Environmental Remediation of Contaminated Sites
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Lecture - 50
Case Study: Surfactant Extraction Part-II

Hello everyone. Welcome back to latest lecture session. Again a very quick recap of what we have been up to, right. We were looking at I believe surfactant based extraction of relevant contaminant, right. In that context we looked at the relevant calculations let us say and then moved on to looking at a particular case study, for which we had some data available online or in the public domain.

And the case was relating to again particular army site in the US let us say or army base and again the solvent or the contaminant that we are looking at here is again the solvent, which is PCE, which is used for let us say dry cleaning purposes and so on. So the particular case or case study that we were looking at was regarding a particular pilot scale study and we looked at the relevant aspects and so on. So very quick recap of what are some of the aspects that we discussed.

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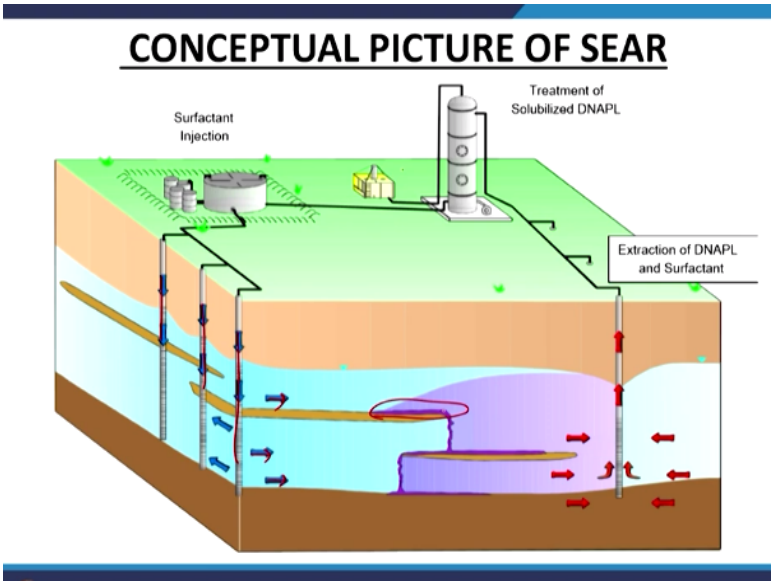

So here again, they had particular DNAPL. At the bed of a particular impermeable or on the top of a particular impermeable layer and what are we trying to do or what are they trying to do.

They are going to inject surfactant let us say and through different hydraulic control let us say, they are going to flood this particular system with the relevant surfactant and that is going to dissolve this DNAPL. So this is not the dissolved PCE.

But the PCE that is present as PCE itself or the non-aqueous phase liquid, let us say. So that is what we are trying to remove and then they are going to try to pump this out and again I believe they also looked the relevant aspects.

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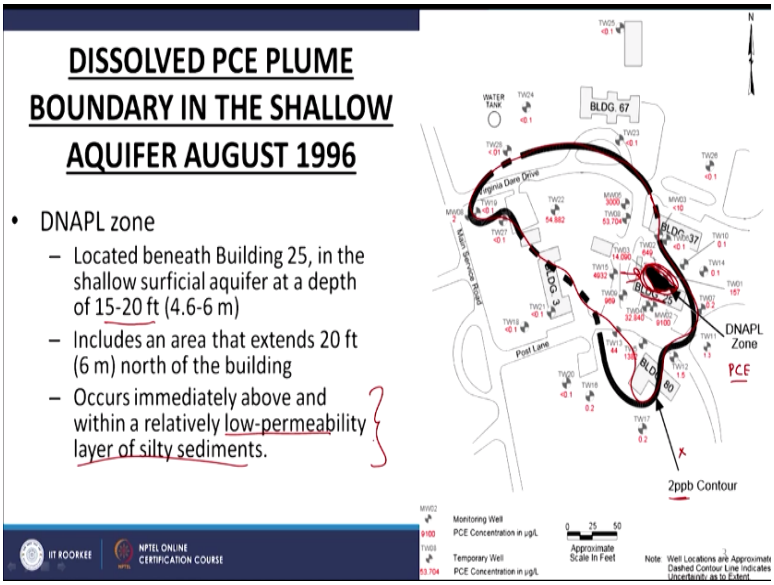

Before we go further, this is the relevant PCE NAPL let us say or the DNAPL that they are looking at and the DNAPL consist of the PCE primary, let us say. And the plume once that groundwater is contaminated, I believe this is the one for the contaminated plume for 2 PPB levels let us say right. Again but this is not the what they were trying to look at. They are looking at remediating this particular or part of this particular DNAPL, let us say.

And to see if it is effective or not and if it can be what do we say scaled up from pilot scale. So let us look at what else we have, right. We have a DNAPL zone and again as we mention beneath a particular building and relatively shallow depth, if I may say so, right. Of course immediately above and within a relatively low permeability layer of silty sediment. So as we were just discussing, we have a relatively impermeable layer and the DNAPL exist right on top of it or it has already permitted a bit into this particular impermeable layer, let us say.

So that is what we have. Again why is that important, because obviously you know the extracting it is going to be an issue now, especially the permeability if is relatively low, right. So let us move on. So what was the flow chart.

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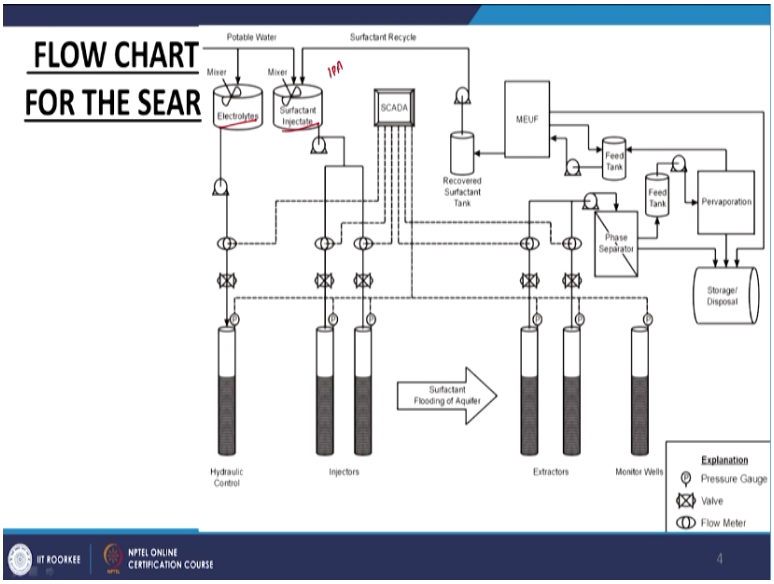

So they looked at electrolytes, surfactant and also solvent. I believe they have some solvent, isopropyl alcohol. They are injecting the mixture of these 3 particular aspects and you know injectors they were injecting it. They were trying to have some level of hydraulic control and then they were flooding the relevant aquifer with the relevant surfactant, which was injected through this injectors and then obviously they were extracting the relevant surfactant.

And then you have first phase separator where DNAPL is removed let us say. Here why are we looking at all these relevant aspects here? They were trying to recycle the relevant surfactant. Again freed tanks of pervaporation, I believe we looked at that in very or you know little detail or did not spend much time, more or less I believe without adding let us say antifoaming agents or such that, they are trying to remove the relevant or get or extract the relevant surfactant.

In that case let us say or scenario, they were looking at pervaporation and again you have this particular recover tank and then the surfactant is recycled let us say. So that is what we have here

and this is the relevant DNAPL that can be treated further. Now that it is relatively more concentrated, let us say. So that is something to keep in mind, right.

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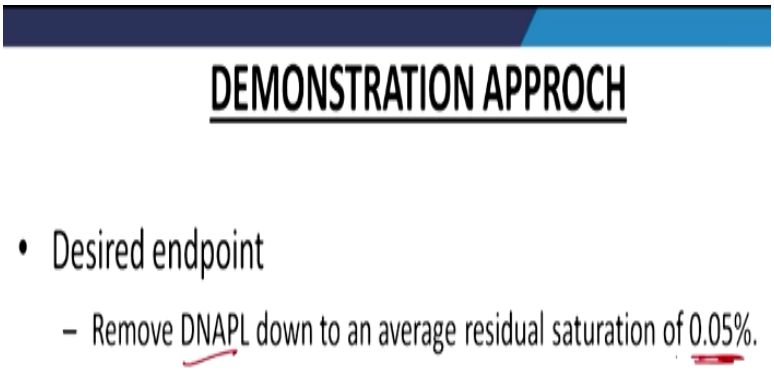

So what are we trying to look at, we are trying to bring down the NAPL to average residual saturation of 0.05%, let us say. I think it was around 2 or 4%, I think 14% by weight or so on, but again here we are bringing that down to 0.05%, let us say.

