Environmental Remediation of Contaminated Sites
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Lecture – 15
Remediation of Contaminated GW
Introduction to Source Control

Hello everyone, so again welcome back to the latest lecture session. As these are norm I guess let us have a quick recap of what we have been up to right. So we have been discussing let us say ground water remediation or we have contaminated ground water and we are looking at the relevant aspects about or what are the relevant options for you to be able to remediate that particular contaminated groundwater right.

So in that context we looked at various options primary containment let us see and then I believe moved on to pump and treat right. So in the context of pump and treat obviously we dwell up what do you say for a considerable period of time up on the relevant aspects. Let us say which would let us say determine the feasibility of the relevant pump and treat process yes. So in that context let us try to summarize what are the relevant aspects.

Let us see or which are the aspects that you need to consider let us say which can affect the feasibility of this pump and treat process considerably or even adversely let us see right.

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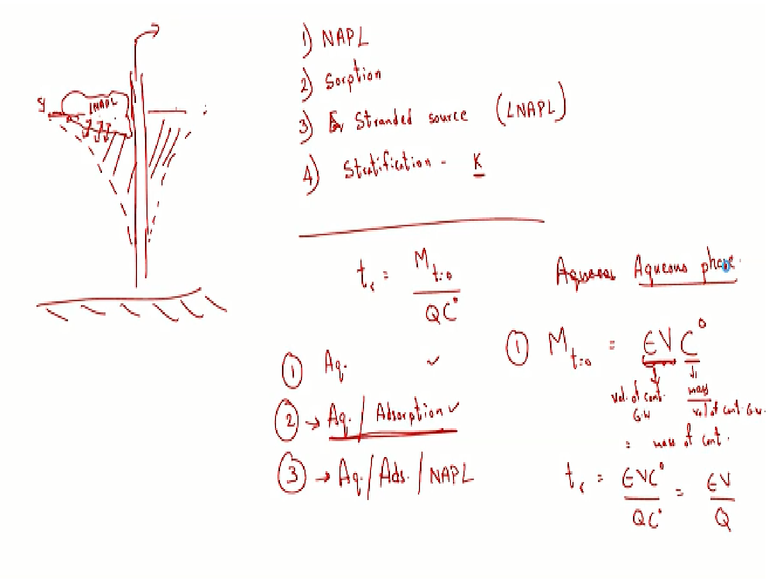

So the first aspect but we typically need to consider is the presence of NAPL right and then typically we also look at sorption. Sorption of the relevant compound onto the organic fraction of the soil. Third, I believe we also looked at what do we say stranded source let us say again typically a feature when we have LNAPL right and I believe we looked at other cases too when we had what do we say different strata or stratification let us see right.

So then the relevant hydraulic conductivities will be different for different strata out there and thus obviously the contaminant transport is not going to be uniform right. So let us just have a quick recap of these four aspects here. So NAPL obviously non-aqueous phase liquid right it is on acquiesce right so again typically they are remarkably hydrophobic. So they can act as reservoirs for what do we say hydrophobic compounds let us say right.

So let us see how hydrophobic compound and you have water here and you have NAPL here right. So typically let us say the righter fraction of the relevant hydrophobic contaminant would want to stay in the non-aqueous phase liquid phase right. NAPL right and again that is one particular aspect we looked at. So even if you pump out all the groundwater let us say right you are still going to have the reservoir of the contaminant in the NAPL.

So let us say you started from here let us say ground water concentration is in equilibrium the concentration in the NAPL let us say and then let us say you remove this particular concentration or contaminated the groundwater right. But what happens now again you are going to have equilibrium bridge between these two phase of NAPL and the relevant ground water as in the contaminant is going to change phase from NAPL or some of it.

From NAPL phase into the groundwater right so again you are going to have issues with rebound yes so that is one particular aspect we looked at and similar context we will look at sorption. As an adsorption of a hydrophobic compound let us say or hydrophobic contaminant let us say onto the organic fraction of the soil or let us if you have mineral oxides too there right. So again what is the key aspect here hydrophobic compounds right.

Again typically it would obviously not want to stay in the aqueous phase let us say. So when you have organic fraction let us say or organic carbon present in the form of soil let us say or in the soil part right. So obviously this particular compound would want to what we say be absorbed on to the relevant organic or the organic fraction of the soil. So moving on then standard source so here we have another aspect as in let us say you start you have LNAPL right.

