Environmental Remediation of Contaminated Sites
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Lecture – 12
Remediation of contaminated GW Javendel et al's approach

Hello everyone, so again welcome back to the latest lecture session, let us as these customary have a quick recap of what we have discussed in the last session and then move on to the relevant aspects. So, I believe we have started looking at the relevant aspects with respect to remediation of contaminated groundwater, so as we discussed earlier we are going to get look at or consider 2 major types of contamination.

And how to remediate them, one would be contaminated groundwater, the other one would be contaminated soil or sediments, so in that context we start looking at the relevant aspects with respect to contaminated groundwater and one of the what we see ways that people often look at or have looked at anyway let us say is pumping the water out let us say and that can also be a part of pumping it the water out and treating the water or just a strategy to contain the plume.

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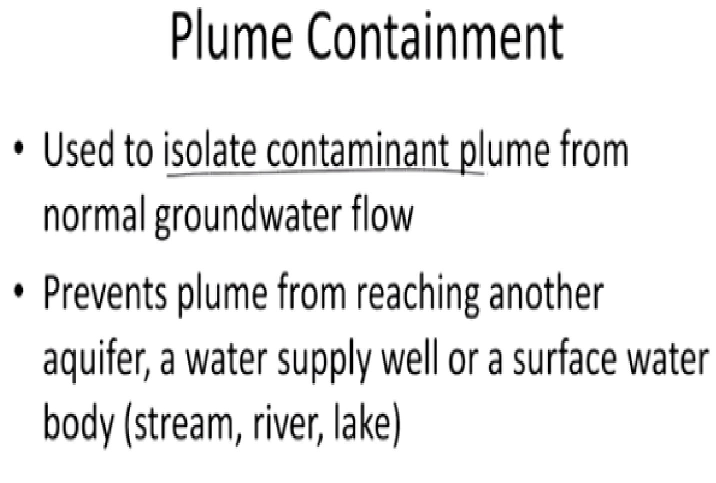

So, in that context we looked at I believe the aspects with respect to plume containment right, so we looked at plume containment and the context of isolating the containment plume, right and also trying to avoid let us say the plume reaching another aquifer as in let us say you have let us say surface water body near by a river or a stream let us say and you have a contaminated site nearby that is led to contamination of the groundwater.

We obviously do not want the containment to be spread over a wider area let us say causing further what do we see adverse effects to a greater number of population let us say, right or greater populous let us say, so thus obviously you want to limit that so, again in such particular scenarios or depending obviously on the site, you want to limit the or contain the plume.

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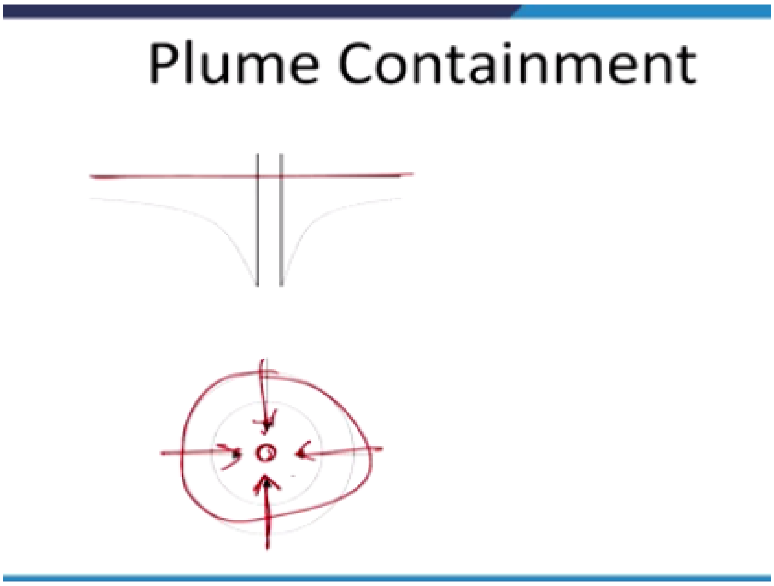

So, in that context we looked at certain aspects, one aspect obviously that we looked at initially was that you know, we consider one particular case let us say when you know the hydraulic or the slope of the energy gradient or the hydraulic gradient is something like this and if we have a pump or the start pumping out here, the flow lines would you know be something like this as in they would all float towards the or the ground water would flow towards the what is it now pumping well, right and symmetric and would be symmetrical I guess, right.

But obviously, this is not the case you know that ground or you know earth surface has angulations, it has slopes let us say and obviously, thus your what do we say groundwater to will follow more or less that certain profile let us say, when we try to consider the groundwater flow direction anyway right, so obviously in that context we need to look at the slope of the energy gradient or the hydraulic gradient, yes.

