Environmental Remediation of Contaminated Sites

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Lecture – 13
Remediation of Contaminated GW by Pump and Treat-I

Hello everyone. So again welcome back to the latest lecture session. Let us have a quick recap of what we have been up to. I believe we have been discussing the relevant aspects with respect to the placement of relevant wells, right. And the context of pump and treat, yes. So we have been looking at, let us just have a recap of what we have been up to again.

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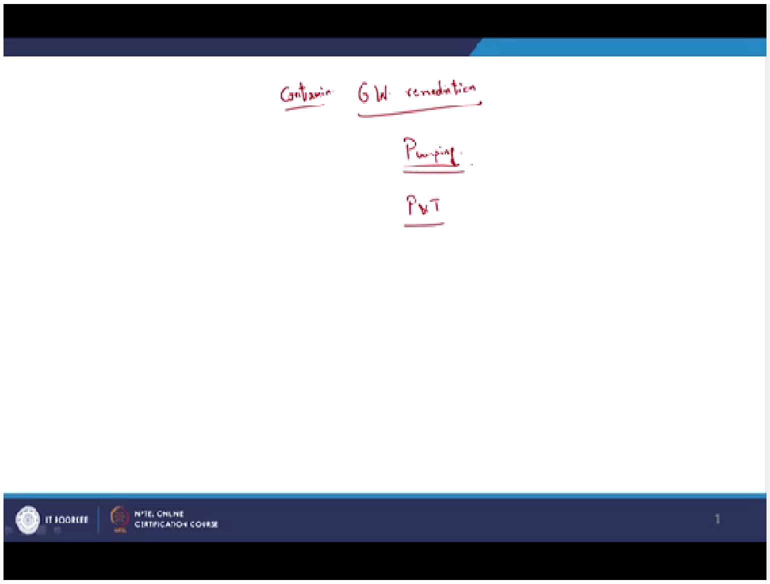

Contamin. GW remediation

Pumping.

P&T

So we looked at the relevant aspects or we are looking at the relevant aspects with respect to ground water remediation or contaminated ground water remediation, right. So in this context, we looked at or we have been looking at the relevant aspects with respect to pumping the water out. So in that context, we did see that obviously the placement of the wells or the extraction wells depending upon the shape of the plume is of considerable importance.

So in that context, we looked at the relevant design provided by (()) (01:22). And I think the relevant aspect is that they had a factor of 50 of 2 as in it consists that you need to pump out twice the, what we say, amount of flow, let us say that would go through particular cross section. That is something we looked at. And then I believe we moved on to the relevant aspects with respect to what are the issues that you might face or what are some of the cases that you, practical cases that you might face with respect to pump and treat, right.

So initially we looked at pumping the water out, let us say, or extracting the contaminated plume. And then I believe, we moved on to pump and treat. And in pump and treat, obviously what are we trying to do here? We are trying to pump the water out and treat the water. So in this context, obviously we did have one example as in ground water contaminated in or near Ghaziabad, let us say, with Chromium from, I believe, some particular fan manufacturing company, right.

And then now what are they up to? They are pumping the water out, treating it by reducing it from Chromium 6 to Chromium 3 and then I guess, applying it on land, right. So again treatment options different cases. So typically a redox process depending upon the type of contaminant or AOP again depending on the type of contaminant. And then you try to promote reduction, let us say, of the contaminant.

Obviously if it is oxidized and you want the change the oxidation state from the higher oxidation state to a lower oxidation state, right. But typically, let us say, we encounter reduced compounds as contaminants. So then obviously you can go for one of these advanced oxidation process, right. Or you can also go for granular activated carbon, air stripping if it is relatively volatile compound and so on.

But volatile compound pump and treat may be not a good option in the first case. So let us look at again as I mentioned some of the aspects that you need to consider when we consider the feasibility of or look at or investigate the feasibility of pump and treat, let us see. So here we looked at some cases.

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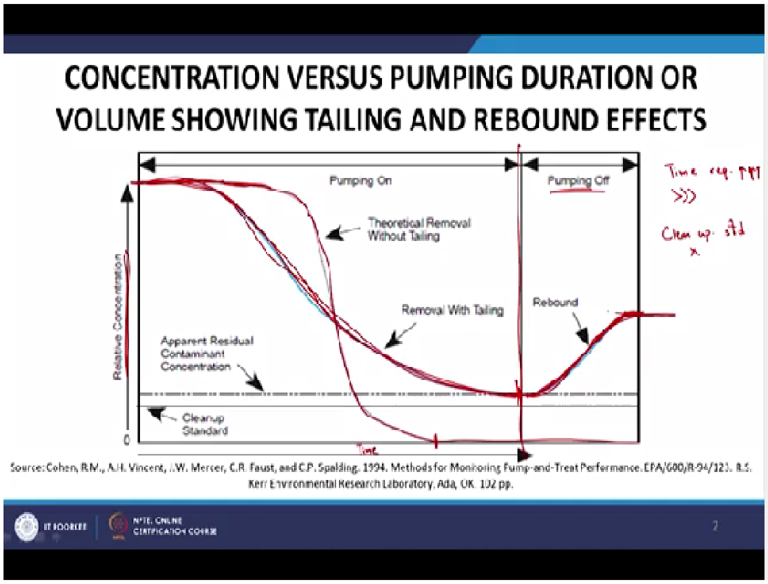

CONCENTRATION VERSUS PUMPING DURATION OR VOLUME SHOWING TAILING AND REBOUND EFFECTS

Source: Cohen, R.M., A.H. Vincent, J.W. Mercer, C.R. Faust, and C.P. Spalding. 1994. Methods for Monitoring Pump-and-Treat Performance. EPA/600/R-94/123. R.S. Kerr Environmental Research Laboratory, Ada, OK. 102 pp.

