Environmental Remediation of Contaminated Sites

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Lecture – 49
Case Study: Surfactant Extraction: Part - I

Hello everyone. So again welcome back to the latest lecture session. I believe you are looking at particular example relevant to these surfactant extraction based remediation right and in that context we had a particular NAPL right and you know the scenario was such that you are some surfactant to be able to let us say dissolve that particular NAPL and then the relevant question was that or the scenario that we face was that for different volumes of surfactant let us say what would be the relevant scenario let us say right.

So I believe we already worked out a part of the question but let us look at the question once again.

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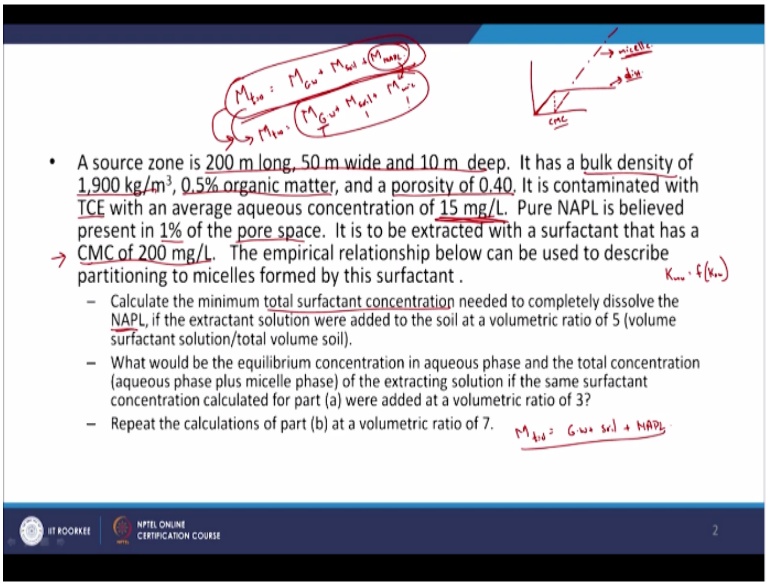

- A source zone is 200 m long, 50 m wide and 10 m deep. It has a bulk density of 1,900 kg/m^3, 0.5% organic matter, and a porosity of 0.40. It is contaminated with TCE with an average aqueous concentration of 15 mg/L. Pure NAPL is believed present in 1% of the pore space. It is to be extracted with a surfactant that has a CMC of 200 mg/L. The empirical relationship below can be used to describe partitioning to micelles formed by this surfactant .
  - Calculate the minimum total surfactant concentration needed to completely dissolve the NAPL, if the extractant solution were added to the soil at a volumetric ratio of 5 (volume surfactant solution/total volume soil).
  - What would be the equilibrium concentration in aqueous phase and the total concentration (aqueous phase plus micelle phase) of the extracting solution if the same surfactant concentration calculated for part (a) were added at a volumetric ratio of 3?
  - Repeat the calculations of part (b) at a volumetric ratio of 7.

So we have a source zone right that is given out here and the bulk density of the soil is given, the fraction of the organic matter is given and relevance is that the relevant NAPL can be adsorbed onto the organic matter in the soil. The porosity of the soil is given, it is contaminated with trichloroethene and aqueous concentration, aqueous as in the concentration in the relevant water let us say or the groundwater is 15 milligram per liter.

Keep in mind this is not the solubility low but let us say it should have been solubility if there was equilibrium but again we will discuss these aspects later. So again 15 milligrams of the relevant TCE per liter of water, pure NAPL is believed to be present in 1% of the pore space and it is to be extracted with a surfactant that has a CMC of 200 milligram per liter. What is this about?

As in as you know, initially when you start putting in the surfactant let us say right most of it will be at the interface let us say or it as in the surfactant will occupy the interfaces and after that as in the point or threshold being the critical micelle concentration which is the CMC. Then, you will have formation of the relevant micelle let us say right. This micelle obviously right, this is the micelle.

Now here this refers to the dissolved phase or let us say the relevant surfactant at the interfaces let us say and this is the micelle phase let us say. Both are more or less dissolved but there is a different phase here I guess right. Again, so only after you reach or you add enough surfactant such that you reach the critical micelle concentration will you start forming the micelle and that is what you have out here.

And empirical relationship for Kow or Kmw as a function of Kow was available right though I do not have it here. So we were supposed to calculate the minimum surfactant let us say or the total surfactant needed to completely dissolve the NAPL right. So the total mass initially is present in the groundwater in the soil and in the NAPL right. So the question more or less is how much surfactant do I need to add such that all the contaminant in the NAPL will dissolve let us say.

So where will it dissolve into? It will dissolve into the relevant surfactant. So this after I add surfactant what will the scenario be? While the mass will still be the same as the initial mass right. It will now be in the form of in what do we say dissolved in the groundwater and adsorbed onto the soil and now in the micelle let us say. It would not be in the NAPL anymore right.

But the total mass is going to be the same as in you are going to look at the scenario where all the NAPL has dissolved into the relevant micelle let us say right and again there can be equilibrium between or different equilibrium between the groundwater and soil but as you are going to see here we are going to consider slightly different scenario let us say right. So in this context we went ahead and I believe calculated the total mass that was present initially in the groundwater, the soil and the NAPL let us say right.

And that is where we were at, so obviously as we just discussed the next stage is that you want to be able to calculate the amount of micelle or the surfactant concentration right. For that, you want to know the amount of micelle that you need to add let us say per volume of water or such let us say right.

So that is something we are going to do or calculate how now by equating this total mass which we calculated earlier to the new particular scenario let us say which is that the contaminant is in the phase of groundwater, soil and micelle let us say right. So let us look at that particular aspect out here.

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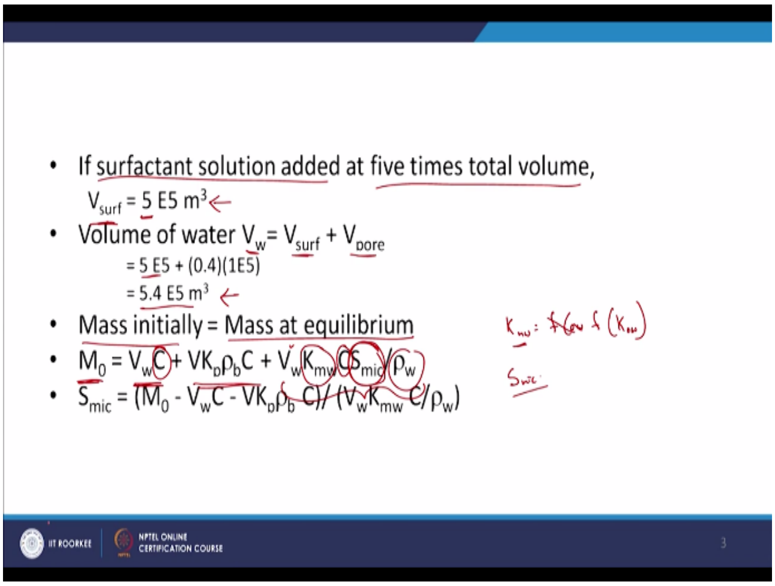

- If surfactant solution added at five times total volume,
  $V_{surf} = 5\ E5\ m^3$ ←
- Volume of water $V_w = V_{surf} + V_{pore}$
  $= 5\ E5 + (0.4)(1E5)$
  $= 5.4\ E5\ m^3$ ←
- Mass initially = Mass at equilibrium
- $M_0 = V_w C + VK_p\rho_b C + V_w K_{mw} C S_{mic}/\rho_w$
- $S_{mic} = (M_0 - V_w C - VK_p\rho_b C)/(V_w K_{mw} C/\rho_w)$

K_{mw} : fn of (K_{ow})

S_{mic} :

So another aspect is that we mention that the surfactant solution is added at 5 times the total volume so this is what we now have, the volume of surfactant is now obviously available right and so the total volume of water will be taken to be both the volume of surfactant and the pore volume that was initially available let us say right. So it is 5.4*10 power 5 meter cube as in keep in mind that you are going to keep pumping this level of surfactant through the system now right.

That is the amount of surfactant come and water that is going to be available to let us say dissolve the relevant contaminant let us say right. So that is something to keep in mind so obviously as you can see we add considerable amounts of surfactants right. So we will move on, so as we discussed mass that was present initially is going to be the mass again at the new equilibrium let us say when we add the relevant or enough amount of the surfactant let us say right.

Because we are not degrading the mass or the contaminant, we are only changing it from one phase to the other so let us look at what we have so this M0 is what we had earlier and this is still the mass in the groundwater, mass in the soil and this as we looked at earlier is the mass in the micelle let us say right and this is what we are trying to calculate and obviously for this we need volume of water.

This is what we have here right that is something we have. Kmw we have a relationship in terms of the Octanol water partitioning coefficient right function of the Octanol water partitioning coefficient will now look at that. I believe density we have that, concentration is the same as this particular concentration in the relevant water right, that is how we are going to use this particular aspect and from that particular.

And once we put in all these variables or plug in all these variables, we will be able to calculate as micelle the variable that we are trying to calculate let us say right. So before that I need to calculate Kmw, let us look at what we have, there was an empirical relationship given.

