pumped out? Let us say rate of Q, ground water pumping rate, let us say, is Q and the concentration of that relevant contaminant, let us say, initially is C0, let us say, right. So the mass that would be removed will be QC0, I guess, right. Mass per time anyway, QC0, let us say, +no reaction leading to forming or losing the compound, let us say. This is simple case that I am considering obviously, right.

So let us see what it is. So integrating this, what do I have here? Let us say, I have dM/dt out here, integral and QC0 negative integral out here. So what do will I have here? Mass at time t-mass at time, so 0 to t and 0 to t, right. So again I am going to have, what do I have here please? Mass at time=0. So this is the mass of the contaminant left after I pumped the water out for a certain time t and Mt=0 is the mass initially present of the contaminant present in that particular contaminated zone.

That will be equal to, I have 0 here, so that is going to be equal to 0 here, -QC0*t, right. So that is what I have out here. And let us try to rearrange and understand the relevant terms please. Integral 0 to t, right. So time for remediation is equal to, let us say, M time=0-QC0*t, right. So, let us say, this is the equation that I have, right. But, let us say, I want to obviously try to estimate the case when all the contaminant or there is no more contaminant left in my particular aquifer, let us say, right.

So at that point, what does that mean? So when time=time of remediation, that means that the mass left at time t is going to be equal to 0, right. So after time of remediation has been reached, what am I going to have? I am going to have Mt0=QC0t, times remediation. So from here I can calculate the time required for remediation. So that is equal to obviously the mass that is initially present/the mass that I pump out, right.

So here what I have? I have a generic calculation, let us say, for pumping the contaminant out. So what is this, I guess? I have time required for remediation, right. And how did I get that? Obviously by assuming that at the time of remediation or once I achieve that particular time of pumping, all the mass left in the particular contaminant zone is removed. So the mass left at time t=0, right.

So the time required for remediation=what is this particular variable? This is nothing but the mass or total mass of the contaminant initially/QC0. What is the QC0? It is the rate at which you are pumping out or removing the mass by pumping it out, right. So obviously here, C0 will change, right. The rate, I mean, as you keep pumping out, the concentration of the contaminant in the ground water will not be constant.

Obviously it is going to change with particular time depending on the conditions. So obviously you are going to have different cases I guess, right. But again this is one way I can calculate that. So now let us apply this particular aspect or let us say, this particular generic calculation to the 3 cases as in. Let us say, what are going to be the 3 cases we are going to look at?

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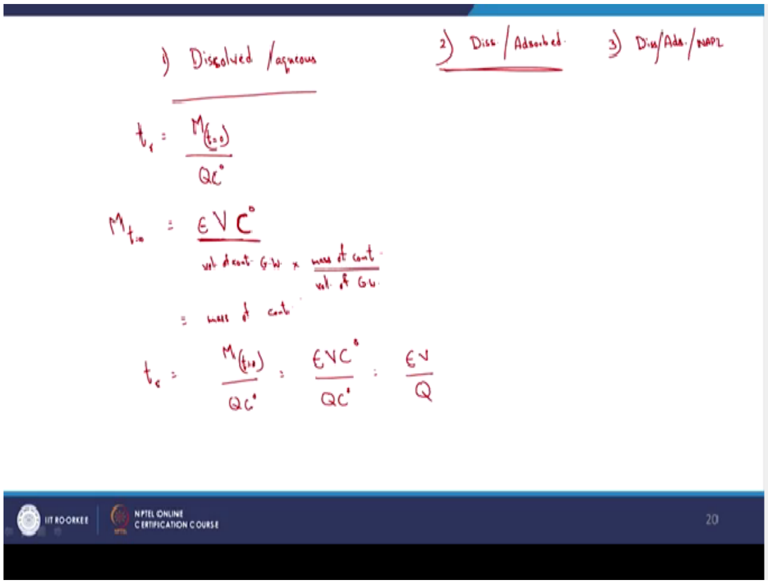

1) Dissolved / aqueous

2) Diss. / Adsorbed.