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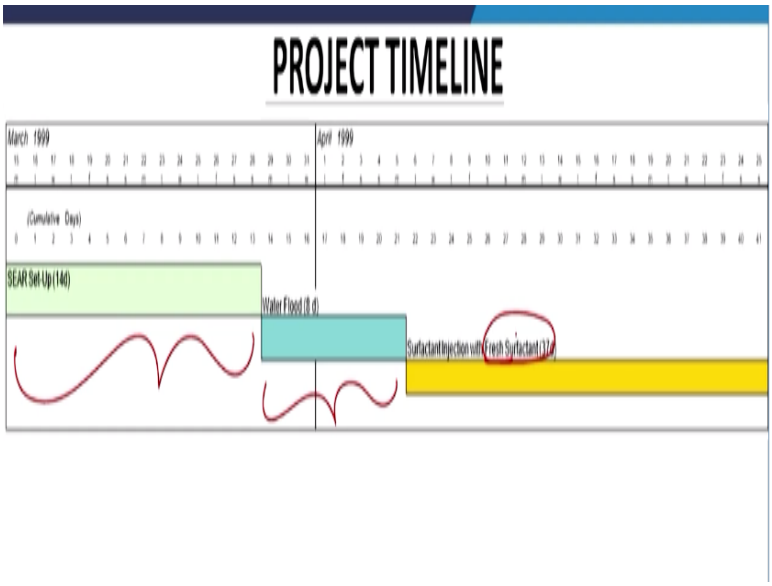

So timeline, obviously they were looking at only a few months. So half a month for what do we say setting of the system and then flooding the system with water initially and then for around 40 days or so, they inject the relevant system with fresh surfactant, right that is something to keep in

mind with fresh surfactant and then they again flood the relevant system with recycle surfactant this is the total of 37+10, so 47 days, let us say.

So total of 47 days I guess, they were flushing the relevant system with the surfactant, let us say. That is something to keep in mind, and looks like they again extended the recycle or you know flooding with 10 more days with the recycle of surfactant. So now I am going to end up with 57 days more or less and then you know they were obviously pumping the relevant surfactant out and then they pumped water in again for 34 days, let us say, right.

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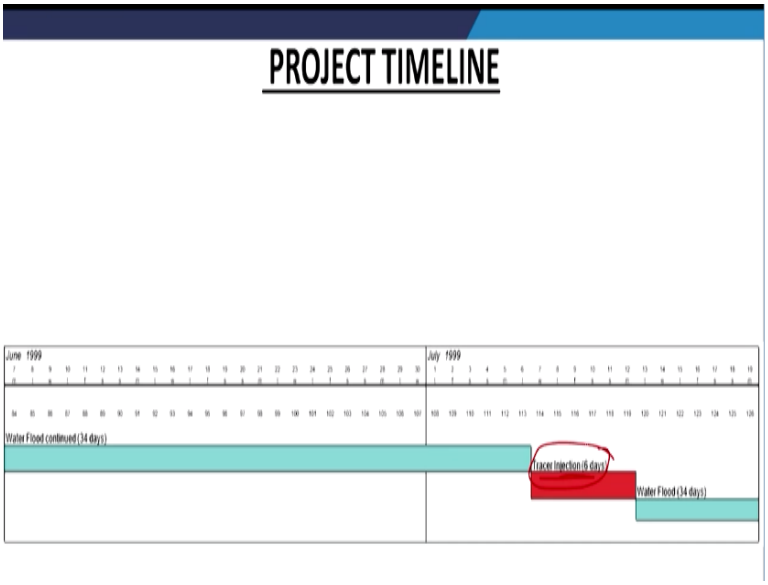

So water flooding and then traced of injection obviously to look at the relevant aspects as in you want to know let us say sometimes if flow paths that were available earlier maybe were clogged now or such. So they also want to look at the relevant aspects among other aspects anyway. So trace of injection.

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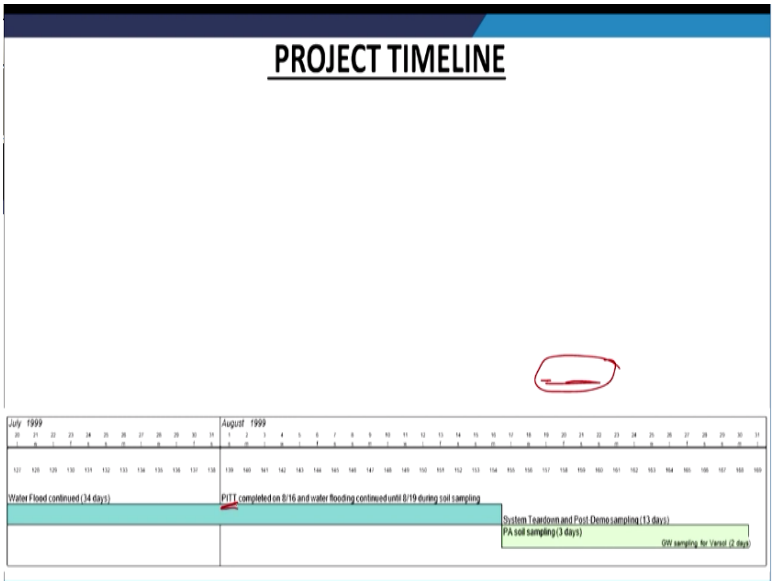

And again flooding water, more flooding of the relevant water and this is again a particular post treatment based sampling let us say and here they are taking the system down and I believe May, June, July, August so 4 months or 4 and half months let us say or here I have more number of days here I guess, but I believe that around 5 months was the effective time if I am right and they were able to look at already know the demonstration of this pilot scale plant. So let us move on. So surfactant flow rates just to get an idea about it.

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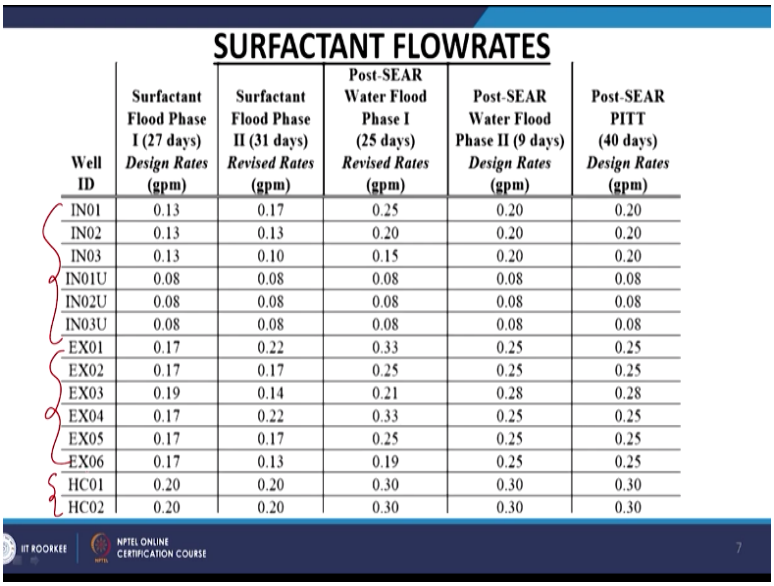

Well ID	Surfactant Flood Phase I (27 days) *Design Rates* (gpm)	Surfactant Flood Phase II (31 days) *Revised Rates* (gpm)	Post-SEAR Water Flood Phase I (25 days) *Revised Rates* (gpm)	Post-SEAR Water Flood Phase II (9 days) *Design Rates* (gpm)	Post-SEAR PITT (40 days) *Design Rates* (gpm)
IN01	0.13	0.17	0.25	0.20	0.20
IN02	0.13	0.13	0.20	0.20	0.20
IN03	0.13	0.10	0.15	0.20	0.20
IN01U	0.08	0.08	0.08	0.08	0.08
IN02U	0.08	0.08	0.08	0.08	0.08
IN03U	0.08	0.08	0.08	0.08	0.08
EX01	0.17	0.22	0.33	0.25	0.25
EX02	0.17	0.17	0.25	0.25	0.25
EX03	0.19	0.14	0.21	0.28	0.28
EX04	0.17	0.22	0.33	0.25	0.25
EX05	0.17	0.17	0.25	0.25	0.25
EX06	0.17	0.13	0.19	0.25	0.25
HC01	0.20	0.20	0.30	0.30	0.30
HC02	0.20	0.20	0.30	0.30	0.30

So I believe we had a set of injections wells and flanged by different rows of extraction wells and also to what do we say wells for hydraulic control, let us say. So just different flow rates during flooding 1 and 2. So 27, 30, so 60 days more or less and water flooding let us say. They looked at

water flooding 2 phase of water flooding and again the PITT phase let us say, right and what do we have out here. So as you can see I guess depending upon the heterogeneity of the system, you cannot have the same flow rates everywhere.

Initially they started out with particular flow rates for one set of injection wells and another for another set of injection wells and how do they go about it, they go about it based on initial models let us say and obviously based on the performance during this particular injection system or cycle they are going to modify the relevant injection rates let us say or flow rates during the relevant or subsequent cycle let us say.