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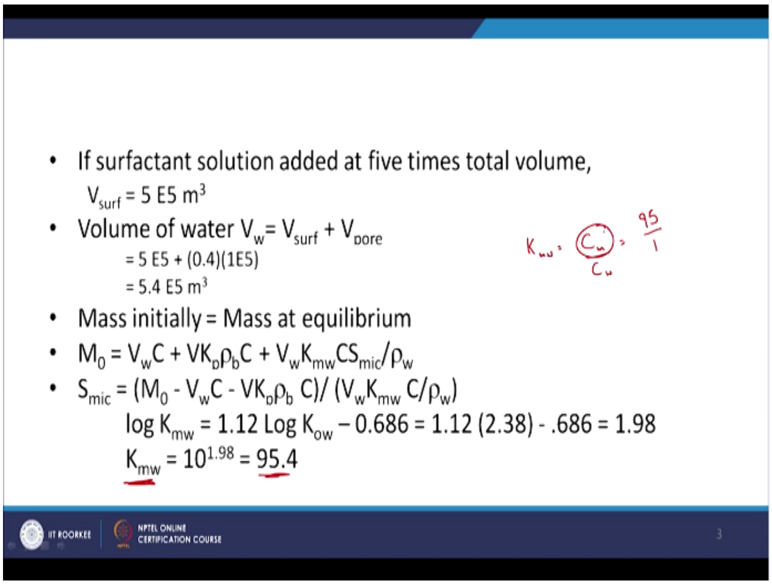

- If surfactant solution added at five times total volume, $V_{surf} = 5\ E5\ m^3$
- Volume of water $V_w = V_{surf} + V_{pore}$
  $= 5\ E5 + (0.4)(1E5)$
  $= 5.4\ E5\ m^3$
- Mass initially = Mass at equilibrium
- $M_0 = V_w C + V K_p \rho_b C + V_w K_{mw} C S_{mic}/\rho_w$
- $S_{mic} = (M_0 - V_w C - V K_p \rho_b\ C)/\ (V_w K_{mw}\ C/\rho_w)$
  $\log K_{mw} = 1.12 \text{ Log } K_{ow} - 0.686 = 1.12\ (2.38) - .686 = 1.98$
  $K_{mw} = 10^{1.98} = 95.4$

$K_{mw} = \frac{\boxed{C_m}}{C_w} = \frac{95}{1}$

Again, if we just rewrite this particular equation and this is how this is the equation that we are trying to solve for let us say, so that we can get as micelle right and how do we solve for Kmw, there was a particular empirical relationship given here right. So Kmw is dependent upon Kow and we see that we end up with Kmw to be 95.4 right and what is this Kmw, similar to the Octanol water partitioning coefficient for the particular compound.

This Kmw is the partitioning coefficient of the relevant compound between micelle and water let us say. So if you have micelle and water, what is the partitioning coefficient or what is the preference of the relevant compound. So here as you see, let us say you have Kmw which is nothing but let us say the concentration of the compound which is TCE here in the micelle let us say phase to the concentration of the compound which is again TCE in water will be 95:1.

So obviously it strongly prefers to stay in the micelle let us say right or you know in micelle phase that is something we discussed and that is what we are all very aware of. So with this particular aspect let us say we need to go further.

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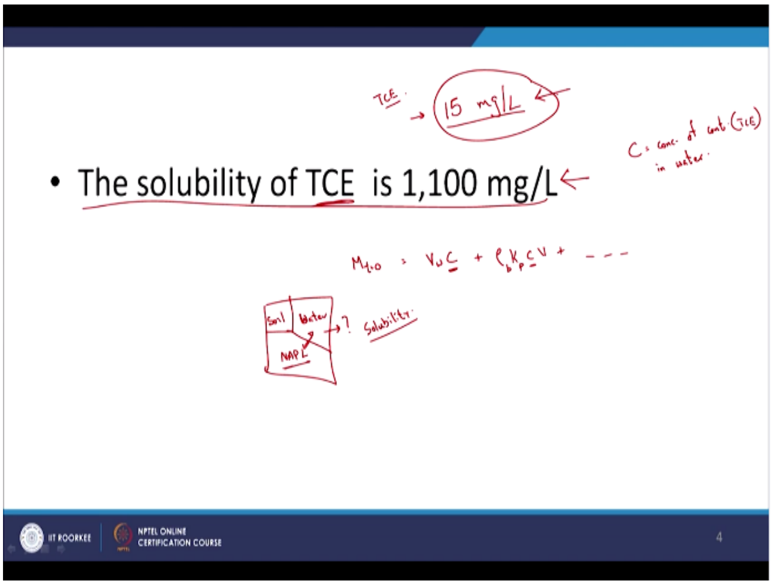

TCE. → 15 mg/L

C = conc. of cont. (TCE) in water.

- The solubility of TCE is 1,100 mg/L

$M_{t,o} = V_w C + \rho_b K_p C V + \text{- - -}$

But one aspect as I mentioned earlier was that we had M total=0 and we had it in terms of Vw*C and so on rho b Kp C*again I guess there is another term I am missing here right the partitioning coefficient I guess right I think I have that too. Yes, obviously the volume right, again we have so on and so forth but again here we have concentration. The concentration is or the concentration variable that is the concentration of contaminant which is TCE in the water let us say right.

So one aspect here we need to obviously make some assumptions. So as we mentioned here based on the relevant data it seems the solubility the maximum concentration that TCE can hold or have in or water can hold of TCE let us say is 1100 milligram per liter but keep in mind initially it was only present at 15 milligram per liter let us say. This is what we had earlier right.

This was the initial concentration of TCE dissolved in water but if there was true equilibrium what concentration would have been present, as in earlier we had soil let us say, I am using a very general what do we say diagram here and we had water and we had NAPL which is the pure compound let us say right NAPL let us say. So if true equilibrium had been reached let us say then what would be the concentration in water let us say.

It would have been this solubility let us say based on the solubility or the maximum concentration of the relevant contaminant that would have been feasible in that relevant phase which is water so but the information that is given says that the concentration in water was only 15 milligram per liter so that means there is no equilibrium or equilibrium has not yet reached between the relevant aqueous phase and the NAPL let us say right.

So here now we have faced with the dilemma as to what concentration to choose let us say when the new equilibrium you know is considered as in now we do not have NAPL anymore, we only have the surfactant. So to be let us say you know to be on conservative side let us say I am going to choose that you know I am again going to have the same concentration let us say right typically that would not be the case, same concentration of 15 milligram per liter right. So that is something we are going to have.

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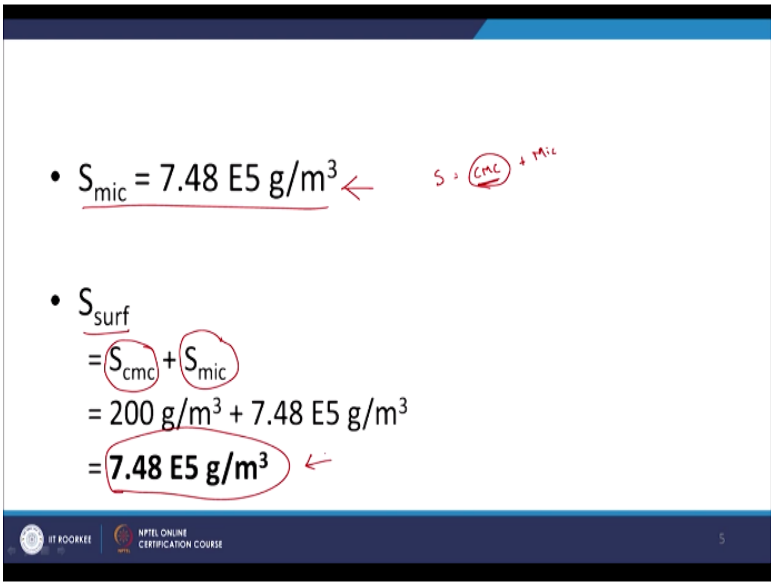

- $S_{mic} = 7.48\ E5\ g/m^3 \leftarrow$ $S = cmc + mic$

- S_{surf}
  $= S_{cmc} + S_{mic}$
  $= 200\ g/m^3 + 7.48\ E5\ g/m^3$
  $= \mathbf{7.48\ E5\ g/m^3} \leftarrow$

And based on that particular aspect, I end up calculating this as micelle but the total surfactant will be the one present in both the critical micelle concentration because this is how much I need to add before the micelle is formed and the one in the form of the micelle let us say right. So let us look at what we have out here. So total surfactant that I need to add is based on the amount of surfactant that I need to initially add before the micelle is formed.

And again the amount of micelle required based on what now, how did we calculated this? We calculated this particular variable based on let us say the amount of surfactant need to completely dissolve a particular amount of NAPL right for a particular volume of water let us say or the surfactant. Based on that, we calculated these aspects and we end up with the particular value which is considerably high.

Almost, looks like approaching the density of water. So that typically tells you that concentration is way too high that means typically let us say we do not we go for larger volumes of surfactant let us say, typically these concentrations of surfactants are not practically feasible I believe right but again so how would you offset that, you will have more volume of your relevant what do we say surfactant let us say right.

Earlier, we looked at 5 times let us say but typically will have relatively higher values. Again, but we will use this particular value to look at the further calculations right. So this is what we have or this is the amount of surfactant that we need to add let us say to completely dissolve the relevant what is it now NAPL. If you are adding the surfactant at 5 times the total volume let us say right. That is what we have out here. So let us look at the next case.