I think a simple figure would make this clear right and let us say this is your ground water table and this is your extraction well and LNAPL typically light non-aqueous phase liquid so it is unlike the DNA pill itis not going to what we see reach through or you know permeate through to the impermeable layer here right. So let us say you know this is my LNAPL here right so if I start pumping obviously you know I am hoping to have a cone of depression right.

And let us say all the water in this particular zone has been pumped out let us say right. So after a certain time I would assume that or you know I would observe that there is no further particular concentration of the contaminant detected in that particular what to say water that is being pumped out. So then let us say I stopped pumping then what happens now. Again you know this ground water table is going to probably come back towards original levels right.

And then you again you have contact between the groundwater and LNAPL right say. So again now you have what do we say the system we will try to reach equilibrium as in the relevant compound. We will try to I guess again inter change phase from and NAPL into the ground water and again you are going to have contamination of the relevant groundwater here right. So that is one aspect where we discuss I guess stranded.

So and stratification let us say as an I think the aspects or example that we looked at to was that we have sand, clay, silty sand, gravel and so on. So the key aspect is you know let us say I am pumping water out because all this different strata let us say they have different hydraulic conductivities. As in the water can pass through some of these particular media right to be more easier easily compared to some of the other strata like clay right.

For example, I guess hydraulic connectivity remarkably righter in sand compared to clay right. So if I keep pumping water out or you know pump water out from that particular aquifer which has both sand and let us say clay right. Obviously the water will move through easily through the sand but not through the clay right. So here let us say if any contaminant has diffused into clay layer that obviously will not be remove at the same rate.

As the contaminant that is going to be or that was present in the sand layer right. So that is one particular aspect and I believe there are other you know minor aspects we discuss too. But due to lack of time I am going to move on right. So and then we started looking at let us say how do I estimate the time for remediation right. So in that context we do the simple mass balance and we came up with a way to calculate the time for remediation as the total mass present.

Let us say of that particular contaminant initially by the rate at which you are removing or pumping out the particular contaminant right. So I think a simple mass runs we arrived at this so again what is this about and the time for remediation and the pump untreated should typically be equal to the rate at which I am pumping pardon me the total mass of the contaminant right divided by the rate at which I am know pumping the mass of that contaminant out.

So that is what I have here so in that context obviously we looked at three cases or rather we need to look at three cases some of which we already discussed. So case one is one we have a compound only in the aqueous phase or its only dissolve let us say. Case two when you have the compound in the aqueous phase and also absorbed onto the soil let us say and also at adsorption okay.

And case three right when you have the compound in the aqueous phase and it is dissolved and you have absorption and you also have the NAPL right. So I believe we discussed these two aspects right and I believe we need to look at some particular we are going to look at a couple of examples in this context and then we want to discussing three right. So before we go further let us just try to recap what we have discussed in this context.

So the total mass of the containment in the case of let us say case one is going to be equal to porosity times the total volume right. So this will give me an idea about the volume of the contaminated groundwater right times the concentration of the relevant compound right. So it is a what do you have here the units of concentration are mass per volume of water or contaminated groundwater right.

And here I have porosity times total volume will be what is this now volume of contaminated groundwater right. So I obviously ended up with the mass of contaminant right. So again in this context obviously time for remediation will be epsilon VC0/QC0. So in that context it is going to be epsilon V/Q right obviously here we are assuming that CO or the you know the concentration does not change all right.

As you start pumping out but I mean that minor assumption that we can make at this stage. So obviously as you see here its is similar to the if I can call that the retention time here let us say right. So it is just the time required to pump out the total contaminated groundwater but in which context though only in the context of if the compound is only present in the aqueous phase right. And the aqueous phase or is only present in the dissolved phase right.