So initially they start out with 2 different sets of flow rates for the 2 different sets of injection wells and then typically higher as you would expect for the extraction wells and for the hydraulic control and then as you can see during the second phase though, they modified that slightly based on obviously the lessons learned during the first phase, they modified the relevant flow rates during the second phase.

But again the trends are that obviously as you can see extraction wells, they typically have higher flow rates let us say and also obviously hydraulic control in this case based on the relevant permeability or the relevant heterogeneity of the system now, let us say. So with respect to water again same case, right relatively higher what we say injection rates for 1 set of injection wells compared to wells compared to the other and then much higher extraction rate for the water and then again for hydraulic control let us say.

Even phase 2 I guess they modified that slightly or actually plot about more homogeneity in the system, I guess once the system was flooded with water, they could you know afford to do so and that is what we have here relatively similar profile, let us say. So we are going to move on again depending upon the heterogeneity of the system, you need to obviously be able to Taylor the relevant flow rates I guess, right. So that was we have out here.

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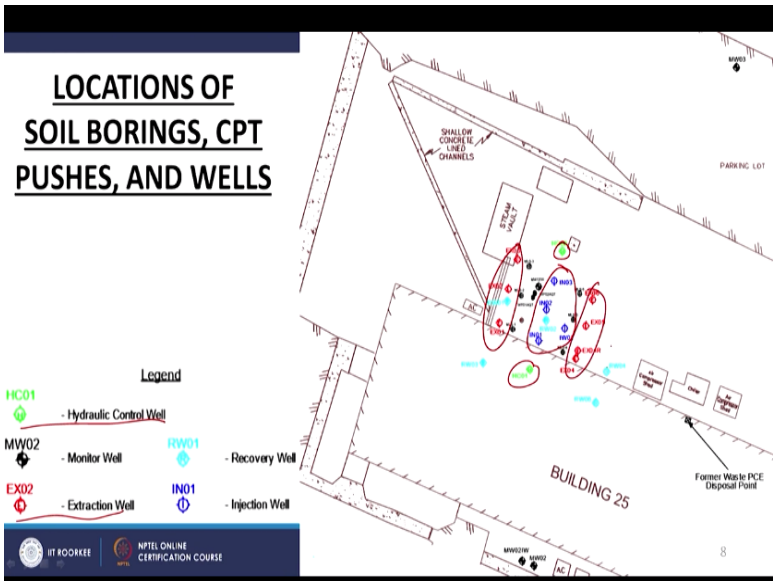

So again before we dig further, we will have a quick look again or to what we have. So to achieve hydraulic control, they had 2 such particular wells as you can hydraulic control well. Then you have the injection wells out here, that is what you have and you also have the extraction wells and the recovery wells during I believe the PITT phase. So let us move on. So again before move on though, we have 1 set of injections well. And then flanged by what do we say 2 rows of extraction wells. So let us move on out here.

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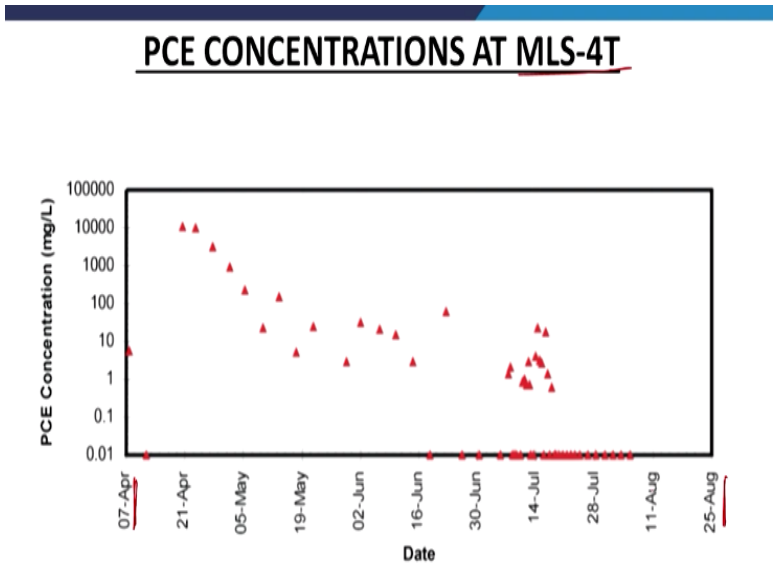

PCE concentration at the particular monitor well, we also had different what we say monitoring well. So at the particular well, we have this data. First let us look at what we have, we have something in April and then in August, let us say. More or less from the start to the end of the

particular you know this particular demonstration cycle let us say and we have concentrations in milligram/liter remarkably high. Obviously here we are looking at very high concentrations, right. So either these are maybe just above the relevant DNAPL phase let us say.

So as you can see the concentrations are very high and then you see a relevant decreasing trend let us say and that is something to keep in mind now, but one aspect that needs to be kept in mind is that this is not the linear scale, this is logarithmic scale as in here is 10,000 and here it is 1000. So when I compare these 2 data points this and this it means that you know it is almost 10 times less. So know it is 100 times less out here.

So compared to the initial case, I have 1, 2, 3 almost 1000 times lesser value out there let us say by the end of my particular cycle now. So that is something to keep in mind and PC concentrations are different monitoring well. Again we have relatively high concentrations out here, but in the other 1 let us say, not as high removal, again that is because of heterogeneity in the particular system, let us say.

You have the DNAPL, and some of it in the relevant water, some of it also in the relevant adsorbed on the soil and also again you know keep in mind that this was only a particular pilot scale study let us say. So again though, they were able to achieve almost 100 times lesser concentration as you can see, 10 times and further 10 times, 100 times lesser concentration and again that is something worthwhile it say to consult it say when you are going to look at scaling it up now.

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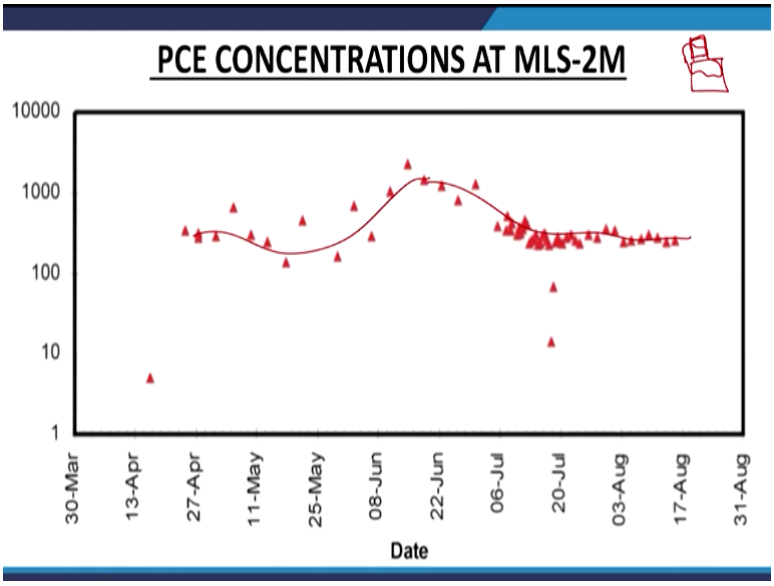

So we are going to move on. So another particular well I guess, right but here you see some rebound if I may see so, and again you know more or less similar profiles, but again keep in mind that the location of the relevant monitoring wells if you looked at the relevant figure earlier was in symmetrical or such and also you need to overlay the relevant plume or the DNAPL plume let us say over that particular site and then look at it as in there was a building out here.

And the plume was something like this and they were only trying to look at this particular stretch or path let us say. So obviously the profile of what do we say the groundwater concentrations let us say of PCE, the PCE in the groundwater concentrations are going to be relatively different. So again we are not trying to match the relevant data with respect to the particular site location because we did not have as much data.

And more importantly this is a pilot scale study limited to a particular area only. Again you know if you see rebound now, it could be due to what is it now, desorption from the soil or movement of what do we say the DNAPL or dissolution of some of the DNAPL. There are various reasons why you can see may be some increase, let us say but again at this particular level, you see that the concentrations were also initially relatively low, that is something to keep in mind.

As in most often not, if you remember or if you can recall the data from the relevant to or previous or preceding data sets let us say. We were more or less around these concentration

ranges. So initially at this particular well, we were anyway at low concentrations and that is one of the reason for this particular system to not have achieved further removal let us say, right. Again the various factors set play.