So typically let us say what would I expect now. I have a contaminated plume and I am pumping the water out, right. So obviously when would my job be done? Let us say, if I pump out a volume equal to the contaminated plume volume, right. But typically that is not the case. So let us see why that is the issue I guess. So here we have the relevant concentration or relative concentration on the y axis and time on the x axis, let us say, right.

So in the theoretical case, let us say, if or the ideal case any way, right, depending upon the time or type of contaminant, you would vary from one extreme to the other or typically it is a mixture of the relevant cases here, right. So here I will start pumping water out and I see that the concentration in my outlet, let us say is high, right, is remarkably high. So as I am able to pump out almost all the plume, I see a steep decrease in the concentration that I am pumping out.

What is that mean? Let us say that I have pumped out almost all the plume. So that is why I see a steep decrease and then reaching below the relevant standards and then I stop pumping, let us say somewhere out here. And then I see what I would expect as in the concentration not changing anymore, let us say, right. But obviously that would not be the case and let us look at some of the typical behaviours that we encounter.

Here though typically let us say depending upon type of contaminant, you would not pump out lot of volume of water at relatively high concentration or the concentration you typically measure, let us say. So let us see why is that after we understand some of the aspects here. So here you see a sort of a tailing, right. So this is the tailing here, yes. So why is this an issue now? So as you see here, the time required, let us say, to reach the relevant standard, let us say, right, is relatively more.

So though obviously this graph has not been drawn to scale. Typically let us say whenever you have tailing and rebound issues due to the type of contaminant in the ground water, let us say. Let us say, ideal case may be you needed, let us say, 2 or 3 years to pump the water out. But let us say when you have a hydrophobic compound or NAPL or so on, we are going to discuss what they are later on, right.

You are going to observe that or we can calculate the approximate time required for remediation later. That the time required for pumping out can be a few hundreds of years or tens of or many tens of years, right. So that would obviously make the relevant process unfeasible or infeasible, right. So again here we have, we can observe tailing and after we stop pumping, and this is our reference here where we stopped pumping. Obviously pumping off.

You again see that the concentration of the relevant contaminant in the water, let us say, again increases. And that is something, that might seem counterintuitive but let us look at what are some of the aspects, let us say, or in which conditions, let us say, would you expect such tailing and then again a rebound once you stop the pumping, right. So obviously when you have such rebound, you are going to have issues with what do we say, getting the concentration down to the relevant standards, yes.

So again tailing and rebound, so let us see what are some of the aspects. But what are the practical issues? The practical issues are that time required to pump the water out is remarkably high, let us say, remarkably high. And typically, reaching the cleanup standards is not feasible, typically not feasible, right. So let us look at some of the aspects that can lead to the relevant, what do we say, issues with respect to tailing and rebound.

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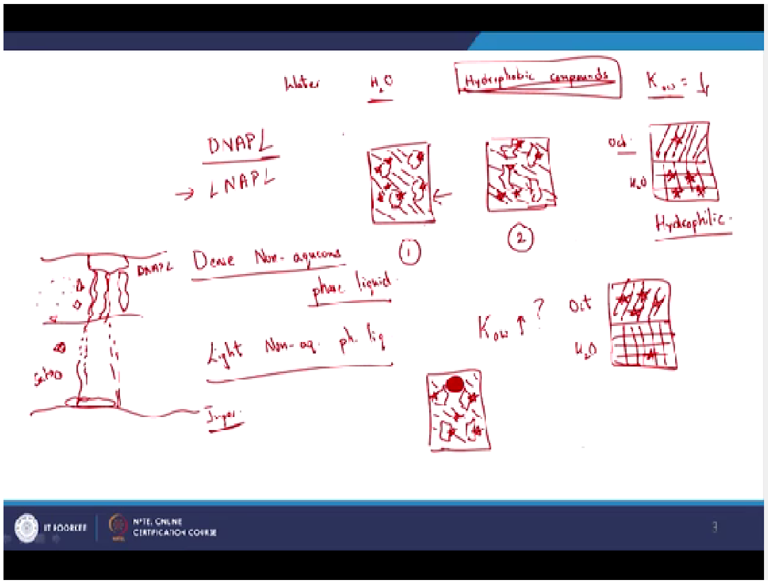

So typically, let us say, you are pumping water out, right. I am pumping water out or H2O, right. Why is that? Because the ground water is contaminated, right. But what are the sources of the contaminant here, right. There can be different types of sources salt phase and nonaqueous phase and so on, let us say, right. Nonaqueous as in if you have an industrial solvent leaking, let us say, to the subsurface, let us say.

For example, TC, trichloroethane, I guess, right. Or let us say you have hydrocarbon, let us say, from your underground storage tanks in your petrol bunks, let us say. As we talked about it briefly, where do we have the, where do the petrol bunks stored the petrol or the hydrocarbon here? Petrol or diesel. They obviously store them underneath the surface, right. And again, we have, we call them the underground storage tanks and they typically leak.

So you can have contamination of the relevant subsurface and the ground water, right. So how do I go about looking at, analyzing, let us say, if pump and treat is the relevant option that I should choose in this context to. So here, let us say, keep in mind that when we pump and treat, we are obviously trying to pump the water out and treat it, right. So again the key is pumping the water out.