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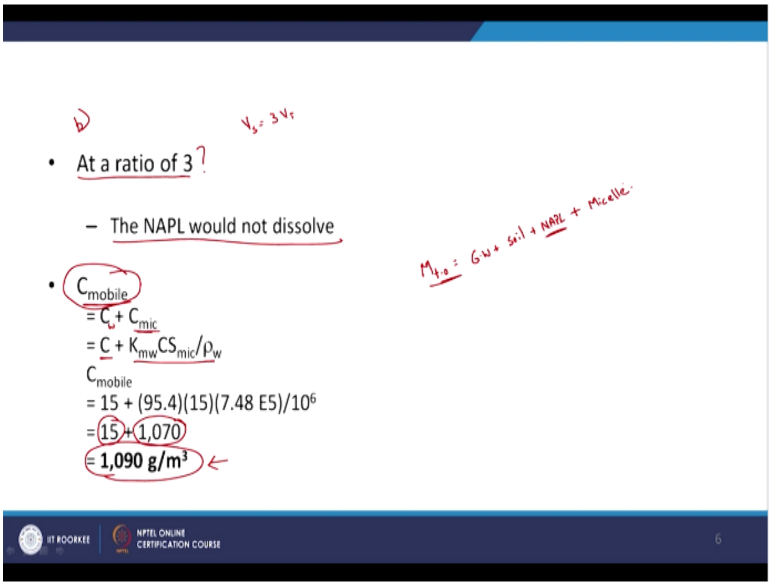

b)

$V_s = 3V_T$

- At a ratio of 3 ?
  - The NAPL would not dissolve

$M_{T.0} =$ G.W + Soil + NAPL + Micelle.

- C_{mobile}

$= C_w + C_{mic}$

$= C + K_{mw} C S_{mic} / \rho_w$

C_{mobile}

$= 15 + (95.4)(15)(7.48\ E5)/10^6$

$= 15 + 1{,}070$

$= \mathbf{1{,}090\ g/m^3}$

So the part B says that or asks us if you at a ratio it as in the surfactant volume let us say is 3 times the total volume let us say right so what is the case going to be right but the issue here is that let us say, earlier we calculated the relevant scenario let us say or analyzed the relevant scenario such that we add the surfactant at 5 times the volume right and for that particular case we calculated the relevant concentration of micelle let us say or the surfactant required such that everything dissolves let us say.

So in this case if at the same surfactant concentration you are adding less volume of the surfactant, what is going to happen? So that would mean that all the NAPL will not dissolve let us say right. So that is something to keep in mind. Earlier we calculated the case such that at a particular volume and at a particular concentration all the NAPL would dissolve. So if I am decreasing the volume.

But keeping the same surfactant concentration obviously all the NAPL cannot dissolve into the relevant surfactant let us say right. So that is what we have out here. So the NAPL would not dissolve let us say right but I believe the case asked for the concentration let us say that is in the mobile phase. When we asked about concentration in the mobile phase, it means the concentration both in the water and in the micelle phase.

So this is what we have dividing by the volume of water and we end up with the concentration of the relevant compound in the mobile phase let us say obviously these are relative terms let us say to be around 1000 gram per meter cube let us say right considerably high. As you can see in water, it is 15 gram per meter cube and in micelle the concentration is remarkably high let us say right.

Obviously, that is as expected as you know that the Kmw value was around 95 let us say right. Again, here though if you look at the particular case for M total let us say what it would be though? Here we would not asked to calculate the M total; we were only trying to look at let us say the concentration of the relevant contaminant in the mobile phase right, mobile includes both the surfactant and the water and that is why we looked at.

But for this particular case where will the surfactant be or in what phases, it will be present in groundwater, it will be present in soil, it will still be present in some NAPL form. Why is that? Because all the NAPL would not dissolve and some of it will also be present in the micelle phase let us say right. So that is something to keep in mind now right. So let us move on.

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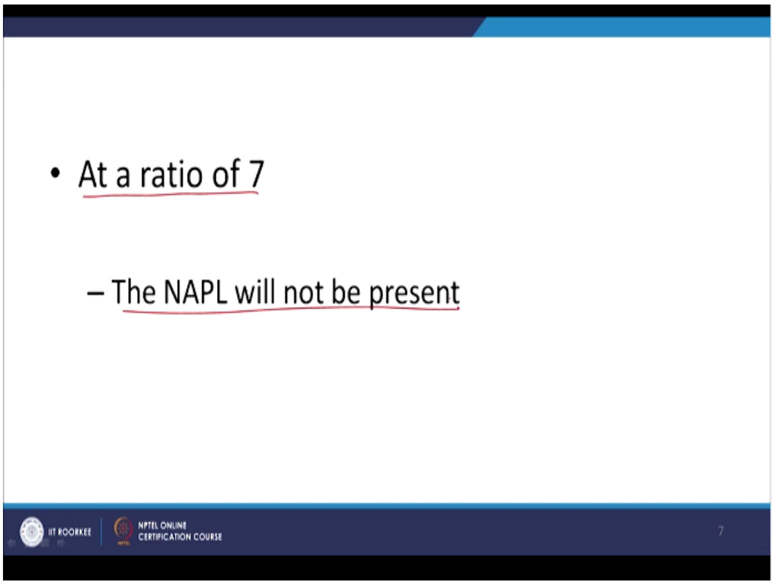

- At a ratio of 7
  - The NAPL will not be present

So the next aspect is I believe let us say when we add the relevant surfactant let us say at volume of you know 7 times the total volume right. So again we need to look at initial case, as in initial case, we added the volume 5 times of the total volume, volume of surfactant was 5 times the total volume and then for that particular scenario we calculated the relevant surfactant let us say.

That is required to completely dissolve the NAPL. So now unlike in the case B or part B we are increasing the volume of surfactant or we are providing more surfactant let us say right.

So what will that lead to let us say, that will lead to obviously complete dissolution of the NAPL and also that the concentration of the contaminant in this particular micelle let us say will now be lower let us say.

So let us look at that, obviously NAPL will not be present right that is something we discussed earlier yes.

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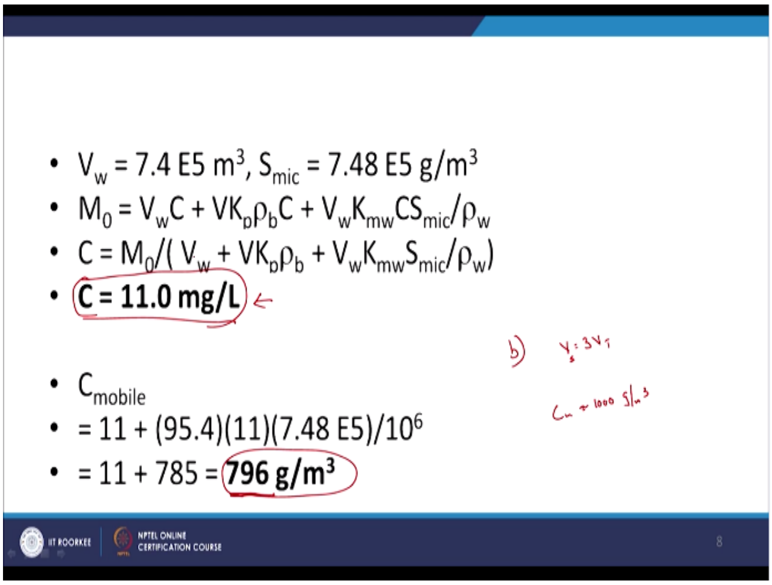

- $V_w = 7.4\text{ E5 m}^3$, $S_{mic} = 7.48\text{ E5 g/m}^3$
- $M_0 = V_wC + VK_p\rho_bC + V_wK_{mw}CS_{mic}/\rho_w$
- $C = M_0/(V_w + VK_p\rho_b + V_wK_{mw}S_{mic}/\rho_w)$
- $\boxed{\mathbf{C = 11.0\ mg/L}} \leftarrow$
- C_{mobile}
- $= 11 + (95.4)(11)(7.48\text{ E5})/10^6$
- $= 11 + 785 = \boxed{\mathbf{796\ g/m^3}}$

b) $V_s = 3V_T$

$C_m \approx 1000\text{ g/m}^3$

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So volume of the relevant water was recalculated let us say and in the micelle right, this is what we have from part A and now as we know no NAPL will be present, the total mass is out here right and this is what we have, this is in the groundwater, soil and in the micelle phase right. We are going to plug this relevant values into calculate C let us say. So C is 11 milligram per liter let us say right.

So that is what we have out here and the mobile phase as we looked at or understood earlier, we now have it to be 796 gram per meter cube. In part B, when we had it at I believe what was it, volume was 3 times the total volume, volume of surfactant, this particular C mobile was around 1000 gram per meter cube but now obviously because you are adding more of your particular surfactant which is 7 times the total volume compared to 3 times, obviously the concentration let us say is going to decrease.

And again keep in mind here that we recalculated for the concentration of the relevant what do we say contaminant in water or let us say the in water more or less yes because the total volume has changed here let us say right. So that is something to keep in mind right. So I guess with that we understand what do we say how what do we say or the levels of surfactant that you need to add.

And get an idea about any approximately idea in a way the levels of surfactant needed, the concentrations that would typically be in the surfactant let us say after equilibrium has been reached and so on and so forth but obviously these are for these calculations are for understanding the relevant scenario let us say right. As in you obviously cannot pump 5 times the volume of surfactant in one go right.