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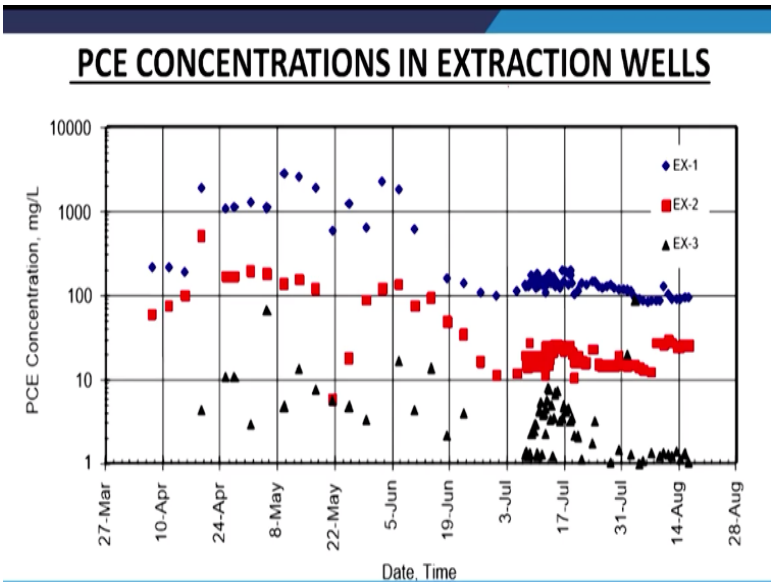

So again moving on so PCE concentration in the extraction wells. So before we go further lets understand what we are doing now let us say. We looked at different monitoring wells and how let us say the concentration changed typically it decreased, why is that, you have the surfactant that is being pumped in and overtime let us say the concentration would be removed let us say. How is that, the particular surfactant would act as a particular media let us say.

A phase for where this particular hydrophobic PCE can be transformed to. The PCE that was earlier in the form of just PCE or dissolved in water or adsorbed in soil is now in the my cell in the relevant surfactant let us say. So that is something to keep in mind. Here what are we looking at, the concentration in the extraction wells. So what would you expect, initially you would expect a lot higher what do we say concentrations many more or less and mass too, right.

And then more or less as you remove the PCE that is already present in the relevant soil let us say, you are going to see lesser and lesser concentration you know out there. So let us look at what we have, we have on the Y axis, the PCE concentration keep in mind these are extraction

wells and again from March to relevant August period, let us say. We are looking at 3 extraction wells. So extraction level 1, 2 and 3, so you see that typically there is a peak that is achieved.

And then it flattens out, again a relative peak, and then flattening out and more or less maybe similar profile here for all the 3 wells. So initially let us say you know, you are going to have time required for equilibrium to be reached and then once the equilibrium is reached and more of the PCE starts dissolving, you hit the peak that is what you see here, again this is the concentration that they recovered from that particular surfactant, right.

So more concentrations were removed here, but as you keep moving further down with respect to the time let us say what is going to happen now. So you have some concentration of PCE in the water, in the soil or in the NAPL and you have some concentration of the PCE in the my cell or in the surfactant. So here they are at equilibrium, let us say. So overtime what will happen now as more and more mass moves from these 3 phases into the surfactant.

You see the mass out here is going to decrease, let us say. So then the concentration of the relevant PCE in equilibrium with this particular system will also be less. As this moves less further down, again further down. So typically that is what you would see out here, you know more or less relevant to the relevant equilibrium aspects let us say between all the 4 phases here. Let us move on.

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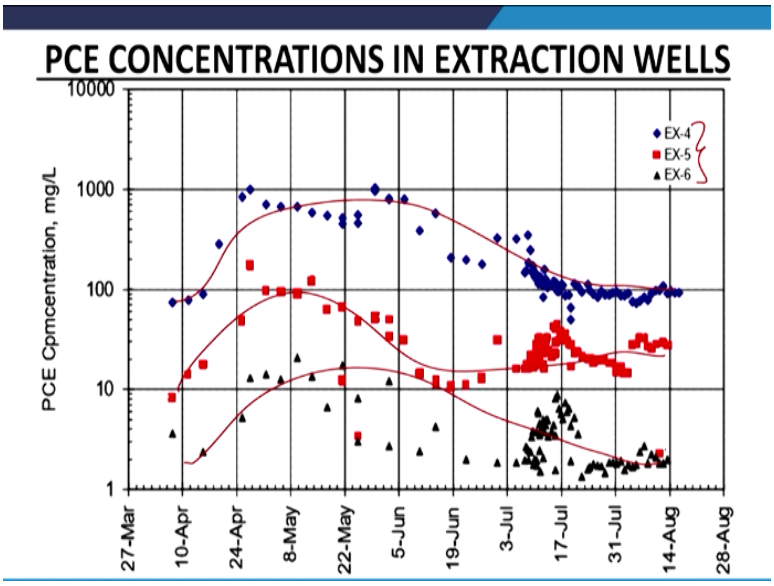

So again in a different extraction well, set of extraction well 4, 5, and 6 and again single trend, you hit peaks and then decrease peaks and relevant decrease peaks, and relevant decrease let us say. Again keep in mind that the system is relatively heterogeneous and again that is why you see somewhat slightly different profile, but what do you see typically, initially you see relatively high concentration let say that are sustained for some period of time and then the concentration that is in the extractant are drops of let us say. Let us move on.

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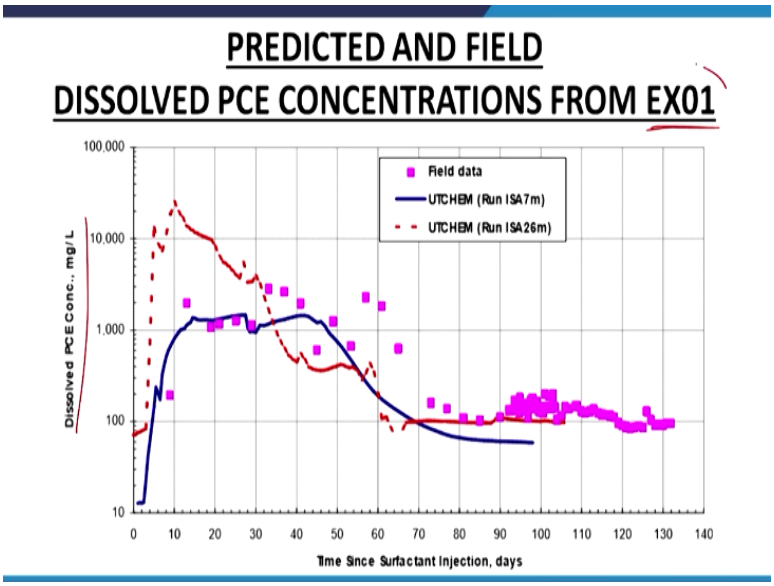

So PCE predicted concentration and field concentration from the extraction well 1 now. So before you start you know running your system let us say, you are obviously go into look at some relevant models let us say. How well models be relevant, why are they useful. Obviously there

are different variable that play here or aspects that need to be estimated before you set up the system.

As in based on the model you will know, how much how to design your treatment system, how much surfactant to be used, for how long you need to keep pumping it and so on and so forth. So for that you are going to have models let us say, right that you can look at or used to predict let us see how good they were in predicting the actual field data, let us say. So here we have dissolved PCE concentration and here we have let us say.

Again we are looking at extraction well one and times since this surfactant injection initially in days. So we see a period of almost around 140 or 150 days. They looked at 2 models, 1 and 2, 1 is out here, the red colored 1 and the other is dark blue coloured 1. Obviously this one may be did not do as well. I think this will be relevant to the relevant depth or such but we did not have enough information to be able to you know look into it in more detail.

But as you see, this particular model was able to predict the relevant or actual field concentrations or actual observed concentrations later on pretty well. So again how well this help, let us say. If you have model that works fine, you estimates now or going to be estimates in the relevant aspects that you use, let us say, are assumptions that you make based on that model are going to be relatively accurate. If not, you might be way off.

Thus either underestimating or over estimating and thus allocating more resources are maybe not playing you know not having planned in the right manner let us say. So obviously you know models play a critical role, right. So let us move further.

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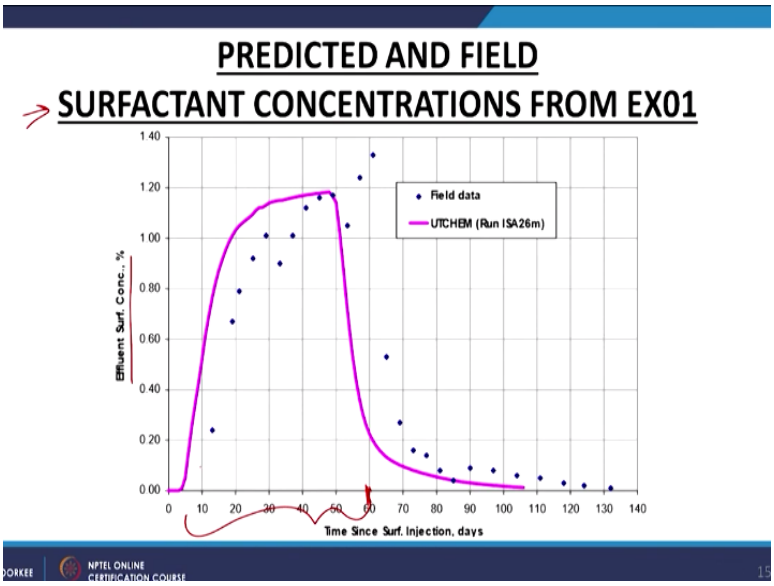

So again predicted and field surfactant concentration from extraction well 1, right. Here obviously surfactant concentrations, so this is surfactant concentration on the Y axis and time since injection obviously we looked it around 140 or 150 days that is what we have here. So initially during the flooding phases let us say I think they were around 60 days. So until this period, the system was flooded for around 60 days and so on.