So if the contaminant, let us say, prefers to stay in different phase as in it does not want to stay in water or in the aqueous phase, let us say, then obviously that is going to cause issues. So what kind of compounds are we concerned with? We are concerned with hydrophobic compounds, right. And the issue here is they do not want to stay in water or stay in the dissolved or in the aqueous form, let us say.

They would want either be adsorbed on to the organic fraction on soil, let us say, or, let us say, stay in as a separate phase and so on. So again, let us say, if this I take a sample out in a box, let us say, from my aquifer and these are the soil particles, let us say, yes. And there are pore spaces filled with water, let us say, yes. So the compound, let us say, rather than staying in the dissolved phase, let us say, this is my compound.

Let us say, I will mark it with a star, rather than staying in the aqueous phase, it would stay adsorbed or it would want to be adsorbed on to the soil or the organic fraction on the soil. Again why is that? Let us say, if that is a hydrophobic compound, let us say, right. So what is the key here? That though you measure a certain concentration of the relevant compound in the water, let us say.

The total mass of the contaminant in that particular control volume, let us say, or the total mass of the contaminant is actually significantly higher than what you would calculate if you just look at the volume of contaminated water and the concentration of the contaminant in the contaminated water, right. So that is something that I need to look at, let us say. So what happens here is, let us say, if I pump the water out, let us say, and I remove these 2 moles, let us say.

Let us think of these 2 stars as the number of moles of that particular contaminant, let us say. So in the case 2, let us say, this is my case 1, initial case. So case 2, I am able to pump that water out, let us say. And these are my soil particles here. As I pump that water out, that water is going to be replaced by the surrounding ground water, right. So now what is going to happen now. You are going to have desorption from the relevant soil, let us say, desorption of the relevant compound from the soil into again the ground water.

And still you are going to obviously have some particular contaminant adsorbed on to the soil particles. So here we are talking about equilibrium, let us say, right. So equilibrium as in phase, equilibrium may be or equilibrium between the fraction that is adsorbed on to the soil and the fraction that is or the compound or the fraction that is in the aqueous phase, right. So how can I get an idea about this?

Obviously, let us say, I can look at the metric KOW, the octanol-water partitioning coefficient. So what is that about? It gives you an idea about, let us say, if I have octanol, let us say, as solvent, right. And water, if I have water here and octanol and I place a particular compound here, let us say, and I observe the equilibrium, let us say. If, let us say, after equilibrium, so again we are just trying to understand the octanol-water partitioning coefficient.

So what is that is about? So, let us say, if I take a container and have, let us say, equivalent volumes of, what is it, octanol and water here, let us say. And I put in a certain compound, let us say. And if I observe that, let us say, more number of moles of the compound would want to stay in water and not in octanol, let us say. What does that mean now? KOW value will be relatively less.

Or that the compound is hydrophilic, right. So obviously if the compound wants to stay in the aqueous phase, that is prime compound, that can be, that is the case for, application of pump and treat, right. But, let us say, if the case is such that KOW value is relatively high as in what does that mean, let us say, right? So in the K octanol-water partitioning coefficient meaning being high, what does that mean?

So that the number of moles of the relevant compound would want to stay in this particular solvent, let us say, octanol rather than staying in water, let us say or in the dissolved or in the aqueous form, let us say, right, or in the aqueous phase, pardon me, right. So it does not want to stay in water. Considerable fraction would want to stay in the octanol here, let us say. So again what will that give me an idea about?

That will give me an idea about how hydrophobic is the relevant compound, right. So K octanol-water partitioning coefficient, so typically in soil, you have, let us say, the clay or the organic fraction 2, let us say, right. So depending on higher organic fraction, this hydrophobic, in the soil, pardon me. This hydrophobic compound, let us say, will be in equilibrium with the contaminant being adsorbed on to the organic fraction of the soil and also some of it in the water.

So there is going to be an equilibrium, right. So if I pump the water out, right, again what is happening here? The equilibrium has shifted, yes. But once fresh water comes in contact with the soil, what is going to happen? Obviously it is going to reach an equilibrium again, right. So again I pump this water out. I again shift in equilibrium, say again, we have an equilibrium reached. So again I pump the water out.

Again it rebounds because again there is going to be an equilibrium, right. So obviously as you see, this particular contaminant adsorbed on to the soil, let us say, adds as a considerable source for the relevant contaminant, right. So again that is one particular case. So there are many types of hydrophobic compounds out there. And 2 types of compounds that are typically uncounted are referred to as DNAPL and LNAPL, right.

This stands for dense nonaqueous, again the key is that it is nonaqueous phase liquid, right. And LNAPL refers to light nonaqueous phase liquid, right. So the key here is that we have nonaqueous phase liquid, right, that is one aspect. And within that particular or type of compounds, we have one set of compounds or a set of compounds that have relatively higher density and the other have relatively lesser density, let us say.

And we are going to have considerable issues when we have a particular aquifer contaminated by these dense or less or light, pardon me, nonaqueous phase liquids, so let us look at what they are, let us see? So the key here is unlike this particular case, where you had some particular contaminant adsorbed on to your particular soil, here let us say, the issue is that if you have an independent and these are my soil particles, let us say, right.

And let us say, this is my nonaqueous phase liquid, let us say. So it is in a separate phase. So some of this particular contaminant will be in or dissolved in water, let us say, some. And some of it will also be adsorbed on to the soil. And again as you can see, this is the actual contaminant here. You know it is in a separate phase, let us say. It can be in a separate phase 2, right. So what are the 3 phases we have?