And you cannot typically reach equilibrium immediately let us say right so you are going to on phases let us say right and then you are going to have to flood the system to remove this particular surfactant and the relevant contaminant and so on and so forth let us say right. So in this context let us say will now move on to look at a particular case study. Again, the choice of the case study is based on relevance to what we are talking about.

And more importantly the data that is available you know in the public domain right. So let us look at what I have out here.

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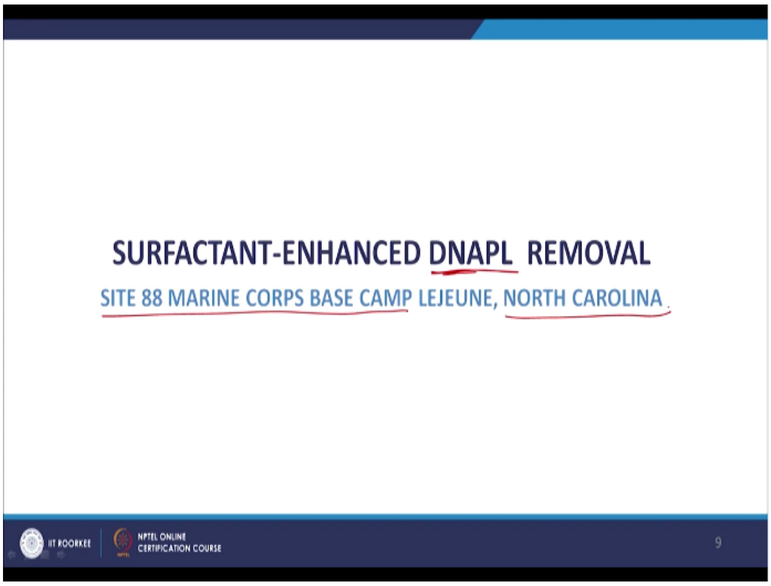

SURFACTANT-ENHANCED DNAPL REMOVAL

SITE 88 MARINE CORPS BASE CAMP LEJEUNE, NORTH CAROLINA

So we have a surfactant-enhanced DNAPL right, DNAPL typically that is the worst particular type of contaminant that you can have or contaminant that you can have the dense non-aqueous phase liquid removal and again we are looking at a particular army site let us say. This is now in North Carolina let us say again right. So again as I mentioned if you look up this particular information you know in the public domain let us say you will be easily able to look at the relevant document.

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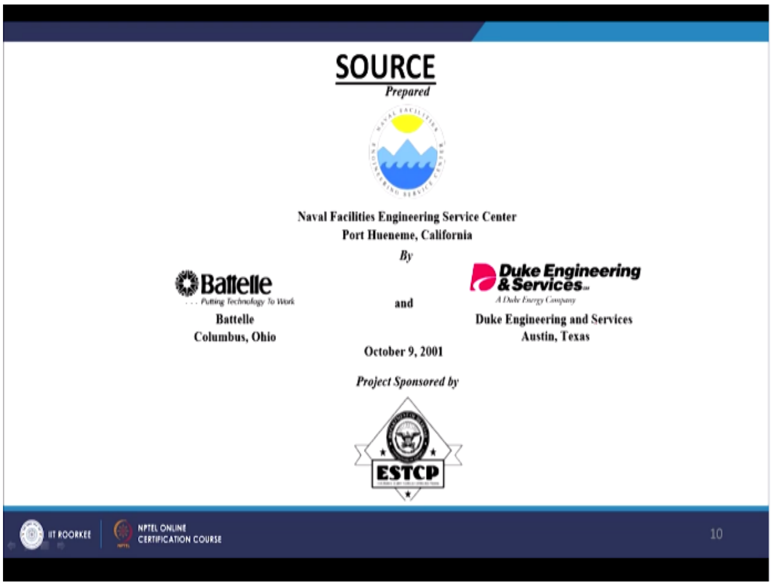

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Port Hueneme, California

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Battelle
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Battelle
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October 9, 2001

Project Sponsored by

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So let us look at who prepared this particular document, so it is by the naval facilities engineering service center right and you have the relevant others out here if not the others pardon me the relevant agencies out here. As I mentioned I am only presenting the data that is already available in the public domain let us say right and these are the relevant institutions let us say or organizations that were involved now right.

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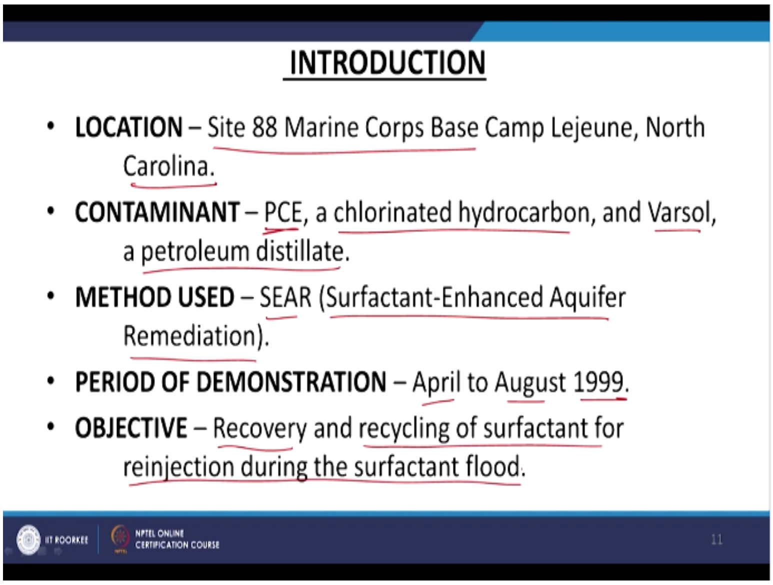

INTRODUCTION

- **LOCATION** – Site 88 Marine Corps Base Camp Lejeune, North Carolina.
- **CONTAMINANT** – PCE, a chlorinated hydrocarbon, and Varsol, a petroleum distillate.
- **METHOD USED** – SEAR (Surfactant-Enhanced Aquifer Remediation).
- **PERIOD OF DEMONSTRATION** – April to August 1999.
- **OBJECTIVE** – Recovery and recycling of surfactant for reinjection during the surfactant flood.

So moving on let us say so let us obviously understand you know what the site is about and so on. So again as I said it is Marine Corps Base let us say right Marine Corps Base in North Carolina and again we have PCE and as we know or you should know by now let us say it is chlorinated solvent let us say right. A chlorinated hydrocarbon typically used as solvent and let us say now Varsol also a petroleum distillate I guess right.

And here we are using surfactant enhanced aquifer remediation let us say right, surfactant enhanced as in here they used surfactant, some electrolyte and also I believe some core solvent let us say right and let us look at some of these aspects right. Again, they looked at surfactant enhanced aquifer remediation right. So they were looking at more or less pilot scale demonstration between April to August of 1999.

And based on this particular pilot scale study they went ahead I believe and looked at larger scale application of this particular surfactant enhanced remediation of the particular site right. So but again due to availability of data we are looking at this particular aspect let us say right. So let us move on, objective is obviously recovery and recycling of surfactant for reinjection during the surfactant flood.

As in here they are not just injecting let us say uncontaminated surfactant all the time, what are they doing, they are injecting a certain amount of surfactant initially and pumping it out and then let us say treating it and then recycling this particular treated surfactant let us say back into the relevant contaminated aquifer let us say to be able to get rid of your DNAPL right, that is something to keep in mind here.

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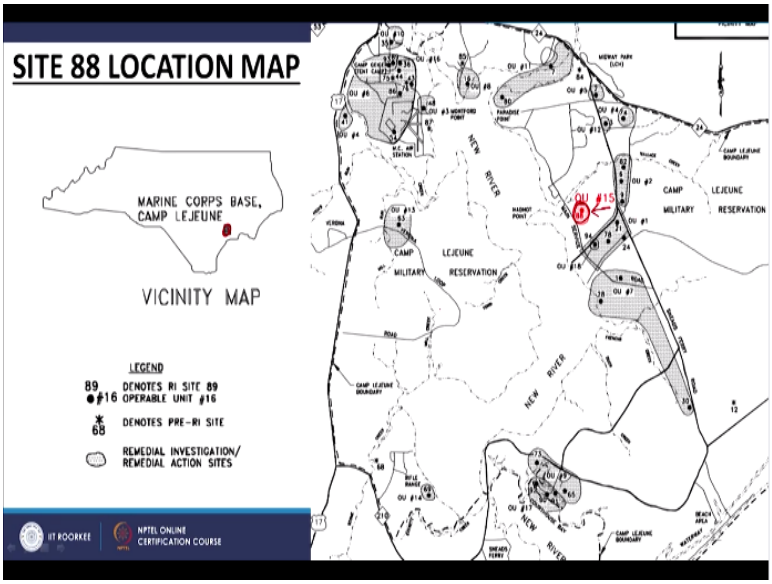

SITE 88 LOCATION MAP

So let us look at whatever we have, so again I believe this is North Carolina and this is where we are talking about the relevant base let us say and here we have looks like quite a few contaminated zones but here we are looking at only one particular contaminated zone let us say for this particular pilot scale study let us say right, operable unit 15 let us say, they were considerable other as you can see a lots of quite a few contaminated sites out here but we are looking at one particular contaminated site within this particular military base let us say right.