So you see that you know the actual concentrations let us say obviously increased and once the flooding stopped, and you flush the system with water during that phase obviously the surfactant concentration would come down, let us say. That is what you would expect and obviously that is what the relevant model predicted too. There is some difference, but again the relevant model was, as you can see or was relatively accurate enough, let us say.

So again what is this up to let us say. Initially let us say you have only the surfactant, and I think the surfactant flooding was done for around 57 days. So you see relatively higher concentrations and then obviously once you stop that particular flooding and just water that is why you see the relevant concentration of surfactant to drop and this is just the residual concentration of the surfactant that is present in the relevant system. So let us move on.

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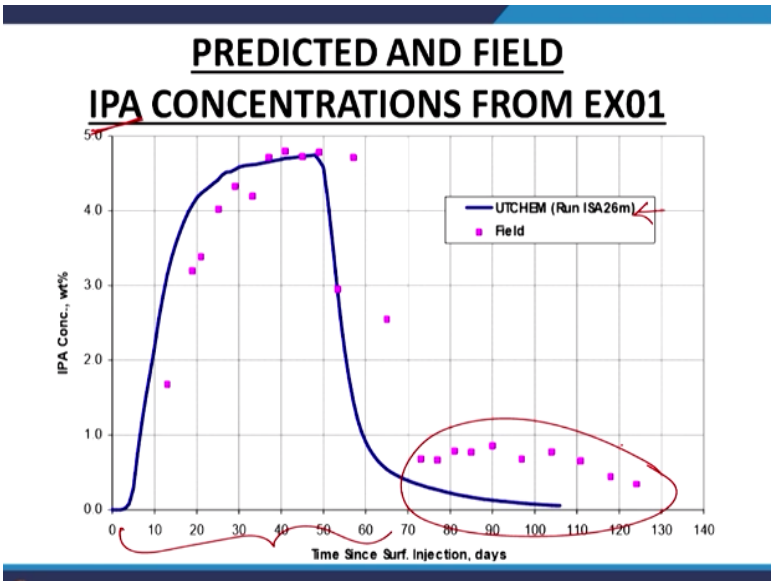

They also looked at another what do we say 1 solvent isopropyl alcohol, right. Again same case here initially they injected along with the surfactant, the isopropyl alcohol the solvent and as you can see the model did a decent job in predicting this particular behavior of the relevant what do we say solvent here and again here during what do we say the flooding with water, you see, you still have considerable concentrations of the relevant what is this now, the isopropyl alcohol.

So what could be some of the reasons let us say. Keep in mind that is relatively more hydrophobic, let us say and thus getting that out might have been an issue, getting that out of the relevant system because you are flooding it with water or if there is considerable organic carbon present on the relevant soil let us say some of the isopropyl alcohol might be adsorbed on to the relevant soil too, but typically you know isopropyl alcohol us typically is biodegradable.

So that is something to keep in mind, right. So predicted and field concentrations from extraction well 1. That is something we just looked that.

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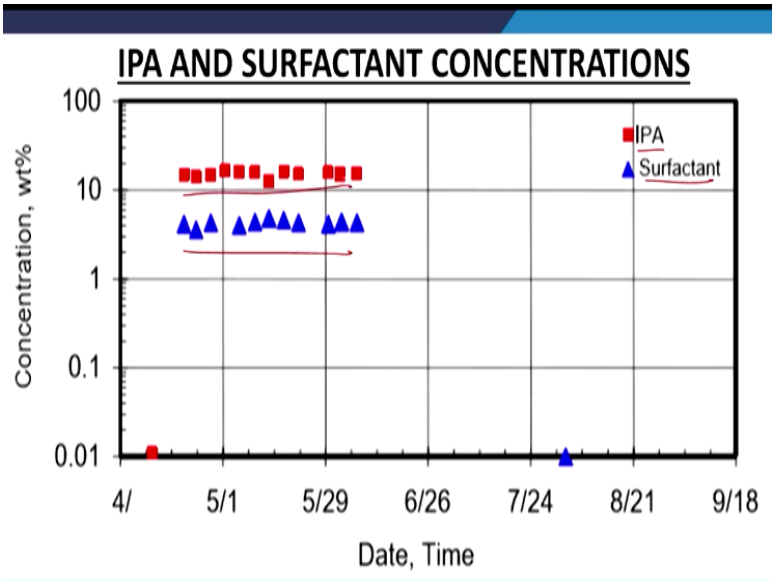

So here we have the isopropyl alcohol and surfactant concentration initially let us say, right and you see the levels in which that they were present or you know injected by percentage by weight and again you see logarithmic scale. So as you can see it is the concentration let us say is almost 10 times or so higher let us say. So that is something to keep in mind. They put in quite a lot of the isopropyl alcohol now.

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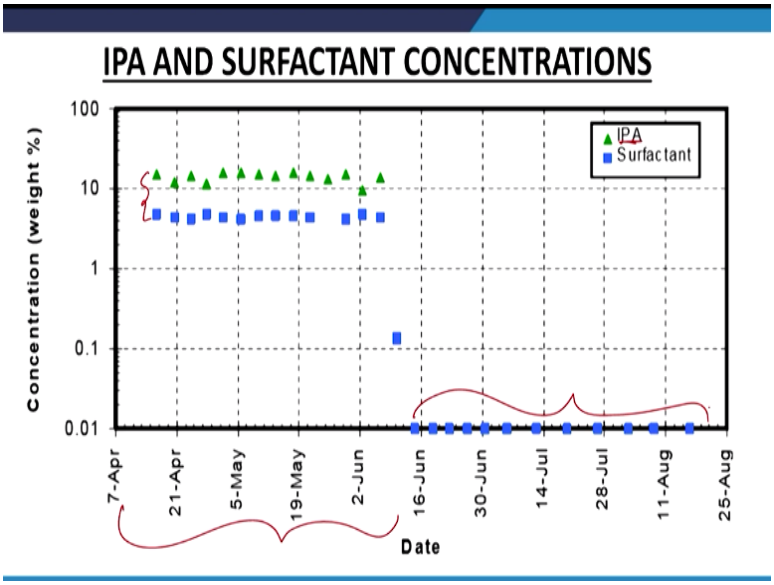

So let us move further, this is for the second monitoring well let us say and here again considerable but not as high level of isopropyl alcohol, but they still put in considerable surfactant and obviously let us say after the end of this particular 60-day period you see that the

surfactant consideration obviously you know comes down and why is that obviously because they were flooding the system with water.

And there is no more source of the relevant surfactant or the isopropyl alcohol out here, so that is something to keep in mind. This is the data from the relevant monitoring wells now. So let us move forth.

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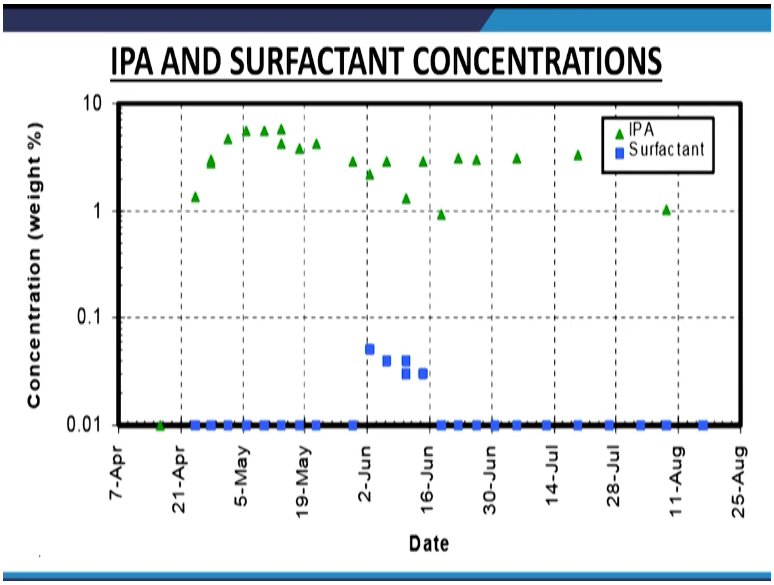

Again another particular monitoring well, again keep in mind the system is pretty heterogeneous and that is what you see out here again but again here keep in mind that the graphs of these are relatively lower concentrations or the axis is different compared to the previous 2 graphs and again the concentration of solvent. This was the residual concentration that we saw even earlier and getting out this residual concentration of isopropyl alcohol seems to be relatively difficult.