It can be dissolved in the water; the contaminant can be dissolved in the water. The contaminant can be adsorbed on to the soil, let us say. And also the contaminant can be present as a separate phase which we are referring to as this nonaqueous phase liquid, let us say, right. So with respect to nonaqueous phase liquid, let us say, if you have a dense nonaqueous phase liquid, then release, let us say, at the subsurface, let us say and DNAPL contamination, let us say, DNAPL, right.

So how is it going to behave, let us say? And this is my ground water level. So it is going to have to travel through, right. And again hydrophobic or depending upon the type of compound, it can be present or it can volatize and be present in the pore space here, let us say. And then once it reaches this particular ground water, some of it can be dissolved in the ground water, right. And obviously, you will have soil out here and soil out here, right.

And the contaminant can be adsorbed on to the soil, right. And if it reaches the semi=impermeable layer here, then again it is going to start accumulating. So this is the soil here I am referring too and again the NAPL after reaching here, what is this now? This is the semi-impermeable layer let us say. Impermeable layer, so the relevant contaminant cannot travel by gravity further down, let us say. So I believe I have some of the relevant graphics here. Let us look at the relevant, what do we say, graphs and try to understand the relevant aspects here, right.
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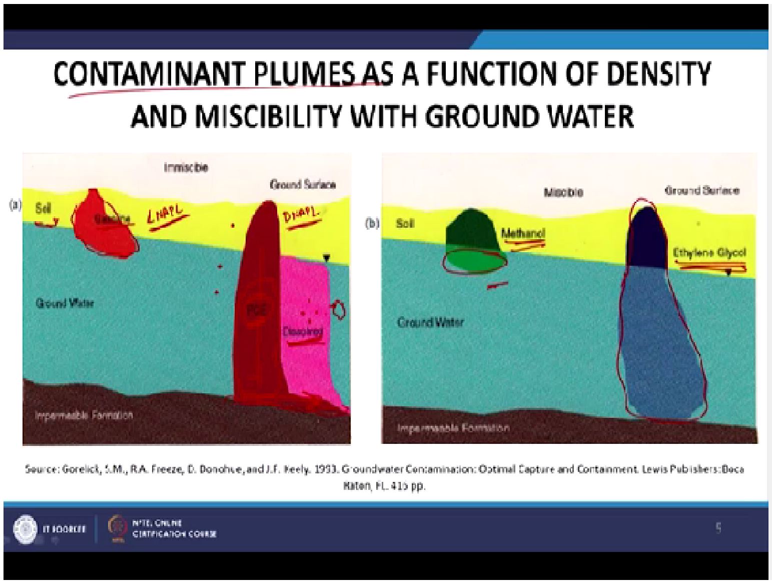

CONTAMINANT PLUMES AS A FUNCTION OF DENSITY AND MISCIBILITY WITH GROUND WATER

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. 415 pp.

So here I guess we have contaminant plumes, the function of density and miscibility with ground water, let us say. So what are the relevant aspects here? I have sources of contamination here and here, right. One case gasoline which is LNAPL, let us say, light nonaqueous phase liquid. Then PCE, let us say, DNAPL. Typically, most of these are solvents or such in industries. And here we have soil and then the ground water and then the impermeable formation.

So obviously gasoline being relatively light, let us say. Again it is that is why we classified that as light NAPL, let us say, right. So it is going to more or less be on the surface of this particular ground water. It is not going to reach the impermeable formation. That obviously DNAPL, dense nonaqueous phase liquid, it is going to obviously be in contact with the water. So you are going to have PCE in the water also adsorbed on to the soil here and here, right.

And obviously it is also going to flow through and then have horizontal transport or be involved or experience horizontal transport, let us say once it reaches the impermeable formation, right. So again different cases here, let us say. But here, let us say, PCE can also have or has some solubility and that is why we see a dissolved phase. But here, let us say, in this, let us say, we see that methanol, again, I guess, we see some of it being dissolved and ethylene glycol, I guess, here we see a case where the solubility seems to be relatively less.

Again case of LNAPL and DNAPL, right. So here the case are that, it can stay in its own phase as you see here and stay as independent phase as a relevant compound itself, right. Or be in the dissolved phase, right. Be in the dissolved phase in the ground water here or be adsorbed on to the soil particle here, right. So different aspects here and thus they act as reservoirs for the relevant contaminant, right.

So here we are only pumping the water out. As soon as the fresh water comes in, again you will have equilibrium between the soil, the NAPL and the ground water, right. So here there are 3 phases again, typically in water we are considering. Obviously if it is in the vadose zone, you will also have the pore space or the gaseous phase, but that is something we are not considering. Right now, we are only considering the contaminated ground water.

So obviously what are the phases I am looking at or considering now? The soil or the one adsorbed on to the soil, the one dissolved in the ground water and the one, pardon me, I am done with dissolved, soil and the one present as a nonaqueous phase liquid. So I have 3 phases. So if I just remove the contaminant in the ground water, right, then again the relevant water flows through again and I am going to have a new equilibrium.

So thus again I will have the contaminant, what do we say, desorbing into or partitioning between the aqueous phase liquid and water. So again the concentration in the relevant ground water is going to increase, right. So that is why what do I see here? I see this rebound. Makes sense hopefully.

So, let us say, here I think that I am done with everything and I stop the pumping. And now again the relevant ground water comes in contact with the relevant, not comes in contact or it reaches equilibrium with the relevant other phases, meaning the contaminant in the subphase and again in the nonaqueous phase liquid. And that is why you see equilibrium being reached and this is the equilibrium here again or new equilibrium I guess, right.