3) Diss/Ads./NAPL

$t_r = \frac{M_{(t=0)}}{QC^0}$

$M_{t=0} = \underline{\epsilon V C^0}$

vol. of cont. G.W. × $\frac{\text{mass of cont.}}{\text{vol. of G.W.}}$

= mass of cont.

$t_r = \frac{M_{(t=0)}}{QC^0} = \frac{\epsilon V C^0}{QC^0} = \frac{\epsilon V}{Q}$

I am going to look at case 1 when the compound is only in the dissolved or is only in the aqueous phase, right. And then I am going to move on to understanding what would be the case when it is in the dissolved form and also adsorbed on to, let us say, the soil here, right. And the third case would be when I have it in the dissolved or in the aqueous form in the ground water and also adsorbed on to the soil.

And also, let us say, as its own phase, let us say, or NAPL, let us say, right. I mean there are different issues with NAPL. May be this is something I should have made clear later or pardon me earlier. So NAPL, if the NAPL itself is a contaminant, let us say, it will obviously act as a reservoir of contaminants, right. But there is another case 2. As in NAPL, if it is not a contaminant though.

By being hydrophobic though, right, it can, what do we say, act as a reservoir for a contaminant which is hydrophobic, right. So again 2 cases. When the contaminant itself is, what do we say, present as NAPL or when you have a non-toxic NAPL present here, right. So again think of this, let us say, very generic example because we look at K-octanol water partitioning coefficient or the octanol water partitioning coefficient.

For example, let us say, assume that octanol is present as non-aqueous phase liquid there and you have that in contact with water. And the contaminant that you put in, let us say, TCE, let us say, can or will stay in 2 phases. What is that now? It bores in the ground water and also in the octanol now, right. So this case though where we are considering that octanol itself is not a contaminant, it still acts as reservoir of contaminants because this TCE or PCE which is hydrophobic, would want to be in this particular non-aqueous phase, right.

So there are different cases that is something we are going to look at. So obviously we are going to try to first now work out the case when it is only in the dissolved form. So obviously how do I get this time of remediation? I know that it is equal to the total mass initially present, right, /QC0, let us say, or rate of pumping here. So obviously I need to calculate the total mass present and the time=0.

So here what do I have now? I have and estimated about the concentration of the relevant contaminant in the ground water, let us say, that is C or C0 here, let us say, right. I have the concentration of the contaminant in the ground water and I know the volume of this particular contaminated zone. So if the total volume is V*porosity V, right, porosity*V, it will give me an idea about the pore volume filled with this particular contaminated ground water, right.

So I have here the porosity*total volume will give me the volume of contaminant ground water, right. That times the concentration would give me the, what will that give me? Mass of contaminant per volume of ground water, right. So that will obviously, what will I end up with? I will end up with the mass of contaminant, right. So I will end up with the mass of contaminant. So in this context, if I try to calculate the time for remediation, what will I end up with?

I will end up with time for remediation=Mt=0/, as I know QC0, so that is going to be equal to epsilon VC-0/QC0, right and then epsilon V/Q, right. And what is epsilon V? it is the volume of contaminated ground water/Q, right. So what does this mean? It means that the time for remediation as you can see here, it is the time required to just pump out that particular contaminated plume, right.

Epsilon V is the contaminated ground water and Q is the rate at which you are pumping the water out, right. So again time for remediation is just as in this case where we see that the contaminant is only in the dissolved form, right. It is only in the aqueous phase or only in the ground water, right. So in that context, obviously if I just pump out all the ground water, that is contaminated.

I am done with my particular case of removing the contaminant from the relevant contaminated zone, right. But now let us try to understand or analyze this particular case where we have the compound in 2 phases, let us say. Both in the dissolved or the aqueous phase pardon me and also in the sub-phase or adsorbed on to the soil, right. So let us look at that particular case.