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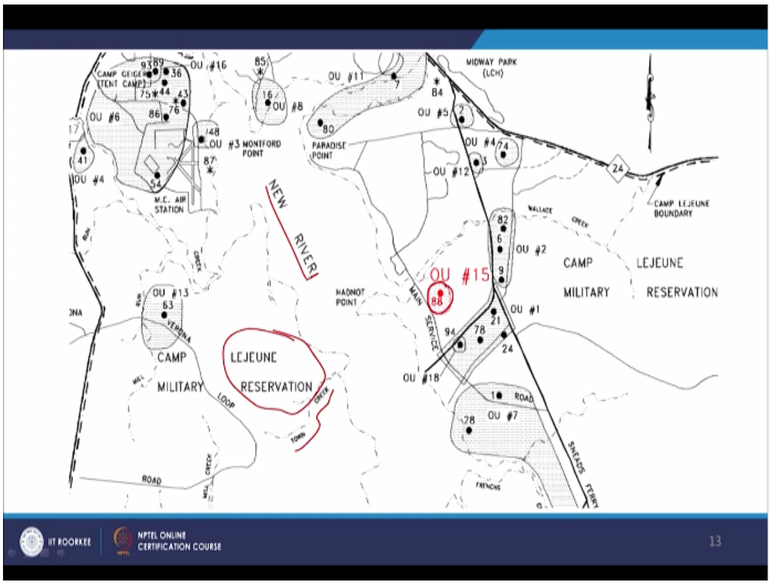

So let us go through, again more or less particular what do we say, we are looking at in better detail but keep in mind again as is the case with most of our relevant sites we have let us say surface water bodies right, again surface water bodies right and also we have what do we say ecologically sensitive areas and so on and so forth nearby right. So these are relevant aspects to keep in mind. Again, as we mentioned we are looking at only this particular unit for now let us say right.

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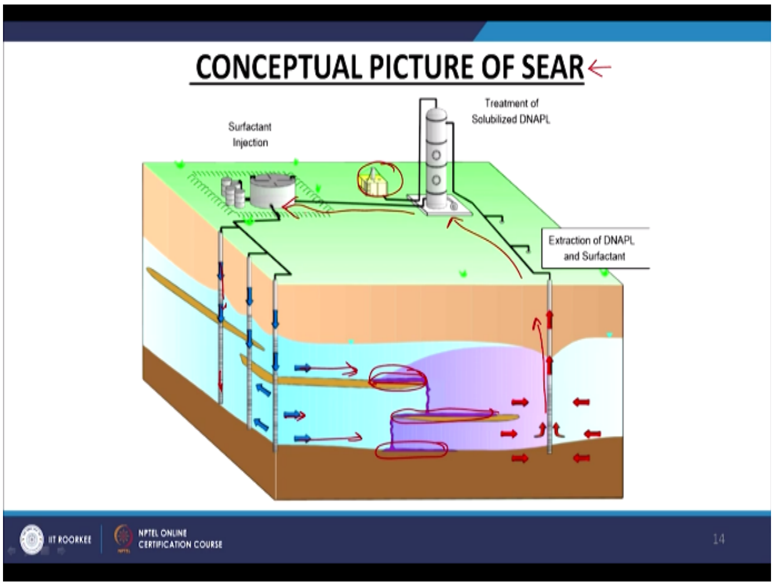
CONCEPTUAL PICTURE OF SEAR

So let us move ahead, so what do we understand from this surfactant enhanced aquifer remediation right, typically we are going to inject the relevant surfactant and then remove that recycle that and then put that back in right. So we will look at that, so we are obviously looking at surfactant injection right and typically we are looking at DNAPL let us say right. So we will have to characterize this what do we say characterize location of the particular DNAPL or site characterization.

So the DNAPL could have had enough time to already reach the relevant impermeable layer or if there are other semi impermeable layers let us say, it could also be deposited out there let us say right. So you see let us say if this is the DNAPL let us say right this is how it would spread out here. So they are injecting the surfactant let us say at different levels right. This is the conceptual model obviously.

We will look at the actual case later on and then they are going to pump the surfactant through this particular DNAPL and this surfactant is going to dissolved part or most of this DNAPL and it is then going to be pumped out and then treated let us say right and then the DNAPL will be collected for further treatment and the separated surfactant let us say or recycle surfactant will again be pumped back in right. It is just a conceptual mode allowed here right.

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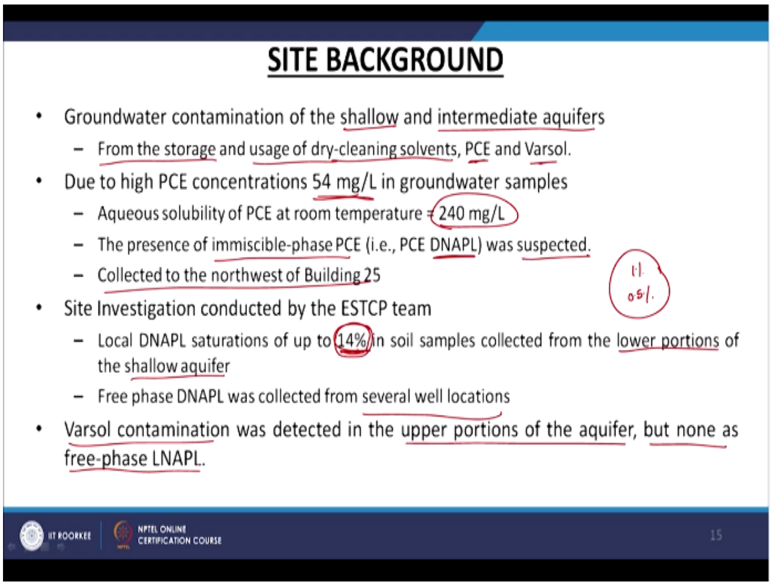

SITE BACKGROUND

- Groundwater contamination of the shallow and intermediate aquifers
  - From the storage and usage of dry-cleaning solvents, PCE and Varsol.
- Due to high PCE concentrations 54 mg/L in groundwater samples
  - Aqueous solubility of PCE at room temperature = 240 mg/L
  - The presence of immiscible-phase PCE (i.e., PCE DNAPL) was suspected.
  - Collected to the northwest of Building 25
- Site Investigation conducted by the ESTCP team
  - Local DNAPL saturations of up to 14% in soil samples collected from the lower portions of the shallow aquifer
  - Free phase DNAPL was collected from several well locations
- Varsol contamination was detected in the upper portions of the aquifer, but none as free-phase LNAPL.

1%
0.5%

So site background again groundwater contamination I guess of the shallow and both the intermediate or both the shallow and intermediate aquifers and again typically when we think of PCE it is from the storage and usage of the dry-cleaning solvents let us say PCE and Varsol let us say. Typically, PCE industrial solvent again so here too let us say they are looking at its usage as a dry-cleaning solvent let us say right.

And due to high PCE concentration or very high PCE concentrations were found 54 PPM let us say in groundwater that is remarkably high let us say right. Again, the solubility seems to be 240 milligram per liter. So it is if not almost at solubility levels but relatively comparable levels with respect to solubility let us say right. That means that the PCE concentration is very high in water and also let us say the invisible phase let us say that is it is present as DNAPL.

Initially, that is what was suspected. Why is that? Because the concentration of the PCE was very high right, that is what we see here, 54 milligram per liter it is almost comparable to the solubility of the relevant PCE let us say which is around 240 or 200 milligram per liter. So typically that means let us say if you are having such a high concentration of a hydrophobic compound in water that means the pure form of the relevant compound or in its NAPL phase let us say is going to be present right.

That is what was suspected obviously right, so then they analyzed the particular site and it was collected to the northwest of a particular building right and then here we are looking at saturation of up to 14%. For example, in all our homework questions until now we looked at I believe saturations of 1%, 0.5% or so on with respect to NAPL right but here you see that almost you know 14% saturation with respect to DNAPL let us say looks like was the case let us say right.

That means large volume or very high volume of the DNAPL is present out there right. So this is a remarkably tricky site to remediate right and again it was collected from the lower portions of the shallow aquifer right and what else do we have and free phase DNAPL also collected from several well locations right and also Varsol which is more or less a LNAPL was detected in the upper portions obviously because it is LNAPL right, relatively light non-aqueous phase or less dense non-aqueous phase.

It cannot what do we say permeate through let us say if I can use the term. It is present in the upper portions of the aquifer but not as in the free phase NAPL right. It is floating out there above the relevant groundwater but it is not present as NAPL itself let us say right. So that is something to keep in mind, so different aspects with respect to the relevant site.