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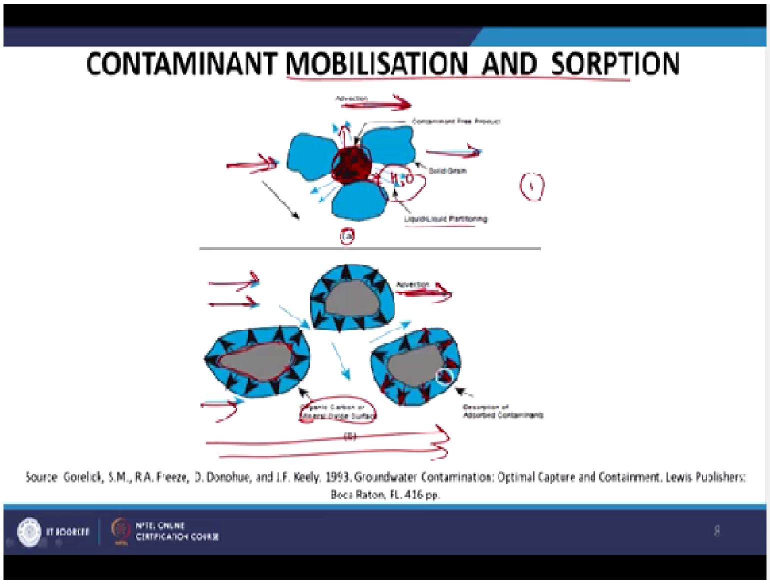

CONTAMINANT MOBILISATION AND SORPTION

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.

So let us look at some of the aspects here. So obviously mobilization and sorption. This is case 1, let us say. So let us say this is the relevant contaminant here as a nonaqueous phase liquid. By a direction, you are pumping the ground water out, that is why you have the ground water flowing through, let us say, right. So what we have here? We have partitioning of the relevant contaminant between water, H20 and the NAPL here, right.

So we have partitioning of the contaminant between NAPL and water here. So obviously as I replace this water, let us say, with uncontaminated water, I am again going to have release of the contaminant from our changing phase from NAPL into the water here, right. So that is one case we looked at, right. And then the second case is when, let us say, you have the relevant compound adsorbed on to the, what is it now, either the organic fraction or the mineral oxide.

So that is what you see here, let us say. This is the soil particle and this is the ground water that is being pumped or the direction of ground water, a direction obviously right because we have a fluid flow in one particular direction or net fluid flow in one particular direction, right. So here I have the contaminant as you see adsorbed on to the soil here, right.

So as water keeps moving through, right, or as water is transported and the relevant contaminants in the water are transported, you are going to have desorption. So that is what you see here. So desorption, right. You have the desorption from the relevant fraction adsorbed on to the soil and again obviously you are going to see an increase in the relevant concentration, right. So again moving on.

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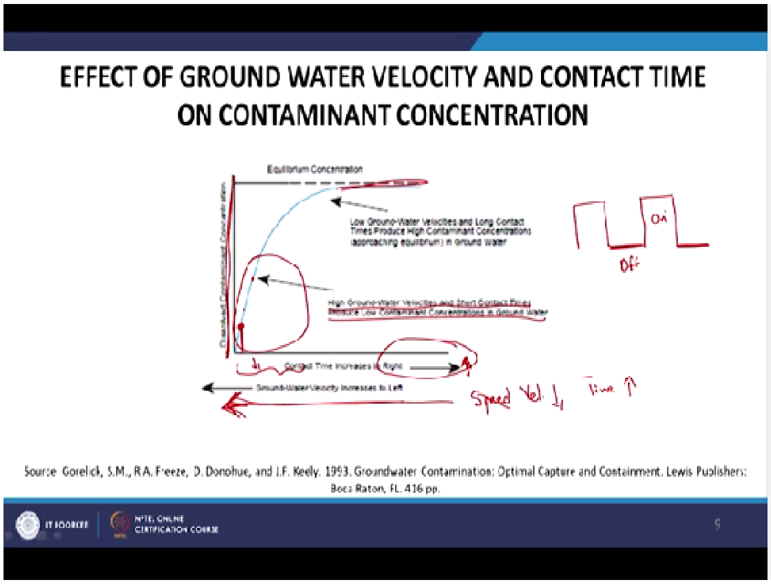

EFFECT OF GROUND WATER VELOCITY AND CONTACT TIME ON CONTAMINANT CONCENTRATION

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.

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So here obviously we have one particular graph here. Let us see what we have. Obviously here we have the case where the ground water velocity increases to the left. So as I go in this direction, the ground water velocity increases. So what does that mean? So if the ground water velocity increases from right to left, it means that in this particular region, the contact time is less and in this particular region, the contact time is more, right.

And here I have the dissolved concentration, right, of the contaminant, yes. So what does this graph obviously tell you now? So if the ground water flow or the velocity of this particular ground water being either pumped out or such, is relatively high, let us say. The time available for contact between the nonaqueous phase liquid or the soil and your water is going to be less. If the velocity is obviously high, the time available for the relevant partitioning and/or the equilibrium to be reached is going to be relatively less, right.

So thus obviously equilibrium will not be reached and you will observe relatively low concentrations in this region, right. That is what you see. So high ground water velocities and thus short contact time is produced, low contact contaminant concentrations. But let us say, if there is enough time available as in the speed is relatively less or the velocity, pardon me, let us say, the velocity is relatively less.