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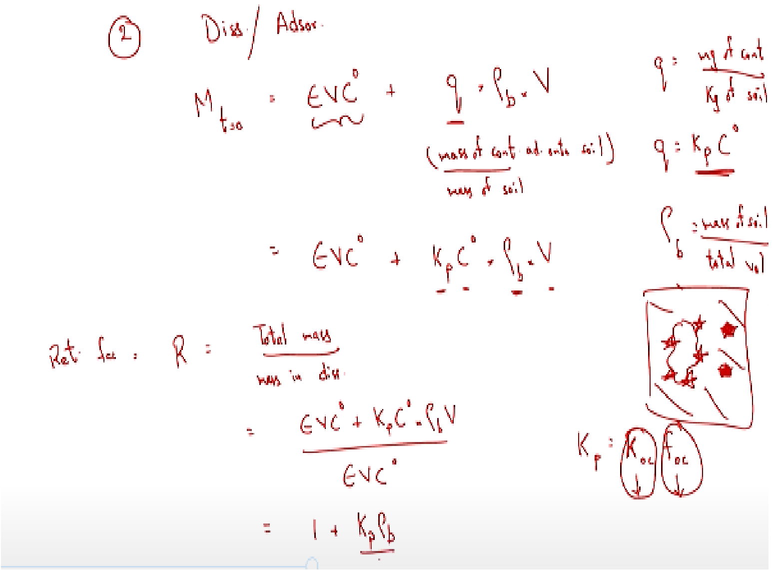
② Diss./ Adsor.

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

$q = \frac{\text{mg of cont}}{\text{Kg of soil}}$

$\left(\frac{\text{mass of cont. ad. onto soil}}{\text{mass of soil}}\right)$

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

$\rho_b = \frac{\text{mass of soil}}{\text{total vol}}$

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

Ret. fac. : $R = \frac{\text{Total mass}}{\text{mass in diss.}}$

$$= \frac{\epsilon V C^0 + K_p C^0 \cdot \rho_b V}{\epsilon V C^0}$$

$$= 1 + \underline{K_p \rho_b}$$

$K_p = \overset{\downarrow}{K_{oc}}\, \overset{\downarrow}{f_{oc}}$

So in this context we moved on and discussed the relevant aspects with respect to case two when we looked at the compound being dissolved in the groundwater and also absorbed onto the soil right. In this context I believe obviously we have looked at the relevant aspects so we are obviously going to have the mass of the contaminant that is in the groundwater this is something we looked at in case 1.

And then I believe we looked at the mass that is present in the are absorbed onto the soil right for that obviously I need the concentration of the relevant concentration on relevant compound absorbed onto the soil. So that is q here q is typically let us say a milligram of contaminant adsorbed per kg of let us say soil now right. And here in this context for linear assuming a linear model we and also looking at the partitioning coefficient right.

So again the compound that is absorbed onto the soil let us say or the ratio of the compound that adsorbed onto the soil and the one in the dissolved phase which is C0 here they will have that there is going to be relationship right. Here I am going to assume it is going to be linear let us say and here I am considering the relevant power co efficient to be the partitioning co efficient kp right and obviously what else or how else do I need to modify that I guess I have mass of contaminant

Per mass of soil right. So obviously I only wanted the total mass of contaminant absorbed onto the soil okay absorbed onto soil right. So if I multiply this by density the dry density right and density units let us say mass of soil or dry mass of soil/ total volume right. So to get my particular term here I obviously need to multiply this by volume here right.

So let us just try to simplify this further epsilon VC0+q as we see here +Kp times C0*rho b times V density of the relevant or dry density of the relevant soil total volume here partitioning co efficient let us say. C0 as the concentration of the compound water and so on and so forth right. So one other aspect again now so what is this particular partitioning co efficient going to depend upon right.

So here let us see what is the case now. I have soil particles and how compounds absorbed on to I guess a star is not a good way to you know to denote a particular compound but let us go ahead and let us say this is my system let us see and how this water out here. So obviously yeah how let us see a fraction let us see or there is going to be a equilibrium between the two phases what are the two phases the compound in the dissolved phase.

And the compound absorbed on to the soil here. So let us say if I remove this particular compound again or both these two compounds in the dissolved phase by pumping the water out what is going to happen now. Again I am going to have this option now the element compound from the soil and you know it will obviously change phase into the aqueous phase and again tried to reach equilibrium right.

So again there is going to be a particular equilibrium coefficient or such so again getting an idea about that is the variable that gives an idea about that particular aspect is the partitioning co efficient. But again what does the partitioning co efficient itself depend upon. So let us say if I have just silica let us say let us say well be a particular hydrophobic compound be adsorbed on silica not really right.

So we are concerned with what do we say the organic fraction of the relevant soil here right. So here again Kp would be dependent upon the soil partitioning co efficient soil water partitioning co efficient times the fraction of organic carbon right. This again is the soil water partitioning coefficient and this is the fraction of organic carbon present. So in this context obviously we assume that all the soil is made up of organic carbon let us say.