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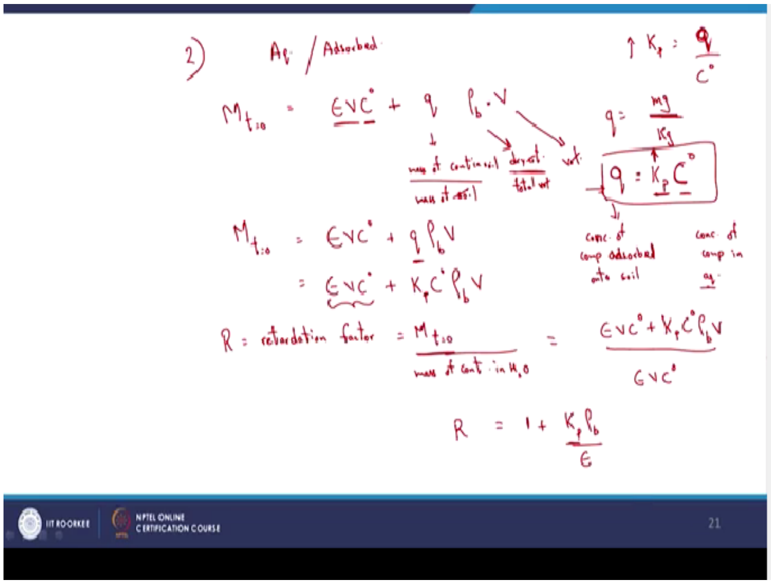

2) Aq. / Adsorbed

$\uparrow K_p = \frac{q}{C^0}$

$M_{t=0} = \underline{\epsilon V C^0} + q \; \rho_b \cdot V$

q → mass of contam soil / mass of soil

ρ_b → dry wt. / total vol

V → vol.

$q = \frac{mg}{kg}$

$\boxed{q = K_p C^0}$

q → conc. of comp adsorbed onto soil

C^0 → conc. of comp in aq.

$M_{t=0} = \epsilon V C^0 + q \rho_b V$

$= \epsilon V C^0 + K_p C^0 \rho_b V$

R = retardation factor $= \frac{M_{t=0}}{\text{mass of cont. in } H_2O} = \frac{\epsilon V C^0 + K_p C^0 \rho_b V}{\epsilon V C^0}$

$R = 1 + \frac{K_p \rho_b}{\epsilon}$

So we have this case where we have both the aqueous phase and also the compound adsorbed on to the soil, right. So here I need to calculate the total mass that is present initially. And how do I get that? So epsilon VC0, right, that is simple because I know this is the volume of contaminated ground water, C0 is the concentration of the relevant compound in the ground water, right, +, I now need to be able to estimate the mass that is adsorbed on to the soil, right.

So typically by relevant calculation, let us say, it would, the concentration of the compound adsorbed on to the soil, the units will be milligram of compound per kg of soil, let us say, right. So let us say if this is Q, right, this is I am expressing as Q, let us say, right. And what would this be dependent upon? We are going to look at that. But if you think of, we are trying to go into, try to express that in terms of variables.

But if you think of the relevant aspects, Q obviously is going to be in equilibrium with the concentration in the water, right. Because, let us say, if the concentration of the relevant compound in water is too less compared to the relevant equilibrium state, right, so the equilibrium would want to shift this way, right. So that is why I guess, we do know that the compound, what do we say, the concentration of the compound in the soil is going to be in equilibrium with, KP is the partitioning coefficient, with the concentration of compound in the aqueous phase, right.

So concentration of compound adsorbed on to the soil will be in equilibrium and how do I get that particular, what do we say, value? I get it by the equilibrium coefficient will be in equilibrium with my particular concentration of compound in aqueous phase, right. Here obviously I am assuming that it is, what do we say, the linear relationship, but there are other ways to or modus too I guess.

Right here, I am just taking the simple case, right. That there is a linear relationship between the concentration of the compound in the aqueous phase or the adsorbed on the soil pardon me. And the concentration of the compound in the aqueous phase, right. So that is what I have out here. So obviously I need to take that in. So what is that about? I know that Q is mass of contaminant/mass of soil, right.