But with respect to surfactant you know most of it let us say again was removed let us say and that was the case out here.

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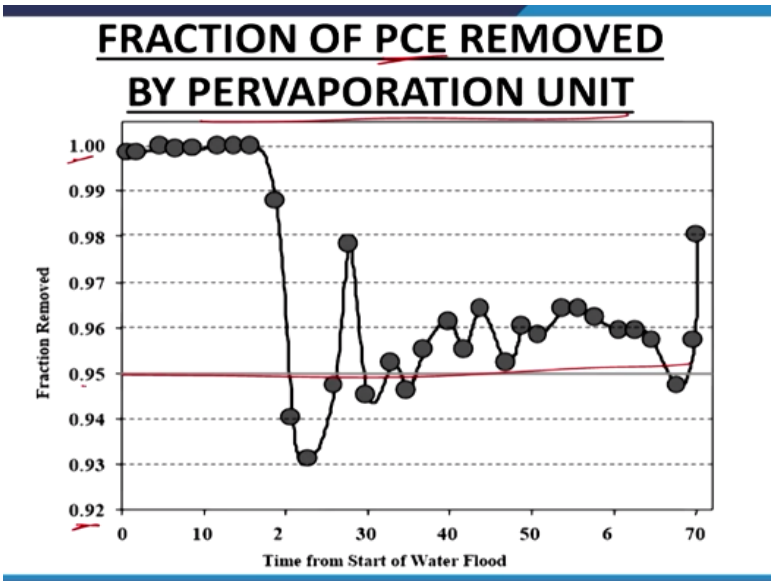

So here we are also going to look at fraction of PCE removed by pervaporation unit and why is this you know necessary to look at it let us say because if you remember for almost 20 days, they were injecting the recycled surfactant into the system now. So obviously you want to look at those aspects let us say such as how easy it is to separate the surfactant, the solvent from the relevant what is this now the PCE now and how also easy is to recycle that and so on.

So obviously that is 1 particular aspect, so you want this particular efficiency to be relatively high. So here access is from keep in mind 0.92 to 1. So typically as you can see here the fraction removed is typically around 95 or 95% of the relevant PCE was removed. So that is pretty high removal that was achieved, let us say. So this particular pervaporation unit, they did job pretty well and that is something to keep in mind let us say.

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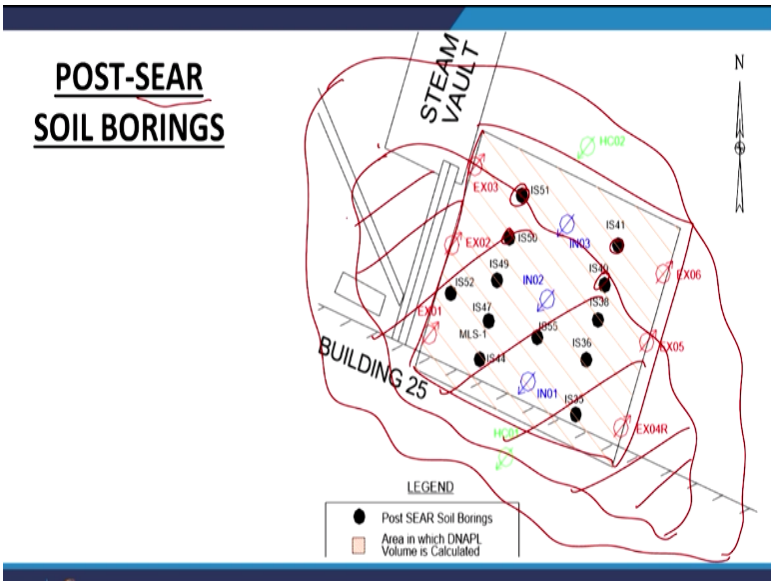

So after this particular surfactant and hands act for, remediation soil borings were also looked at and so now they looked at different soil borings here as you can see, to understand the particular system they you know. Obviously they also want to look at this particular data let us say to be able to understand you know if let say surfactant has been adsorbed on to the relevant what is this now soil or if there is still considerable level of PCE adsorbed on to the soil.

Or even isopropyl alcohol or such, they want to look at the relevant behavior let us say and that is what we have out here. And again as we mentioned earlier only a part of this particular contaminated site was looked at. So as you know as in DNAPL plume was something like this if I am not wrong, and you know only a part of this particular site was looked at let say or maybe it was something like this. Anyway we can look at the relevant data.

This was the contaminated DNAPL plume and this is the site that they looked at, let us say. So let us move on.

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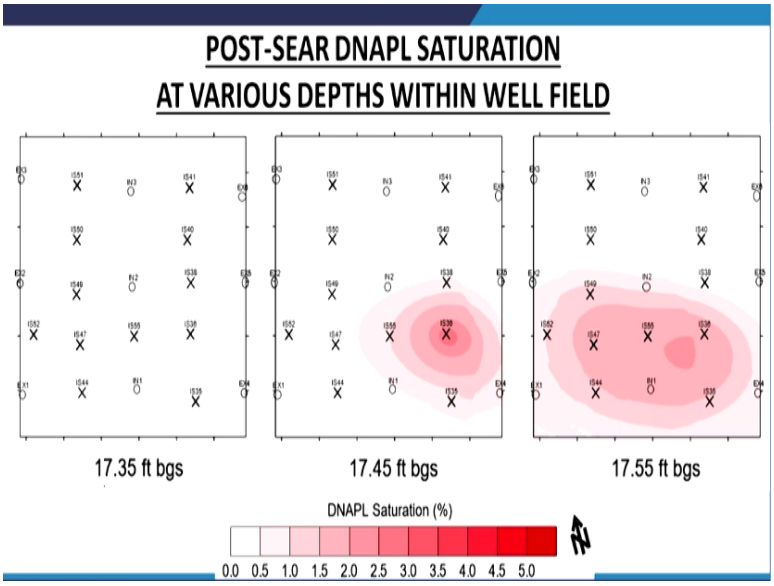

So post-sear DNAPL saturations at various depths within the well field, let us look at what we have. So after remediation, so keep in mind here we have at different particular depths out here. We have the relevant saturation. As we saw the saturation, we know is considerably high again especially at lower depths. So as you can see, this is again still after remediation, but keep in mind mostly they injected it at a particular depth only. So obviously you will not see a lot of removal let us say.

But again the picture would have been clearer if we had let us say before remediation what was the relevant picture, but we could not get that you know clear data, at least with respect to the relevant depth rate. So that is something to keep in mind. So as you can see here you know there is still considerable PCE left, but the relevance of this particular PCE or this remediation let us say will be clear now, when you compare that you know as you keep going further down.

Earlier you knew that there was much more PCE, but obviously as you can see now, let us say now as you go further down let us say, the PCE concentrations are not as high as you would have expected based on the relevant initial data now let us say and that is what you see out here. But obviously the heterogeneous system, so you see the injection wells out here and the extraction wells out here let us say. These are the relevant locations here let us say.

And again keep in mind that the system is pretty heterogeneous out there and I guess you have different zones and such, but for a pilot scale let us say that is decent level of removal, but we are going to look at the data, but here we get the picture that let us say, obviously not all the relevant aspects are removed or at least let us say, there is still considerable DNAPL left.

Again why is that if you keep in mind let say under that particular building there was still a considerable pool of DNAPL and they were looking at removing these particular DNAPL that was outside the boundary of the building now. As they were removing the DNAPL from that particular site, obviously you know some of the DNAPL from the relevant what is this now under the building will move towards that particular site.

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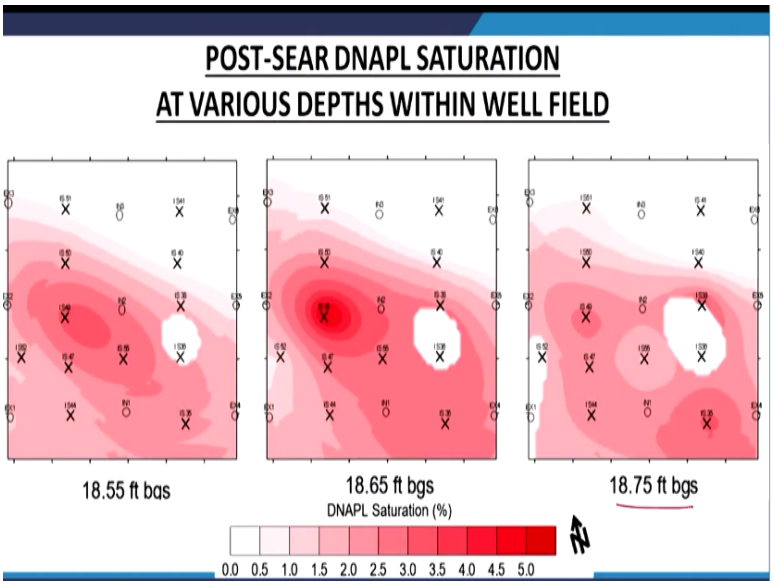

So you have those issues. So obviously it is a relatively mixed picture out here, but obviously at 18.75 and 18.65 let us say you can look at the relevant difference out here.