And here obviously because not all the soil will consist of only organic carbon you need to plug in the relevant ratio of the relevant organic carbon fraction right. So in this context let us look at one particular example to understand let us say the relevant what do we say the relative masses that would be present in the dissolved phase and the mass that would be present in the adsorbed phase.

So in this context I believe we also looked at the retardation factor right and how do we calculate done that is going to be equal to the total mass/the mass the dissolved phase right. So obviously that is going to be epsilon VC0+Kp C0*rho b*V/epsilon VC0 to end up with the retardation factor are being the retardation factor =1+Kp rho b/porosity right. Again I if I look at or try to understand what I have here what do you have here.

I have the total mass by the mass in the dissolved phase right so what will this give me an idea about this as an retardation factor it will give me an idea about the time let us say or extra time let us say required for pumping the total mass of the contaminant right.

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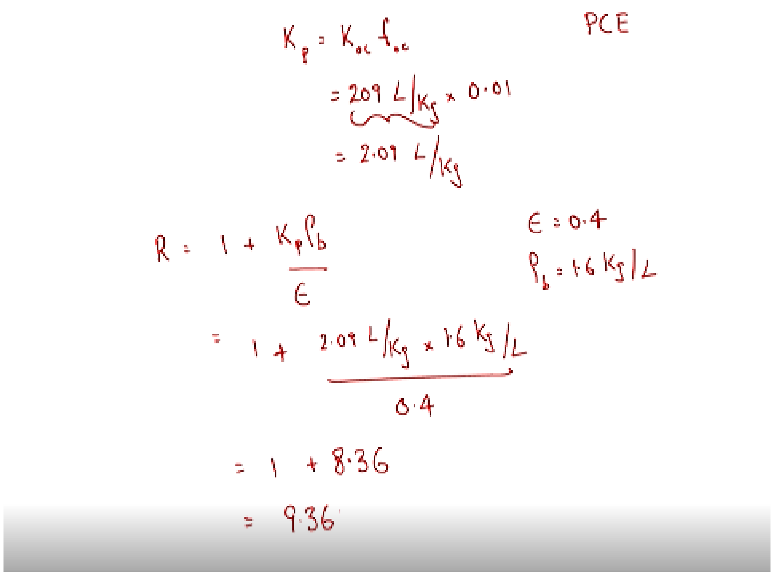

PCE

$$K_p = K_{oc} f_{oc}$$

$$= \underbrace{209\ L/Kg} \times 0.01$$

$$= 2.09\ L/Kg$$

$\epsilon = 0.4$

$\rho_b = 1.6\ Kg/L$

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

$$= 1 + \frac{2.09\ L/Kg \times 1.6\ Kg/L}{0.4}$$

$$= 1 + 8.36$$

$$= 9.36$$

So now let us move on and look at relevant what do you say example. So let us consider the partitioning co efficient that is =soil water partitioning co efficient times foc right. So for a particular example maybe let us consider PCE let us say industrial solvent and toxic too PCE. I believe the data we have are 209 litres per kg times and now fraction of organic carbon present in the soil

I am going to assume it is going to be 1% that is going to be 0.01 so I here I now end up with 209 litres per kg right. I mean these are from the relevant EPA document I guess right the Koc value and now what is my R here or retardation factor was 1+Kp rho b/porosity. So obviously we need to have some what do we see data regarding the bulk density of the soil and the porosity. So typical values which I will take typical values porosity .04.

And bulk density to be 1.6 kg per litre right so now I am going to plug these values in so 1+2.09 litres per kg*1.6 kg per litre/ the porosity is 0.4and what do I end up with looks like I ended up with from what I have calculated previously 1+8.36 right again this is =9.36 obviously. It is again what does this give you an idea about right it tells you that mass of the relevant parcel did element contaminant that is present in the dissolved phase right.

Let us say if that is one the mass of the contaminant that is absorbed onto the soil is 8.36 right and the ratio is 1 is to 8.36 right. So that gives you an idea about the relevant time required obviously to pump the water out for example if it was only in the dissolved phase let us say and if it took you one year right to pump the relevant contaminate out or contaminant out pardon me and now because of this retardation factor which uses an idea about the mass.