That is what I have here. But what I am trying to calculate? Just the mass of the contaminant, right. So I need to obviously be able to eliminate this particular term. So how do I do that? I can do that by bulk density or dry weight bulk density*volume, right. Bulk density is, the way I am expressing it anyway is, the dry weight, let us say, /the total volume and V is nothing but the total volume.

So obviously here dry weight or mass of soil, so volume, volume cancel out, dry weight and mass of soil cancel out and I am just left with mass of contaminant in the soil phase, right. So again let me write it down in a clearer manner. So this is what I have, epsilon VC0+q rho b*V, right. So I can clearly express this or break this down further or simplify this further as I know Q. How is that or what is that dependent upon?

It is obviously going to be dependent upon the concentration of the compound in the aqueous phase as I can see from this particular relationship, right. Because they are going to be at equilibrium with each other. So KPC0 rho b*V, right. So typically though we are trying to understand, let us say, the time for remediation, let us say, right. So that obviously as we know is going to be dependent upon the mass of the contaminant in the ground water, right.

So to get an idea about, let us say, the extra time required for remediating the relevant, what do we say, site if you have the compound in different phases, I am going to come up with a particular factor called retardation factor, R is the retardation factor. Retardation factor, let us say, and that is going to be described as being equal to M time=0, the total mass/mass of compound or contaminant in water or in the ground water, right.

And that in this case is nothing but epsilon VC0+KPC0 rho bV/epsilon VC0 as you can see this is the mass of the contaminant in water. So that is going to be equal to 1+KP rho b/porosity, right. So if the contaminant is present in both the aqueous phases and the relevant soil phase, let us say and let us say, I am trying to estimate the relevant time required for pumping, the particular total contaminant out.

It will obviously be dependent upon the mass present in the soil phase too, right. So to get an idea about that and the additional time required, let us say, to pump such particular contaminated water out, I will need to look at the retardation factor. For example, let us say, if the time required to pump, what do we say, only the dissolved phase out is 1 year and I have case 2 when the compound is in both the dissolved and the, or adsorbed on to the soil and the retardation factor is 10, let us say, so initially if it took only 1 year, not initially, pardon me.

In case 1, if it takes only 1 year. In case 2, if the retardation factor is 10, let us say, it will take 10 years for me to pump out all the particular contaminant. So obviously we are going to try to quantify this or give some or assign some particular numeric to these particular values and calculate the relevant value so that it is clear to you, right. But I guess, I am running out of time. So I will continue this in the next class, right.

So again what have we been up to. We looked at the relevant cases for tailing and rebound and then we moved on to trying to estimate the time for remediation, right. We did a simple mass balance, right. Mass going out, let us say, QC0 and the rate at which mass was changing dM/dt. And we saw that time for remediation is nothing but the total mass present initially/the rate at which you are taking the mass out, right.

And then we moved on to 2 cases. One where we looked at the time required to pump the water out when we have only the dissolved phase, right. And that is something we looked at here, only the dissolved phase. And we saw that in that case if I just pump out all the contaminated ground water, I am done with the relevant remediation. But obviously if the contaminant is present in both the aqueous phase and the dissolved phases.

Because now the contaminant will desorb from the soil into the ground water, if you keep, what do we say, pumping the water out. I need to look at the relevant aspects. So to consider that, I came up with this particular factor called the remediation, or not remediation pardon me, the retardation factor, right.

So obviously the higher the retardation factor, higher the relevant, what do we say, time required. As in, if let us say, KP is higher, right. If KP is high, what does this mean now? What is KP> As you can see, q/C0, right. KP being high means the fraction of the relevant contaminant in the soil, let us say is greater than or is relatively higher compared to the fraction of the contaminant in the water, let us say, right.

Or the contaminant would prefer to stay adsorbed on to the soil rather than stay in the aqueous phase, right. So obviously in that case, the time to remediate or pump out your particular contaminant will be relatively or remarkably high, right. So again this is something we are going to take through in the next session and therefore, today, I am done and thank you.