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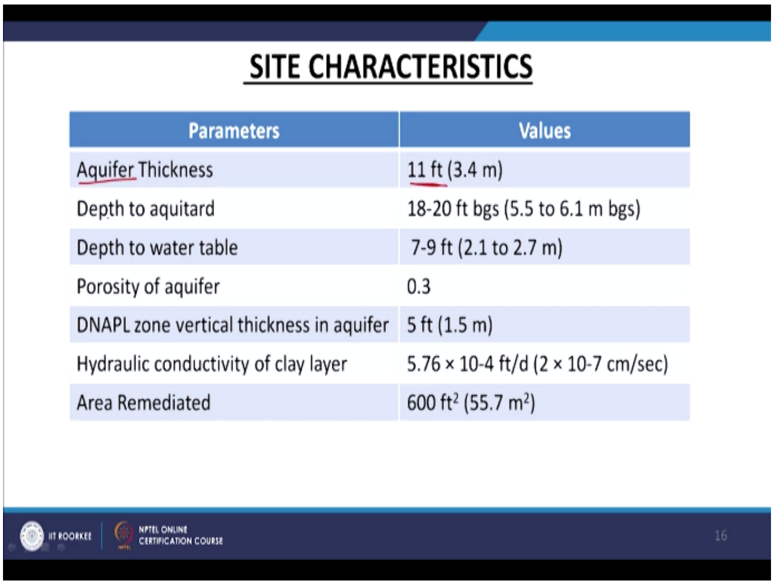

SITE CHARACTERISTICS

Parameters	Values
Aquifer Thickness	11 ft (3.4 m)
Depth to aquitard	18-20 ft bgs (5.5 to 6.1 m bgs)
Depth to water table	7-9 ft (2.1 to 2.7 m)
Porosity of aquifer	0.3
DNAPL zone vertical thickness in aquifer	5 ft (1.5 m)
Hydraulic conductivity of clay layer	5.76 × 10-4 ft/d (2 × 10-7 cm/sec)
Area Remediated	600 ft^2 (55.7 m^2)

So thickness 11 feet that is for the aquifer, depth to the impermeable layer is around 18 to 20 feet so the aspect to keep in mind is that it is relatively shallow right, that is something to keep in mind, depth water table let us say again 7 to 9 feet, porosity right 0.3 and why is porosity a relevant aspect let us say or important aspect because obviously porosity and again permeability let us say I guess we have that here.

Hydraulic conductivity let us say right, so this I guess is a bit of an aspect, again we need the system to be relatively more porous or you know have higher conductivity or hydraulic conductivity so that it is easier to pump your surfactant through right. So that is something to keep in mind. DNAPL zone, vertical thickness in aquifer right that is considerably thick, DNAPL zone is almost 5 feet right.

Area to be remediated as part of this pilot scale let us say is around 600 square feet let us say right, some generic aspects out here. So we analyze this particular volatile compounds let us say by gas chromatography. So they looked at gas chromatography with mass spectrometer right and what did they see? A primarily PCE with some Varsol as minor dissolved component let us say which is from 2-14% by weight let us say right.

That is a remarkably high concentration if I may say so. So actual profile let us see what do we have here?

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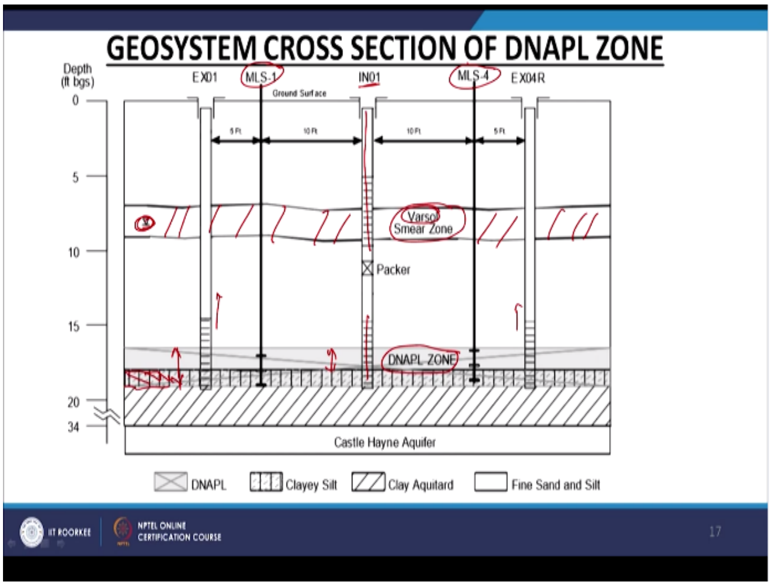

GEOSYSTEM CROSS SECTION OF DNAPL ZONE

We have an injection well right that is what we have out here, injection well and here near this particular impermeable layer let us say or semi impermeable layer we have this particular DNAPL let us say right. This is the DNAPL right, so in this particular site though they have some LNAPL above the particular groundwater table, so this is the groundwater level so they have some particular LNAPL out here.

But the primary purpose was not to remove this LNAPL but not LNAPL; it was not present as different phase but it was also you know that it was also visible let us say with the water but it was not present as a free phase. What was that? Varsol though but again the objective was not to remove this particular phase or relevant soluble Varsol but to look at this NAPL which was the DNAPL let us say right.

So we have the injection well right and then we have the extraction well out here. The spacing seems to be around 15 feet and then also they have monitoring locations in between let us say right. So these are the relevant aspects to keep in mind.

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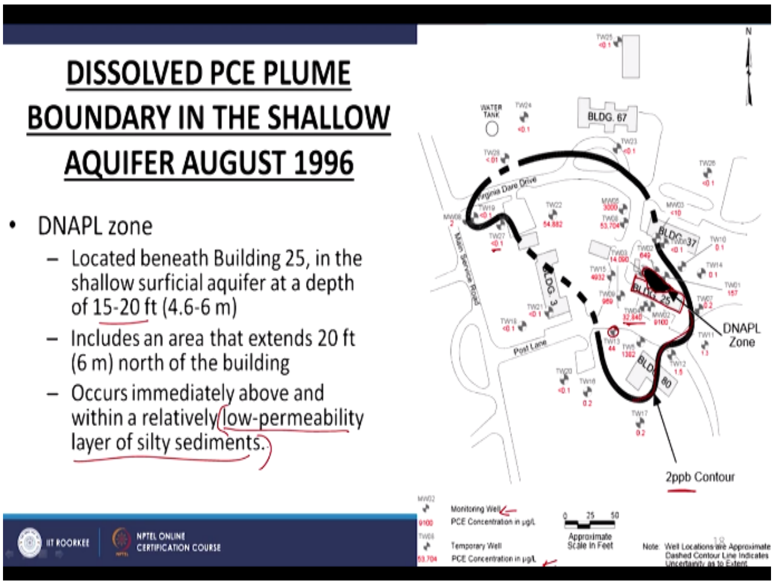

DISSOLVED PCE PLUME BOUNDARY IN THE SHALLOW AQUIFER AUGUST 1996

- DNAPL zone
  - Located beneath Building 25, in the shallow surficial aquifer at a depth of 15-20 ft (4.6-6 m)
  - Includes an area that extends 20 ft (6 m) north of the building
  - Occurs immediately above and within a relatively low-permeability layer of silty sediments.

So we will look at the plume boundary, so this was the building that we were talking about right, building 25 and as you can see a considerable what do we say area is occupied by this particular DNAPL that is remarkably toxic let us say right and also difficult to remove. So once you have this particular contaminant let us say right in its non-aqueous phase liquid form let us say, you are obviously again going to have it in contact to the ground water.

The concentration was relatively high at some locations which was around 50 or 55 milligram per liter of the PCE and then you know groundwater again flows so you are going to have transport of the relevant contaminant. So they were looking at a 2ppb contour and you saw that you know they have a relevant approximate contour out here based on the different concentrations at different locations I believe let us say right.

So PCE concentrations in microgram per liter so they came up with a generic contour level so here around 32840 ppb right, different cases obviously let us say right. Again, will not spend very too much time out here but keep in mind that they had considerable number of monitoring wells obviously because they need to understand the particular site let us say right. So let us move forth.

So DNAPL zone right as we mentioned located beneath that particular building at a particular depth right and also outside extending or protruding outside the area of the particular building occurs immediately above and within a relatively low permeability layer of silty sediments. The key is that it seems it occurs above relatively impermeable layer let us say right that is something to keep in mind.

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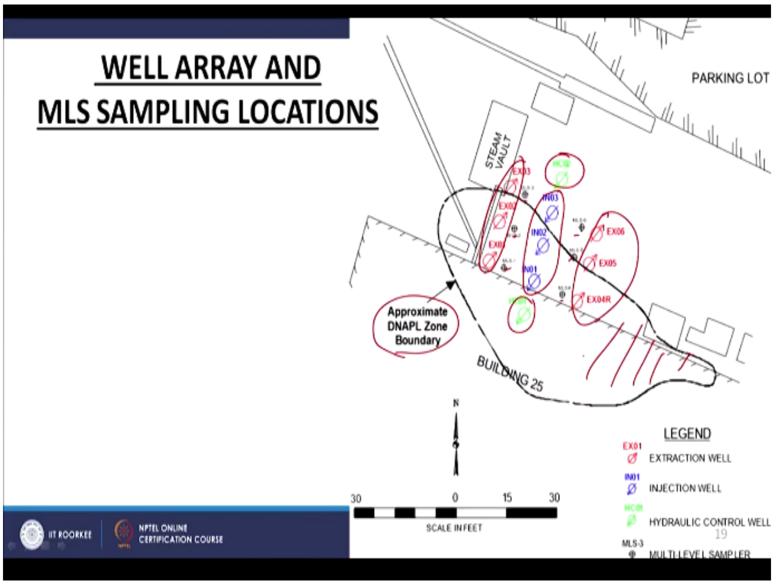

WELL ARRAY AND MLS SAMPLING LOCATIONS

So this is what they actually end up with as in they had 3 injection wells or row of injection wells flanked by two rows of extraction wells and then two rows of monitoring wells let us say and there also they were trying to maintain some level of hydraulic what do we say control let us say and this as you can see is the approximate contour for that particular DNAPL let us say, not the contour the DNAPL itself let us say.

Because this is the building 25 right so this is the actual DNAPL right that is something to keep in mind.