That is adsorbed on to the oil let us see right if this were the scenario you will see that it takes 9.36 years or 8.36 years more to be able to pump the relevant a water right. As you see so if the relevant compounds is hydrophobic as is the case for this particular PCE let us say the time required for what we say pumping out you know obviously increases considerably.

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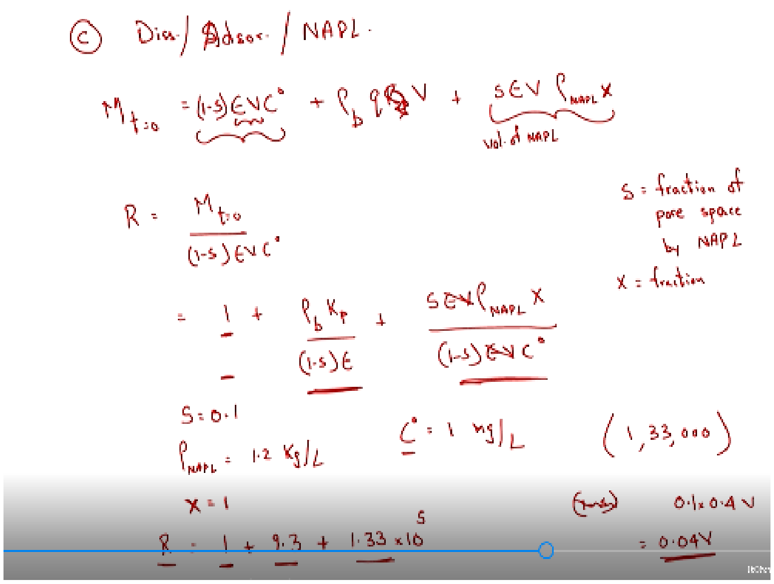

ⓒ Diss./ Adsor. / NAPL.

$$M_{t=0} = \underbrace{(1-S)\epsilon V C^{0}} + \rho_b q \cancel{K} V + \underbrace{S\epsilon V \rho_{NAPL} X}_{\text{vol. of NAPL}}$$

S = fraction of pore space by NAPL

X = fraction

$$R = \frac{M_{t=0}}{(1-S)\epsilon V C^{0}}$$

$$= \underline{1} + \frac{\rho_b K_p}{(1-S)\epsilon} + \frac{S\cancel{\epsilon V}\rho_{NAPL} X}{(1-S)\cancel{\epsilon V} C^{0}}$$

$S = 0.1$

$\rho_{NAPL} = 1.2\ Kg/L$

$X = 1$

$C^{0} = 1\ mg/L$

$(1,33,000)$

$(1-S)$ $0.1 \times 0.4\ V$

$= 0.04V$

$$\underline{R} = \underline{1} + \underline{9.3} + \underline{1.33 \times 10^{5}}$$

So moving on to the relevant or the next relevant aspect so here we are going to consider the case of the dissolved phase right. And also this option or absorbed phase which is the soil adsorption right and also the NAPL case right so let us try to come up with the relevant equation here. So first the dissolved phase we know that it is epsilon VC0 right and adsorbed qKp*volume not Kp p pardon me rho b right plus the mass that is present in the NAPL phase right.

So obviously here there is a minor correction that we need to look at or you know a need to incorporate here as in a where is the NAPL going to be present. It is its going to be present in the pore space right so here the pore space and what the pore volume here it is epsilon V. So obviously if you also have NAPL here we are going to assume that a part of the pore space is filled by NAPL.

And the part of the remaining part is going to be filled by ground water here right. So in that case I am going to assume that S is the fraction of pore space. Let us say that is filled by NAPL let us say or occupied by an NAPL let us say right. So here how do I need to obviously change this particular term here. It has to be 1-S right as epsilon or porosity times volume earlier was the total volume of the contaminated groundwater.

But here now it is 1-S times porosity volume because part of the pore spaces is filled by NAPL right. So here again what do I need I need the fraction of or the volume of the NAPL how do I get that I know there is epsilon S epsilon*volume. So this will give me an idea about the volume that is present in the particular what is this now NAPL right the volume of the NAPL right. So here I how volume of NAPL right.

But obviously I am looking forward the mass of the containment right. So here again I need to multiply that by the density of NAPL right and if NAPL itself is not irrelevant a contaminant or if its acting as what we say a reservoir for contaminant so yeah as we know it can be two cases as in let us say the relevant compound can be the NAPL itself or the relevant contaminant can be the NAPL itself or NAPL.