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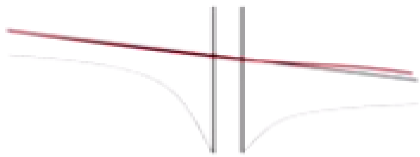

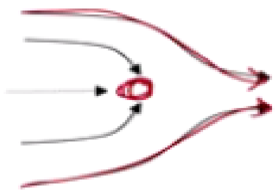

So, obviously you know we are going to have a gradient here and that is what we see out here, right, so in that case if I pump it in from the same location, at the same flow rate, you see that you know there are flow lines; groundwater flow lines which are not going to be captured by the pump here, right. So, the key aspect obviously that we need to consider is where do I place the pump and so on and so forth.

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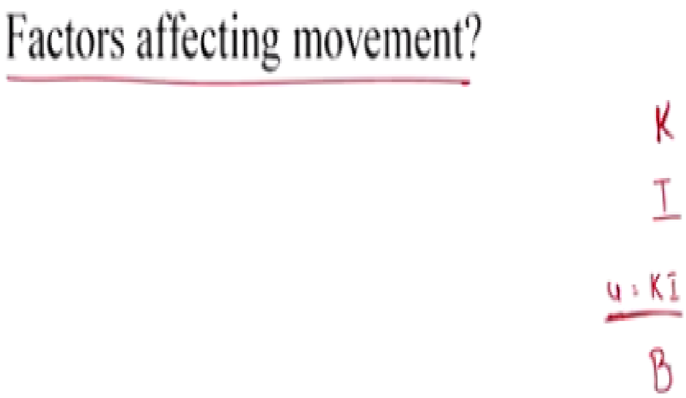

So, in that context obviously, I am dealing with groundwater flow and movement, so what aspects or what do we say variables affect its movement now, so obviously the type of aquifer let us say right you know, clay, clay soil, sandy soil and so on, so but which aspect are we dealing with or considered or concerned with when we talk about these aspects with respect to kind of aquifer, we are talking about the hydraulic conductivity in general let us say, right.

So, we talked about hydraulic conductivity let us say, layman's terms the ease with which let us say water can flow through your particular media let us say, again layman's term obviously, we need to know the hydraulic gradient or the slope of the energy gradient right that is something we need, why is that; obviously, it is going to affect your groundwater flow velocity let us say for example, if it is relatively stagnant or you know, the groundwater flow velocities are relatively less, let us say your strategy for containing them or pumping the water out would be different let us say.

Compared to let us say if you have what do we say groundwater with greater velocity obviously, in that context you might need to have more number of wells because you know the plume would or you know there will be greater number of flow lines let us say that would be there get would have to be capture let us say and in that context obviously, we are concerned with those aspects.

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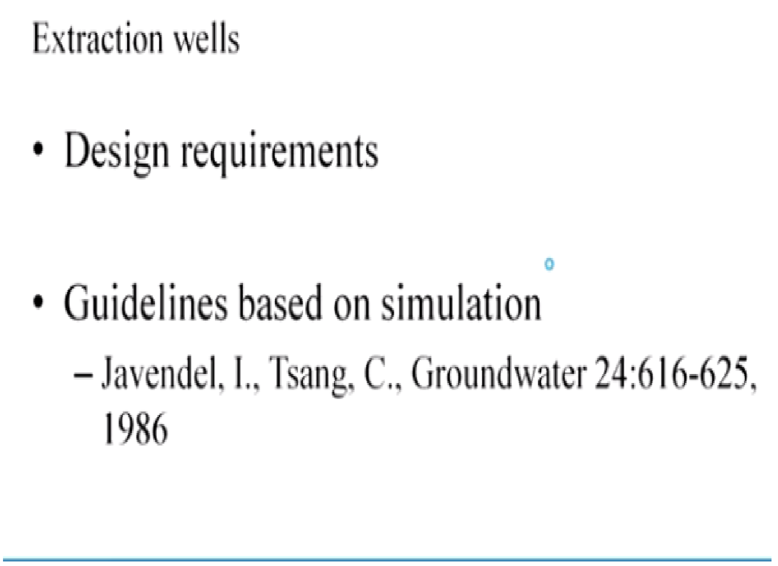

And obviously, the aquifer thickness again right, so these aspects we discussed briefly, so how do we go about that; we have different models we can do that but typically, we mentioned that we look at the design given by or the simulation given by Javendel et al, right so that is something we looked at.

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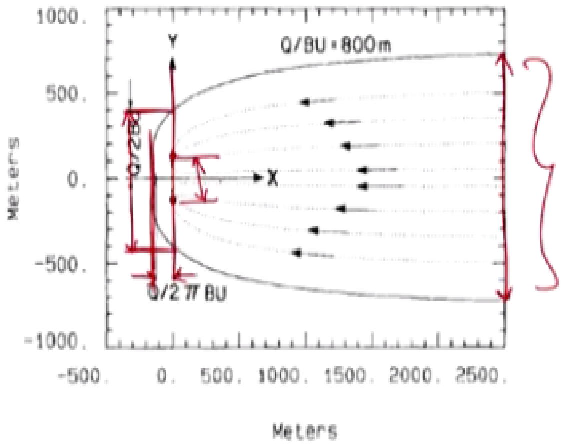

And what did they give us an idea about so, for different number of wells let us say here we are looking at the case for 2 wells here let us say, they give us an idea about what is the distance from the center line of the well which is this to the let us say the stagnation point let us say, right for its capture zone, let us say right, this width right and it also gives you an idea about what is the width required add the or what is the width of the plume that will be captured along the center line of the wells.