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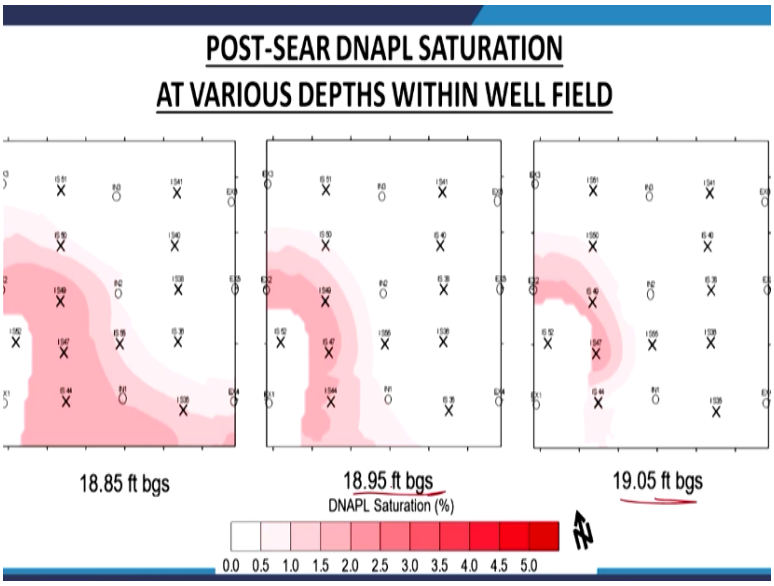

Again as you go further down, you see the different picture. Again that is because they injected the relevant surfactant at different depths at so on and so forth, let us say. Let us move on.

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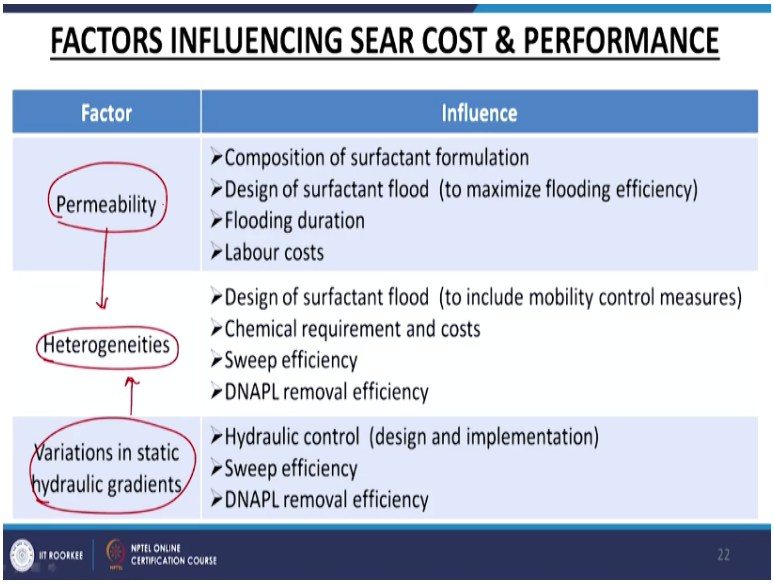

So what are the relevant aspects let us say that 1 needs to be concerned with, with respect to the cost and performance let us say. As we mentioned multiple times obviously heterogeneity will lead to greater complexity in the system and thus greater level of control we look at them and again part of the relevant aspect typically includes permeability let us say of the relevant system.

And then again another aspect typically that might go in within the context of the heterogeneity is the variation in the static hydraulic gradient let us say. So these are different aspects. So within

the context of permeability what you have. So you need to look at the composition of the surfactant formulation let us say. Obviously let us say depending upon the hydraulic conductivity or let us say the permeability let us say, you need to choose different types of surfactants or different mixtures of surfactants let us say.

And as in the design of the surfactant flood, how long and how to go about it and so on typically how long design I guess typically is about how long and that obviously is covered out here, flooding duration and obviously relevant cost, let us say because you know the more time that is required for you know what do we say pumping the relevant aquifer let us say or the contaminated soil let us say with DNAPL or relevant cost let us say are going to increase.

That is what you see out here and with respect to heterogeneity let us say. Again as we discussed earlier, it impacts the design of the surfactant flood let us say, as in let us say if I have if this is the side view let us say and I have this particular layer and then let us say you know this is of clay and DNAPL has permeated or you know diffused into this clear layer and let us say beside that I have relatively sandy layer.

So now when I pump my surfactant through this particular site what happens obviously because of the differing hydraulic conductivity let us say, first you know surfactant or surfactant might go through this particular sandy layer let us say or silty layer, right while bypassing this clear layer. But again clay, there might be considerable fraction of the DNAPL present here right now. So how will that be removed now only when the surfactant has removed that particular DNAPL in the relevant sand layer will again diffusion take place out of the clay into the sand.

So that is going to take place diffusion out of the clay into the sand and then again as you pump more out, you know it is going to be taken out. So these are relevant aspects. So again any other chemical requirements, the sweep efficiency obviously that is something we talked about and also DNAPL removal efficiency, right. All these will be impacted by heterogeneity, let us say. Again variation in static or you know hydraulic gradients obviously in designing your hydraulic control, the sweep efficiency and DNAPL removal efficiency.

You know these are relevant aspect let us say right. So let us keep moving.

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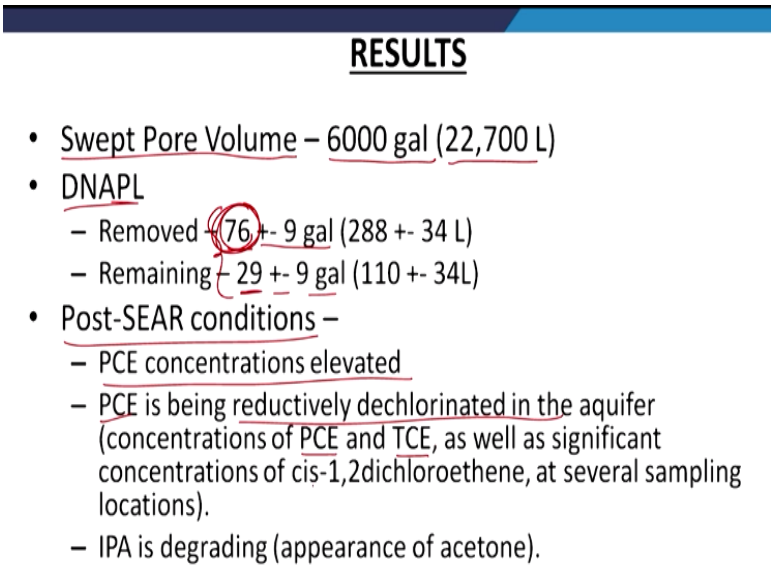

So to get an idea about what we have looked at, I believe we did look at this number earlier what we have been up to or they have been up to rather, they looked at or they pumped enough particular surfactant to fill 6000 gallons or 22,700 liters of pore space or pore volume. So considerable amount of surfactant obviously was pumped through and how much DNAPL did they remove, here they removed 76 and +/-9 gallons.

They estimate that there is still 29+/-9 gallons remaining in that particular system now. So again you get you an idea about the amount of surfactant required to be able to remove DNAPL and again even from our particular equilibrium calculations, we see that considerable amount of surfactant has to be pumped through, but if you looked at in the time period and the relevant control it is relatively not as difficult as it would presume it to be too.

But keep in mind that a considerable amount of DNAPL was removed and if you remember some of the calculation that we looked at far earlier in the class let us say right, we looked at the cases where even very minor fractions, minor volumes of the relevant DNAPL let us say could lead to considerable what do we say effects let us say on let us say on let say groundwater concentrations and concentrations of the contaminant in the soil let us say or adsorbed on the soil.

So again removing this non-aqueous phase liquid is considerably important and tricky let us say and as you can see they did a pretty good job above by removing almost around 75% of the relevant contaminant here. So again what were post SEAR conditions, they say that they were elevated or rebounded let us say again typically because keep in mind that you have other contaminant at different levels or contaminant in the different areas let us say.

Because the relevant people only trialed it at a particular location right and also they saw that PCU was being reductively dechlorinated in the aquifer like PCE and TCE and how did they know that because 1, 2DCE which is what do we say a byproduct was present at significant concentrations at several locations and also the solvent that they injected which was isopropyl alcohol looks like is also degrading or biodegrading that is based on relevant byproduct out here.

So that is something to keep in mind or there could be a symbiosis between these 2 aspects let us say.