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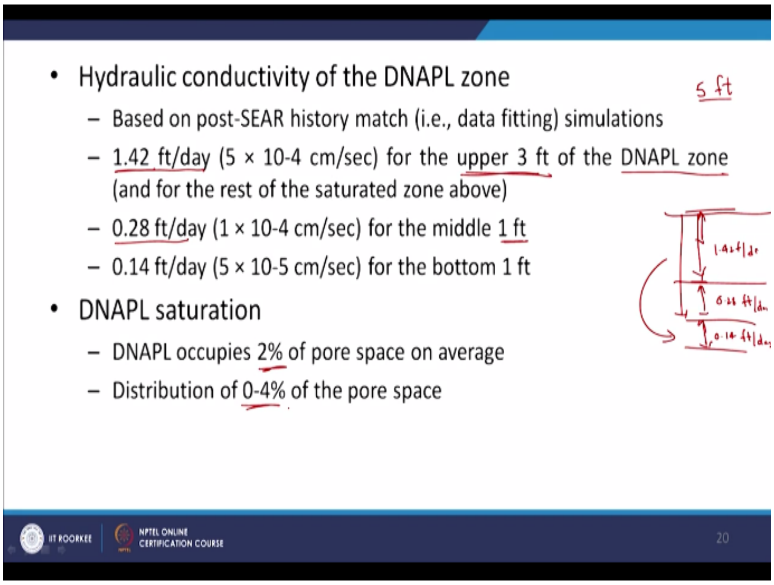

- Hydraulic conductivity of the DNAPL zone
  - Based on post-SEAR history match (i.e., data fitting) simulations
  - 1.42 ft/day (5 × 10-4 cm/sec) for the upper 3 ft of the DNAPL zone (and for the rest of the saturated zone above)
  - 0.28 ft/day (1 × 10-4 cm/sec) for the middle 1 ft
  - 0.14 ft/day (5 × 10-5 cm/sec) for the bottom 1 ft
- DNAPL saturation
  - DNAPL occupies 2% of pore space on average
  - Distribution of 0-4% of the pore space

5 ft

So let us move on, so we have hydraulic conductivity of the DNAPL zone that is relatively important right. This is based on after treatment more or less so it was relatively what now

1.42 feet per day in the upper 3 feet as in we knew that the DNAPL thickness let us say was almost 5 feet let us say right. So we had different levels of what do we say hydraulic conductivity for these you know for in this 5 feet let us say.

Why is that important? So greater the what do we say hydraulic conductivity the easier it would be let us say for the surfactant to pass through and come in contact with your relevant contaminant let us say right. So in the upper 3 feet of this 5 feet DNAPL zone that was a particular value and as you can see considerable decrease let us say almost 5 times let us say right or more than 5 times if I may say so or almost 5 times in the lower 1 feet.

So in this 3 feet of the DNAPL it was 1.42 feet per day and this 1 foot it was 0.28 feet per day and the last 1 foot let us say it was almost half of that 0.14 feet per day right. So compare this particular 1 foot to this particular zone which is that the hydraulic conductivity is almost one tenth or you know 10 times lesser than what it is in the top 3 feet let us say right. So as you know let us say the deeper that this DNAPL permeates into the what do we say relatively less permeable zones let us say.

It is obviously going to get more difficult to be able to remediate the particular site right. So let us move forth, so DNAPL saturation, in this case let us say they are looking at 2% of the pore space on average, keep that it is on average right, distribution is around 0 to 4%, the earlier case was 14% by weight.

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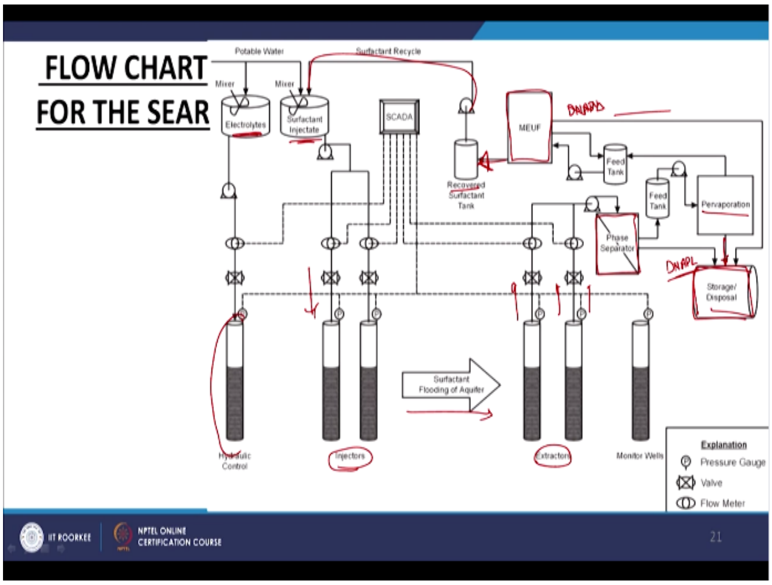

FLOW CHART FOR THE SEAR

And we are just going to look at the schematic here let us say right. What do we have here? We have this surfactant injected as I mentioned they were also looking at some electrolytes being added to this particular solution. So they were also maintaining some level of hydraulic control and then you are injecting the relevant solvent let us say which is also surfactant, electrolyte and some other solvent that they used in this particular case let us say.

Then, surfactant is flooded through the aquifer right and through the hydraulic control you are going to have the surfactant moving towards the extractors let us say right and then they are extracted through these particular extractors and where do they go to, they go to a phase separator let us say right. In this phase separator, the DNAPL let us say is going to a storage or disposal let us say right.

And the other one let us say is again further pretreated or further treated by pervaporation, we are not going to go into that into detail let us say. Again, you are going to have some other DNAPL coming out here and then the feed tank and then again to further treatment, again the further treatment you are again going to have some DNAPL or if not DNAPL let us say you now relatively concentrated or dirty surfactant part of the dirty surfactant again coming back for storage and disposal.

And a part of the surfactant or initial fraction of the surfactant will be recovered and this again will be pumped back in let us say right. So here more or less you have pushed stages of treatment for your surfactant and then the part of it is recovered let us say and then that is reinjected again right. So that is something to keep in mind, so will look at the relevant aspects only in a bit more detail.

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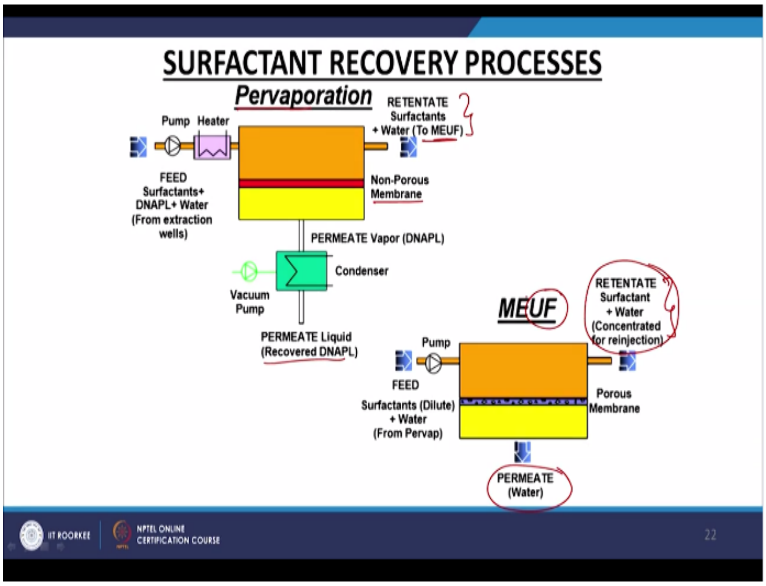

SURFACTANT RECOVERY PROCESSES

Pervaporation

Pump Heater

FEED
Surfactants+
DNAPL+ Water
(From extraction
wells)

RETENTATE
Surfactants
+ Water (To MEUF)

Non-Porous
Membrane

PERMEATE Vapor (DNAPL)

Condenser

Vacuum
Pump

PERMEATE Liquid
(Recovered DNAPL)

MEUF

Pump

FEED
Surfactants (Dilute)
+ Water
(From Pervap)

RETENTATE
Surfactant
+ Water
(Concentrated
for reinjection)

Porous
Membrane

PERMEATE
(Water)

IIT ROORKEE NPTEL ONLINE CERTIFICATION COURSE

So typically pervaporation let here let us say based on the nonporous membrane let us say. What are we going to have? You are going to have separation of the phase. What are the different phases? They are the NAPL and the mobile phase, the mobile phase if I may say so or if not the mobile the surfactant and water. So that is what we are doing out here, so we have the DNAPL here.

And also the surfactants and water here let us see and again as I mentioned they are going to further treated to MEUF. Again, what is happening out here let us say. We are again having permeate which is water let us say and some water surfactant plus water which with concentrated for reinjection let us say right. So this particular concentrated surfactant let us say is now going to be reinjected again.

So again two stages, pervaporation and MEUF right. We are not going to go through that in relatively greater detail that this is more or less based on the ultrafiltration let us say right. MEUF is based on ultrafiltration right.