Or some other non-aqueous phase liquid can act as a reservoir or a phase in onto which let us say the relevant contaminant is present in let us say right. So obviously I am going to multiply that by x let us say x is going to be let us say the fraction that is present in fraction of contaminant present in the relevant NAPL right. So here let me again plugin a few values so let us look at an example.

But I guess before I go further again I need to obviously again calculate or you know to understand system better let us try to calculate the retardation factor. So let us see what that is going to be here so retardation factor is again going to be equal to M time=0/ the mass present in the dissolved phase so which is going to be this 1-s porosity VC0 so that is going to be equal to 1+ rho b and q is nothing but Kp times C0.

So KP right/1-s and porosity +s times porosity times volume and NAPL+mass fraction of contaminant present in NAPL/1-s porosity VC0. So what do I have here or what can I cancel out epsilon V and epsilon V? So this is my retardation factor right we looked at the case earlier in the context of what does it now just the adsorbed phase or be compound being absorbed onto the soil and also the compound being present in the dissolved phase.

We looked at the relevant ratios and we saw that it was one for one part in what do we say the dissolved phase 8.36 parts are adsorbed onto the soil right. So let us try to look at a few a typical values and try to calculate the relevant aspects okay. So I think I have few values here so let us try to look at some of the typical values. So let us say the pore space that is filled by NAPL I will consider that to be 0.1 density of NAPL.

I will consider that to be 1.2 kg per litre these are all typical values not the hypothetical values right. So concentration and we are going to take initial concentration to be less 1 milligram per litter. And let us say I am also going to consider that x which is the mass fraction of the relevant contaminant in the NAPL to be 1 as in that it is pure NAPL let us right that is what I am going to consider here and let us try to look at the values that calculated.

So looks like I end up with ratios of 1+retardation factor =1+9.3+1.33*10 power 5 right. So obviously the three values correspond to the three variables here right so what did this idea about obviously this is a reference the mass in the dissolved phase and this will give you an idea about the ratio of mass in the soil to the ratio of mass in the dissolved phase and this will give me an idea about the ratio of mass in the NAPL to the mass in the dissolved phase right.

So if I look at that I see that you know for one part dissolved I have 9.3 parts adsorbed on the soil and for this though I have let us see 133 right. So this is what I have here so l lakh 33000 right and as you now see let us say if you have NAPL let us see your particular what do we say pump and treat is going to be remarkably or you know is going to be infeasible right. So in this context obviously even a minor volume of NAPL.

Let us say that is present well throw your particular calculations or your particular feasibility of the relevant pump and treat into disarray right. So here let us see let me try to understand what the volume of what do we say NAPL is. So I have 1-2 as I consider to be or pardon me has to be 0.1. 0.1 times porosity was 0.4 times volume right so 0.04 right the volume. So even at such low volume let us say as you can see 4% let us say right.

We see that 4% of total volume is occupied by NAPL we see that you know what is it the retardation factor is remarkably high let us say and then the process feasibility obviously is pretty low as in what is this tell me now that if it takes one year to pump out the water present in only the dissolved phase let us say. But in this case of case you know where I have dissolved adsorbed and NAPL phases it takes me more than a lakh.

Or you know 150000 units or 134000 years I guess or 133000 years to be able to pump that out right. So even if I say decrease some of the other values that the volume of NAPL let us say that is present already know some of the other variables you will still remarkably infeasible. As in you do not want to keep pumping water out for 10s or 100s of years right. So as you see even if I take relatively more conservative estimates for the volume.

Or let us say the fraction of mass fraction of the contaminant in the NAPL and such you still see that it is going to be remarkably in phase right. So with these calculations or estimates you should then be able to what we would say you would be better placed to be able to let us say check for the feasibility of the relevant pump and treat options right. So considering these aspects do typically again what do we need to you know.

What is the crucial aspect here you need to be able to understand your particular aquifer let us say and also know the site or the contaminate site conditions pretty well right? So if you do not do that and you know what to say choose pump and treat as you see you can lead to it can lead to failure yes. So in this context obviously you can do some trials in laboratory and such a right but those are different aspects which you are not going to go into here.