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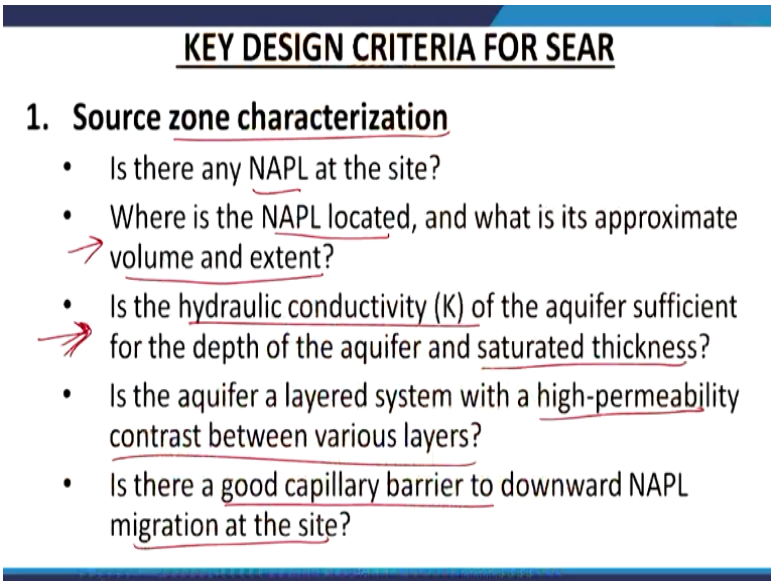

So what are some of the generic design and criteria let us say. We will quickly go through this relevant aspect. Obviously spend considerable amount of resources on zone characterization as in there is NAPL present. If so where is it present and what is its location let us say, that is something else and getting this is a tricky aspect and then site characteristics with respect to

permeability and hydraulic conductivity let us say for the depth of the aquifer and for the saturated thickness that is something to keep in mind.

Because in our case if you remember you know some of the DNAPL was above the impermeable layer and also some of it inside the impermeable layer. So obviously it is pretty difficult to get such particular NAPL out and obviously we need to get such information let us say is aquifer layer with high permeability contrast between various layers. Again we are looking at the heterogeneity of the relevant system, which is what or which was the case in this particular scenario, let us say.

Again is there the barrier to downward NAPL at the site why is that otherwise you know why is that otherwise you know the DNAPL might permeate to great depths and that might increase the relevant what do we say complexity of the system. Here I believe in our particular case are the information that we had was around 16 or so feet below the ground surface, they had a relevant clear layer let us say I believe, are silty clear layer let us say.

That served as an impermeable layer to hold the or to inhibit further downward movement of the DNAPL let us say. So that is something we looked at.

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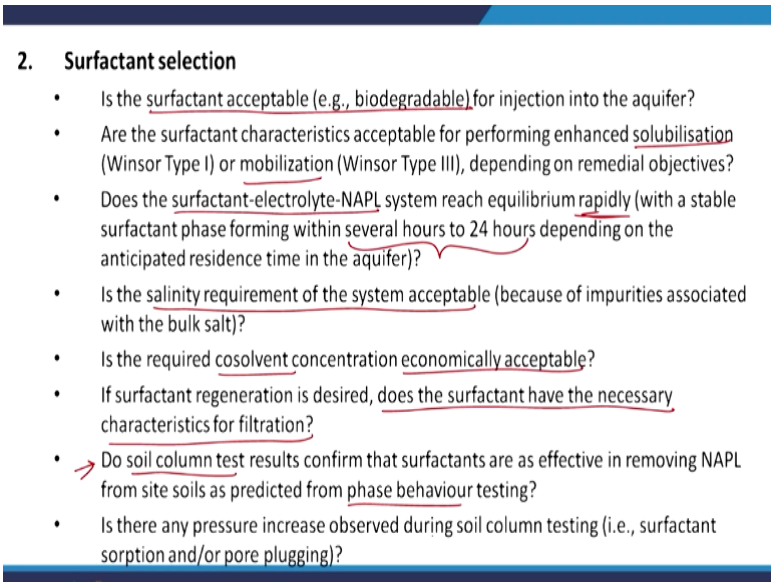

And then obviously surfactant selection, first obviously it is toxic by itself obviously that you saw that residual concentrations of the surfactant what present. So you need to see that you are not introducing a problems. So obviously that is one aspect. So if the surfactant is acceptable or is that biodegradable. So again different aspects with respect to solubilisation or mobilization let us say depending upon the remedial objectives.

And does the surfactant electrolyte NAPL system reach equilibrium rapidly? So why is this important let us say. So you have the NAPL present and then you have surfactant being flooded through. If it takes a lot of time for equilibrium to be achieved as in for the compound or the PCE to change phase from the NAPL into the surfactant, then what will that lead to. That will lead to requirement for greater flooding period, let us say, right.

That will mean more time, more cost, and so on. So you would prefer that the kinetics that are required for this change in phase is relatively rapid, let us say. So here they look like they typically look at several hours or you know less than 24 hours at best, let us say. Salinity requirement is within the acceptable levels obviously, right. Required core solvent here which is the isopropyl alcohol, the cost acceptable.

Surfactant regeneration is desired as we discussed earlier. Surfactant have the necessary characteristics for filtration. They look at obviously change in or phase separation, so obviously surfactant if you are trying to regenerate that, that should obviously meet such needs, let us say. So let us move on. So column tests are to be conducted, let us say as in one way, we are looking at this particular behavior from phase change behavior.

We have my cell, we have the NAPL or surfactant and NAPL, you are seeing that okay, there is going to be transfer taking place. So that obviously again needs to be done on the soil column test, let us say, right to be able to confirm that and is there any pressure increase during soil column testing, as in let us say, as we discussed briefly is this particular surfactant leading to clogging of the relevant pores than the pressure required will increase obviously, right.

That is what you see or is this particular surfactant absorbing on to the soil and so on and so forth. So the relevant aspects and again the relevant model development, let us say.

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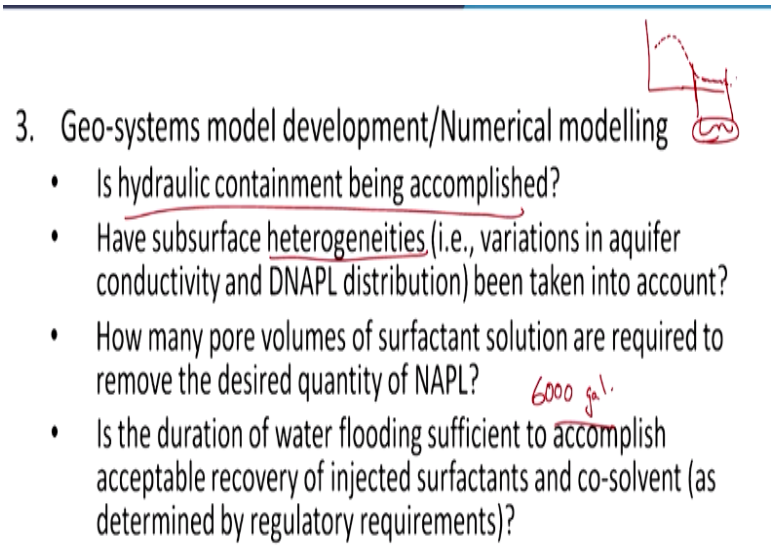

This is required for obviously predicting the relevant aspects upon which let us say base the calculations for your resources and planning, right. So hydraulic containment being accomplished, right. That is something we looked at, let us say. Is it how heterogeneous is the relevant site, let us say, right. Because the more complex the system, typically the model set says they are going to have a difficult job and being able to take the relevant aspects let us say.

And again, how much pore volume are we required to remove. In our case, I think we looked at 6000 gallons, let us say and the duration of flooding is sufficient to accomplish acceptable recovery of injected surfactants and cosolvents, let us say. That is something to keep in mind. As in, initially we looked at I think 57 days or almost 60 days during which the system was flooded with the relevant, what is this now, the relevant surfactant, let us say and the cosolvent, which was isopropyl alcohol.

And later for around 37 days or 47 days, they flooded the system with water and you saw that the profile of these 2 particular surfactant and such was something like initial increase and then decrease during the water flooding, right. So from the model, you will be able to need to predict,

how much time is required for this water flooding to you know bring down the relevant residual concentrations of these particular surfactants to reasonable limits, right.

So that is what you have out here, right. I guess with that, I will end my particular presentation or the particular case study, right. So obviously, as you can see there are quite a few aspects involved, right and it is relatively complex to remove a particular DNAPL contaminated site, let us say, right. If you can look by bioremediation, but that will be typically more effective for the soil or the ground water contamination.

But if you have DNAPL present, that obviously is going to act as a great reservoir, let us say for the contaminant. So typically your effort should be directed at removing that particular pure solvent, let us say or saturated and I guess with that I (()) (38:40) and thank you.