And thus the time available for contact is relatively high, let us say. Then you will have the case where, let us say, the contaminant has, what do we say, had enough time for it to reach equilibrium between the relevant phases, either the soil, a nonaqueous phase and the ground water, right. So that is what you see out here. So depending upon where you are or your ground water, what do we say, pumping rates, let us say in your pump and treat.

You are going to be at different phases of this particular graph or this particular behaviour. So that is something you obviously want to look at as in. If I just pump it at very high rates, the actual concentrations that I am going to remove and thus the mass I am going to remove is going to be relatively less too, right, per time, let us say. But obviously, I need to have a balance between the time required, the resources and so on.

So I need to look at such information regarding whether it is feasible to pump the water out or at what condition should I pump it out as in, is it better to, let us say, have the pumping as in on. I pump it for some time. Let equilibrium be reached as in pumping is off during this time. And again have the pumping on and again stopped pumping, right. Pumping off. So pumping off and pumping on, right.

So I am going to pump the water for some time, let the system reach equilibrium, not reaching the equilibrium, pardon me. Pump the water for some time, then stop the pumping and let the system reach equilibrium, right. And then again restart pumping and again so on and so forth, right. So that is one way to go about it. And here I guess we see the same case here but here with respect to liquid-liquid partitioning.

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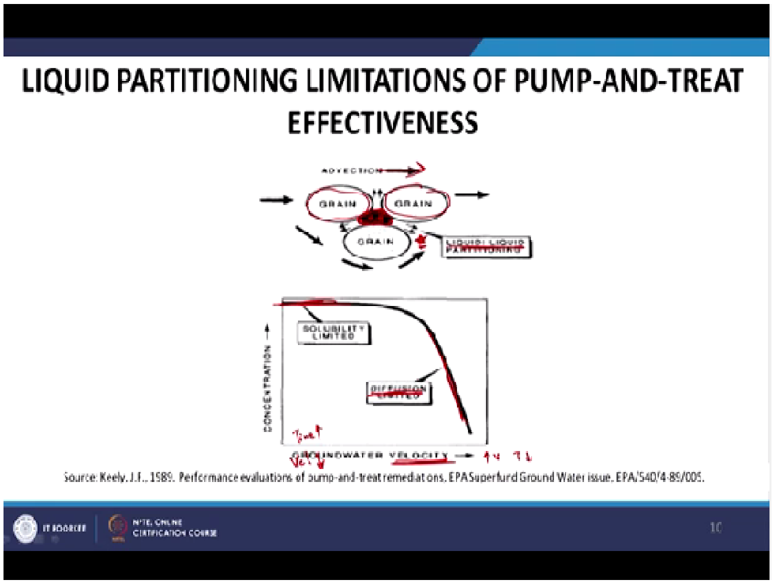

LIQUID PARTITIONING LIMITATIONS OF PUMP-AND-TREAT EFFECTIVENESS

Source: Keely, J.F., 1989. Performance evaluations of pump-and-treat remediations. EPA Superfund Ground Water issue. EPA/540/4-89/005.

This is the soil particle, right. And ground water is being removed and here we have another phase, the nonaqueous phase liquid. So what do we have? We have liquid-liquid partitioning. So in this context, let us say if you have solubility limited and diffusion limited, right. So obviously solubility limited, let us say, you are going to have, what do we say, equilibrium to be relatively reached relatively early.

And that obviously would be the case when the relevant time, let us say, is relatively high, that would be the case when the velocity is relatively low, right. But obviously if the ground water velocity is high, let us say, and time is less, so the contaminant transport from the relevant phase into the relevant ground water will be diffusion limited which is typically again relatively slow process, right, that is something that we see here. And here again, similar case.

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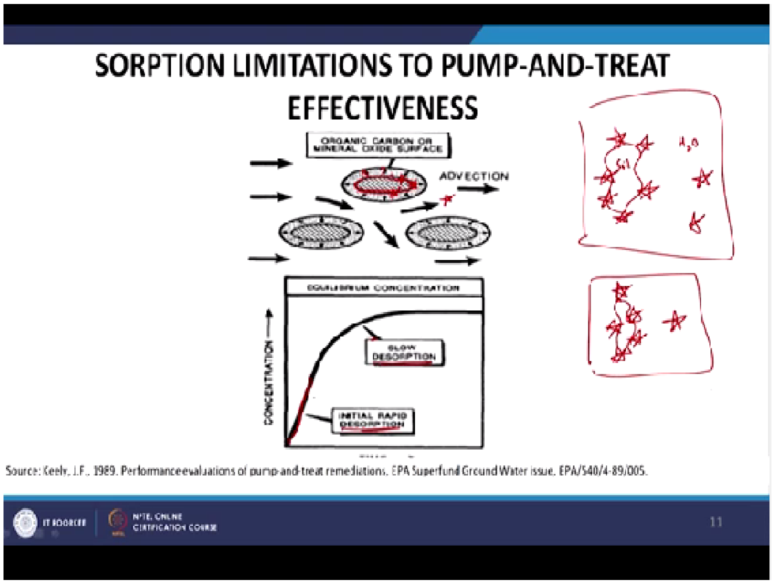

SORPTION LIMITATIONS TO PUMP-AND-TREAT EFFECTIVENESS

Source: Keely, J.F., 1989. Performance evaluations of pump-and-treat remediations. EPA Superfund Ground Water issue. EPA/540/4-89/005.