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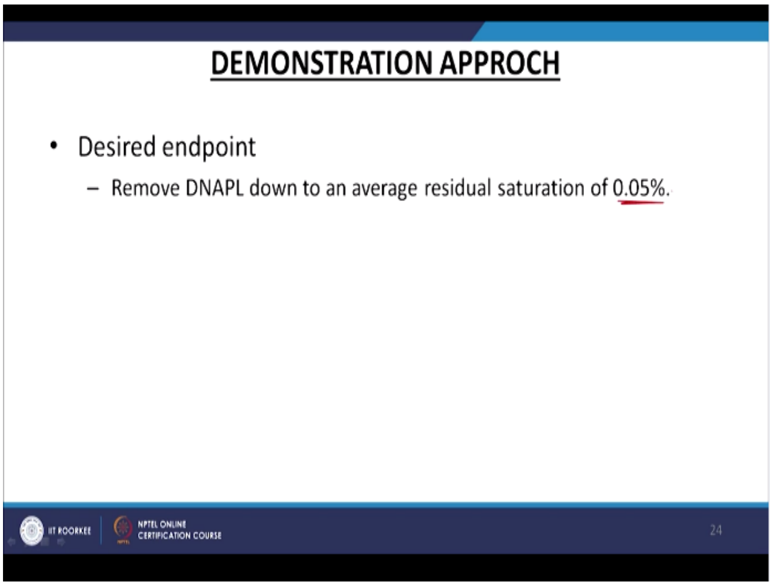

DEMONSTRATION APPROCH

- Desired endpoint
  - Remove DNAPL down to an average residual saturation of 0.05%.

So demonstration approach let us look at the end point, so they want to bring it down to saturation levels of 0.05% that is what they were trying to look at.

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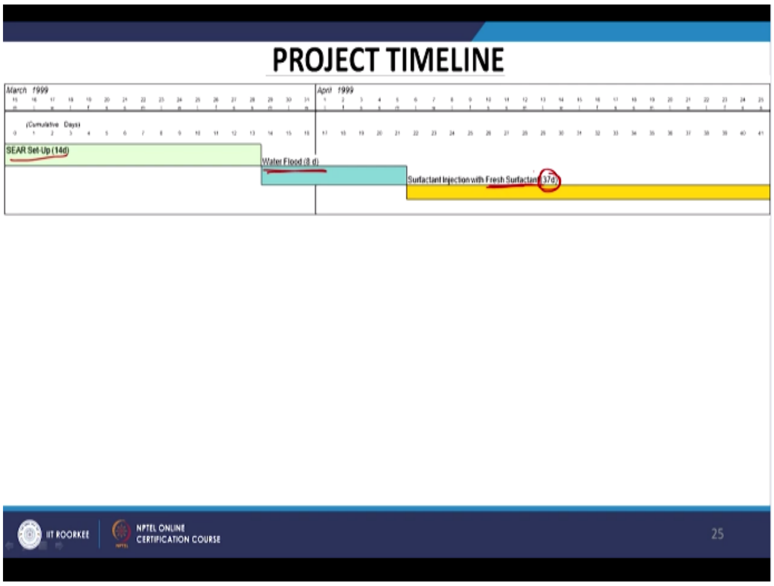

PROJECT TIMELINE

We will just look at the relevant time lines let us say for this particular session and then will end this particular session for now and then carry on this particular session or the relevant aspects in the next session now right. So timeline let us say keep in mind it was only from April to September or such only a few months within or in the year 1999. Why is that? Because they were only looking at pilot scale demo let us say initially let us say.

So they were setting it up 14 days, they were flooding the system with water initially let us say right, they were flushing the system and then they were injecting the relevant surfactant.

The key is that initially with this fresh surfactant and over a period of almost a month or more than a month let us say right. So that is something to keep in mind.

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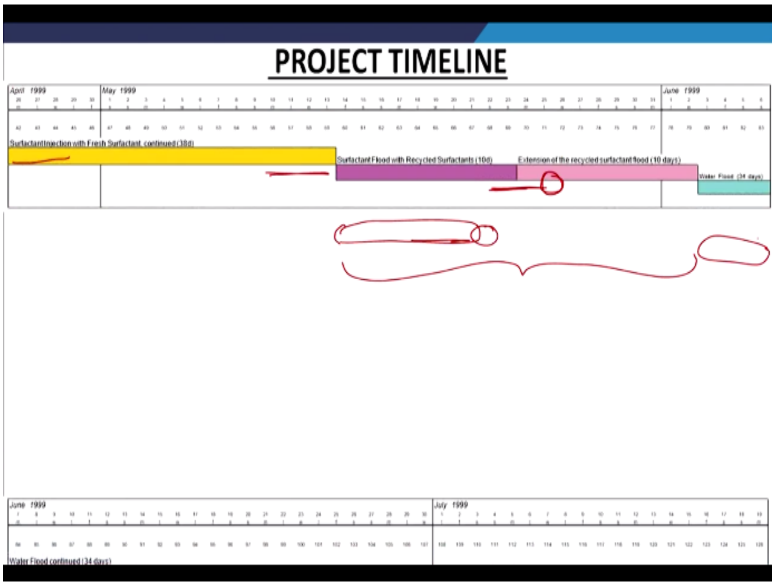

PROJECT TIMELINE

And then again continued let us say for 38 days I guess right, the total you can calculate that and then surfactant flood with recycle surfactants. As in while you are pumping this surfactant through we know that by pervaporation and MEUF treatment let us say the relevant people were again you know recycling or being able to get back some of the relevant surfactant and then again the surfactant flood with the recycled surfactant.

And that was for the period of 10 days let us say and extension of the recycle surfactant flood as in they kept doing that let us say right and then they flooded the system with water let us say.

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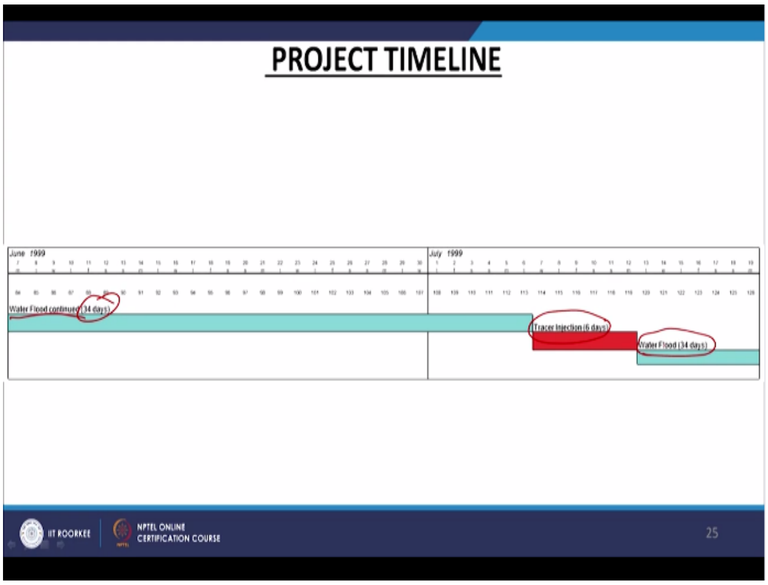
PROJECT TIMELINE

Why they are flooding the system with water? Obviously, once you pump out the surfactant, if there is any residual surfactant or any other relevant phases let us say that are relatively soluble in water, you want to bring them out so that is why they are now flooding the system with water here right. So that is what you see out here. So they are flooding the water almost for let us say period of one month and then they are injecting the tracer to locate the relevant flow paths let us say and then again flooding the system with water right.

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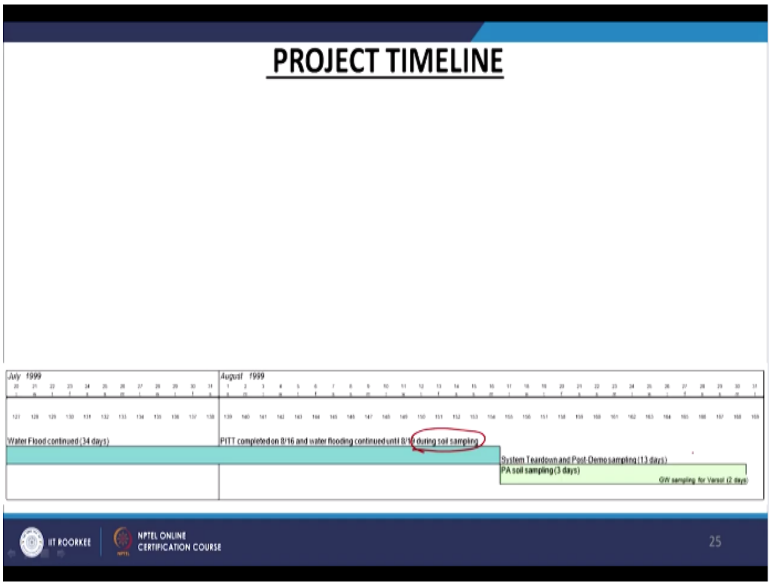
PROJECT TIMELINE

And then treatment completed and water flooding continued till so on during soil sampling, they obviously need to take the soil samples. Why is that? To look at PCE concentration adsorbed onto the relevant soil. As in you do not just want to remove the PCE in the NAPL and also in the aqueous phase which is at the groundwater. You also want to remove the PCE right which is adsorbed onto the relevant soil.

So that is what they were trying to do and then you know they were then bring it down. So I guess within I guess around 4 or 5 months let us say right they were able to complete this particular project for an area of around 55 meter square or 600 square feet let us say right. So again that is more or less a generic what you write, so we will continue this in the next session and thank you.