But again from looks like what people have observed pump and treat widely used across the world typically in the western countries or western worlds right. So here there what you know a transpire was that people who how tried to pump the water out and treat it let us say have underestimated development complexities in the aquifer and typically looks like more systems they just you know stop their particular goal of remediating it.

But only to end up containing the relevant pump right so initially they started out with pumping the water out and trying to treat it. But again because of these kinds of issues that they face let us say most people or most of the relevant are considerable let us say while using the term most considerable number or fraction of the relevant people who chose pump and treat they you know abandoned that particular goal let us say.

And then just try to limit their particular what do we say aspects to containing the relevant pump so that it does not spread to a wider area right.

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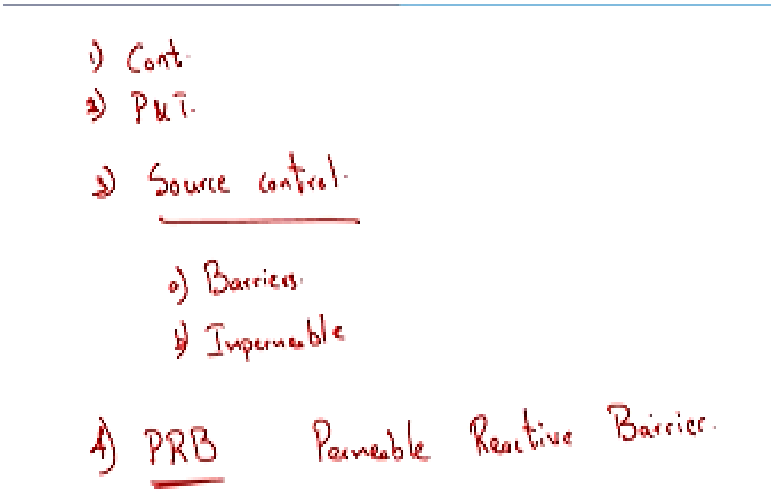

1) Cont.
2) P&T.
3) Source control.
   a) Barriers.
   b) Impermeable
4) PRB Permeable Reactive Barrier.

So in this context let us move onto the other aspect so we have looked at I believe a containment right and then moved on to pump and treat let us say and now we will look at obviously the third case a simple case where we are going to spend a little sometime on it right. So obviously here if you detect the spill or release of the contaminant relatively right so what can you do you can look at source containment or source control right.

Source control right so obviously how is this related to your particular case of groundwater. So typically you have the contaminated soil and then let us say the groundwater then coming in with in contact with this contaminated soil or the relevant contaminant flowing through that particular media and reaching the groundwater right. So in that context obviously effects and early release what can you do now you can obviously try to remediate that particular contaminated soil.

Before let us say you end up with a contamination of the groundwater again contaminate soil relatively limited area or extent of contamination but once it reaches the ground water you see there are multiple issues out there. So obviously you can look at source control as in you can set up barriers or relatively impermeable layers can be constructed right or you can obviously let us say look at treatment of the soil or sediment right.

So here two aspects as in you want to limit the transport of the contaminant or transport of the containment from the soil into the groundwater that is one aspect that you can certainly look at or obviously you are going to look at treating the soil right but that is something we are going to discuss in the later parts of the course right. So these aspects obviously you know or you can obviously try to treat the soil to different ways again.

These are aspects we are going to discuss later on in the during the later parts of the course right. So now we are going to move on to another particular treatment option which is called PRB right. So PRB is a permeable reactive barrier right just a couple of minutes about this particular option and then we will end the session for today. So permeable reactive barrier is one of the most widely use techniques.

Again depending upon the type of contaminant and the aquifer and the depth of contamination let us see but again there are what do we say numerous advantages to this particular process and maybe not widely or not adopted in India yet due to lack of maybe transfer of knowledge let us say maybe the people let us say the relevant people I know who are going to now learn about this can try to implement this and the relevant aspect that they face right.

So again permeable reactive barrier as the name indicates is right its permeable the barrier you are going to put a barrier but that is not an impermeable barrier its a permeable barrier right. So in this context you want to how the contaminated groundwater flow through this particular permeable barrier and the key aspect is this particular barrier consists of reactive media right So you are going to put the relevant compounds.

That are going to either lead to degradation of the relevant contaminant in the groundwater or let us say removal or changing phase from aqueous to absorb right in this particular case right so with that I guess I will end this session and we will continue or you know start discussing PRBs in greater detail from the next session I guess right and thank you.