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If it is from desorption from the relevant soil, let us say. If I can make this clear, how will the contaminant change phase from this nonaqueous phase liquid into this ground water, let us say. Let us say, my contaminant is out here, how can it change phase from here to here now, right. If I get, let enough time, what do we say, if there is enough time available, obviously it will reach equilibrium.

But typically how is the transport going to take place in this particular zone? It is going to be by diffusion now, right. So similarly here with respect to the partitioning between the soil phase or the contaminant on the soil phase and in the water. So here I have my contaminant here on soil, right and here in the ground water, how is it going to take place? By desorption, right. So initially you will have rapid desorption as in, let us say, if my particular soil has relatively high concentration of the relevant compounds and in water relatively less, right.

This is case 1, right. This is my soil and this is my ground water, right. If I remove these or pump out this ground water, what do I have? I am going to have now remove these 2 moles, let us say. And let us say, again a new equilibrium is going to reached as in some of the particles here, we have 1, 2, 3, 4, 5, 6. Let us say may be the fraction will 1, 2, 3, 4. So let us say 5 here and 1 here, right.

Now this will be the new equilibrium after pumping, let us say, after pumping out the water and letting it reached the equilibrium. Again, how is this particular, what do we say, effect of desorption going to, what do we say, affect your pumping and treat or its feasibility now. If the desorption is now relatively fast, obviously it is going to be easier because you are going to have change in phase from the soil to the water relatively faster.

But if it is slow desorption obviously, right, so you are going to have the relevant cases here, right. So again the issue is that the farther you are from the equilibrium concentration, the greater the rate of desorption, right. So, let us say, if this is the equilibrium and this is the initial case, let us say, so the rate of this particular desorption, let us say, or the system would always try to reach this particular phase.

Let us say, if the concentration of the contaminant in a particular soil is out here and the one out here and equilibrium is somewhere out here and you are way far off, right. The rate of desorption will typically be, let us say, higher. But if you are already somewhere nearby, let us say, the rate of desorption is going to be relatively slow here, right. So again that is something that we see out here.

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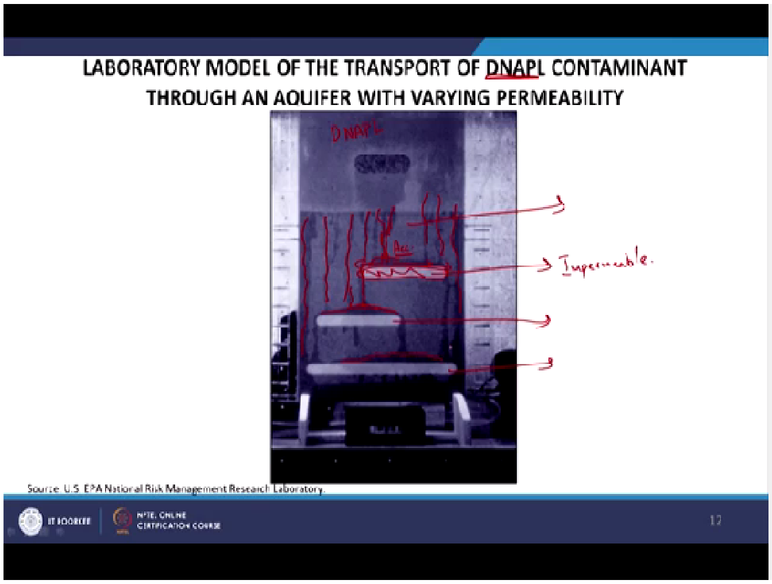

LABORATORY MODEL OF THE TRANSPORT OF DNAPL CONTAMINANT THROUGH AN AQUIFER WITH VARYING PERMEABILITY

Source: U.S. EPA National Risk Management Research Laboratory.

And here we have a case of nonaqueous phase liquid, typically a DNAPL, I guess, the model here. So here we have a source of DNAPL here, right. DNAPL, this is laboratory test obviously. So this particular discs that they have are sources of, or not sources pardon me, are impermeable layers, let us say, right. And that is what we have here, 3 impermeable layers here. So typically what do you see here?

Again here it is a homogeneous aquifer. But even though it is homogeneous, you have, let us say, what can I say, vertical fields which would fasten or hasten the transport of this NAPL. This is all the DNAPL, right. You can see the dark coloured fraction here, let us say. And you are seeing that flowing through in these vertical fields. But obviously once it hits this impermeable layer, what happens now?

It is going to experience horizontal transport, let us say, right. And again that is what, and accumulation too. So you are going to also have accumulation of the relevant compound, right. That is what you see here. You see the accumulation over the relevant impermeable layer and again out here. So the issue here is that if and when you have DNAPL, let us say, remediating that particular side is remarkably technically difficult job, let us say, especially with pump and treat.

And again typically to my knowledge, pump and treat would not serve the purpose if you have a heterogeneous aquifer, let us say, which is what we have here, different impermeable layers and particular homogeneous aquifer. But again if it is a heterogeneous aquifer, let us say, the contaminant will either stay in phase or in a different phases in different types of media. And also, let us say, the transport will be or transport mechanisms will be remarkably different for different cases.

So thus, let us say, if it is DNAPL, let us say, you are trying to remediate that particular contaminated ground water or aquifer is going to be remarkably difficult especially with pump and treat, right. So just to illustrate the types of transport that can take place, let us say, this is the picture we have out here, right.

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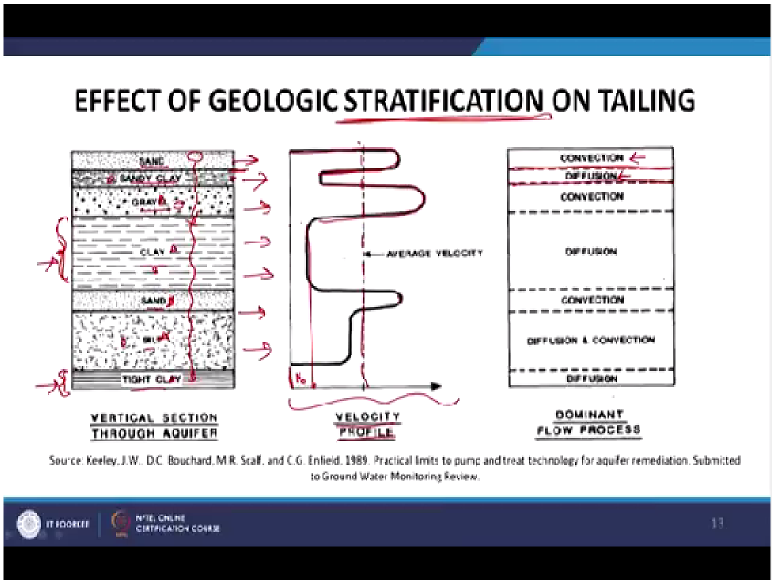

EFFECT OF GEOLOGIC STRATIFICATION ON TAILING

Source: Keeley, J.W., D.C. Bouchard, M.R. Scalf, and C.G. Enfield. 1989. Practical limits to pump and treat technology for aquifer remediation. Submitted to Ground Water Monitoring Review.

So moving on, let us say, there are other aspects that again lead to these relevant effect of or affect the feasibility of this particular pump and treat at that stratification as in. Until now we have looked at, let us say, the contaminant being in different phases, right. And again, we just looked at a picture where the, what we say, transport of the relevant DNAPL is not uniform, let us say, right.

It has vertical fingers or flows through in the form of vertical fingers and accumulates above these impermeable layers, horizontal transport accumulation and so on. So other than that, let us say, another aspect that would obviously affect your particular feasibility of pump and treat is, let us say, you have a permeable layer, semi-impermeable, impermeable layer or different strata. Obviously that is what I am referring to here as when I say or refer to it as stratification here, right.

So what is the issue here? As in the ground water flow velocity itself through these different strata is going to be different, right. So if it stands, let us say, and the hydraulic conductivity or the ease with which water can flow through that particular sand is obviously now going to be relatively high, right. So obliviously more of the relevant ground water will flow through that particular sand layer.

But let us say, if it is sandwich between as clay layer there. Obviously, hydraulic conductivity is less, right. Water does not flow through freely through clay. We do not have the interconnected pores, right. So again what is going to happen? We are going to have different ground water flow velocities. So that is what we see here. So here in this graph, obviously what do we have? We have sand, sandy clay, moving on to gravel, clay again, sand, silt and tight clay, right.

Relatively impermeable layers out here, right. So relatively impermeable layers out here. So now if I am starting to pump water out, right, and if it was a homogeneous aquifer, the velocity should be uniform. But obviously it is not going to be uniform as you can see in this particular graph. Here we have the velocity profile. As in this is the average velocity, right. But as you can see a lot of water, let us say, or the velocity in the sand layer is relatively high.

And typically in gravel too, remarkably high. And in sand too again, right. But through these layers where the hydraulic conductivity is less, you have little to no or no transport through this tight clay or compacted clay and relatively less velocity out here, right. So what does this or how does it affect the system? So if, let us say, you have contaminant release quite some time ago, right, it would reach different layers, let us say, or it would have partition between different layers through diffusion, let us say, right.

So as in initially, let us say, if this was, the contaminant was only present out here, let us say. Through either this particular vertical transport and then diffusion, let us say, the compound, let us say, would be in different concentrations and different layers out here, right. So if I am starting to pump water out in this particular scenario and most of the ground water velocity or the flow actually only takes place through the relevant, what do we say, permeable or relatively high hydraulic conductivity zones, right.

What is going to be the issue? I am only going to be able to partly pump out the relevant contaminant, right. So what needs to take place once I pump out the contaminant from the sand layer here and gravel layer here, then again I need to let the system reach equilibrium as in because we are going to have diffusion in the opposite direction, let us say. As in from the clay layer into the sand, again I need to have the relevant diffusion and then again I can pump the ground water out.

So obviously if I look at the profile here or with respect to the transport in this particular case where the hydraulic conductivity is high, I am going to have convection or advection here. And when the hydraulic conductivity is less in sand or clay, it is going to be limited by diffusion. And diffusion, let us say, is many orders of magnitudes. May be thousands of time slower than transport or through or by advection, let us say, right.

So in this case, the transport of the relevant contaminant is going to be relatively or remarkably slow compared to the transport of the contaminant in this phase which is the sand or high hydraulic conductivity zone, I guess. So that is what you see out here, right. So I guess with that I am going to end this session and we will move on to discussing some more aspects in this regard, yes. And then also try to, we did talk about the relevant aspects in generic terms.

But obviously we want to be able to quantify that to be able to understand, let us say, how long is it actually, how I can try to estimate, let us say, how long it is going to take for me to pump the water out or pardon me, all the contaminant out, right. So then I can see or try to understand or analyze whether pump and treat is the feasible option or not. But obviously you need this background or some particular information, let us say, to actually think of spending or committing more resources for your particular project, right. Again, so I guess with that I will end today's session and thank you.