And it will also give an idea about what is the width of the plume that will be captured for upstream right, so these are different wells and it will also give an idea about the spacing between the different wells let us say, right and you know based upon this obviously, you can design for the relevant aspects.

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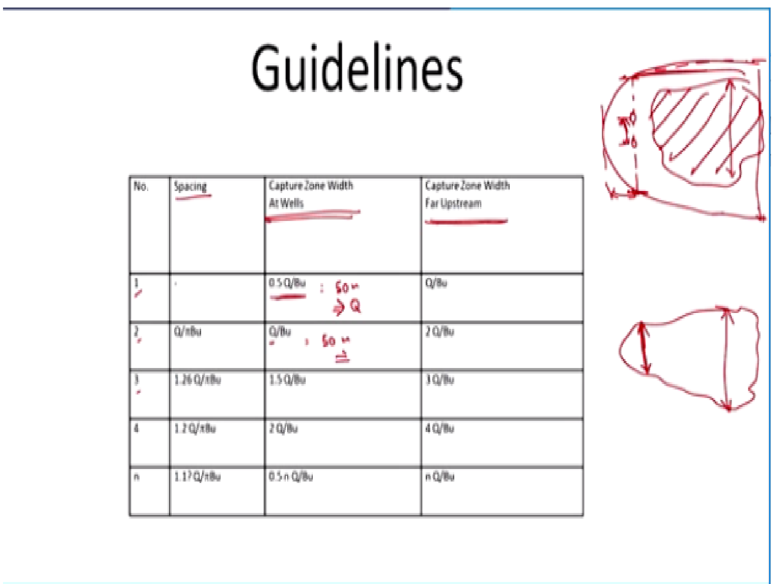

No.	Spacing	Capture Zone Width At Wells	Capture Zone Width Far Upstream
1	-	0.5 Q/Bu	Q/Bu
2	Q/πBu	Q/Bu	2 Q/Bu
3	1.26 Q/πBu	1.5 Q/Bu	3 Q/Bu
4	1.2 Q/πBu	2 Q/Bu	4 Q/Bu
n	1.1? Q/πBu	0.5 n Q/Bu	n Q/Bu

So, here what do we have for example, for 1, 2, 3, 4 and different kinds of wells, we have the spacing between the wells, capture zone width at the wells and capture zone for upstream, right what do we have here; we have let us say, if this is the what do we say, flow pattern that is going to be captured by the let us say 2 wells, let us say, what do we have; we have the spacing between the 2 wells let us say from this table again from that particular literature, we have capture zone width at the wells so we have this particular width.

And we also have capture zone width at for upstream right, it will also give you an idea about this distance too but again that is not mentioned in these guidelines but it is available in the source what do we say literature there, right.

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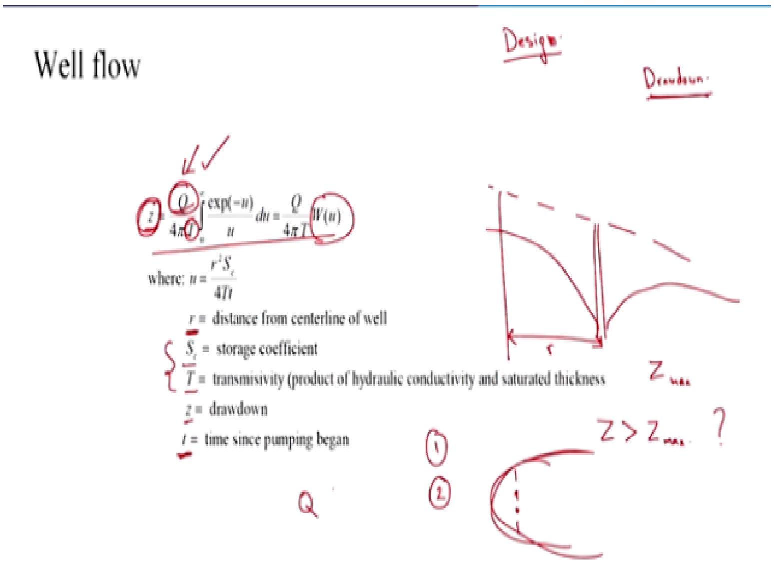

So, then we moved on to looking at design, how do I go about designing the particular I know set up or system now, right, in this context what do we need to look at let us say or what are some of the limiting factors in that aspect, we saw that drawdown let us say, for example you know you start you know setting up an extraction well pumping water out at a certain flow rate let us say, you know you are going to have a certain drawdown let us say, right.

So, typically based upon let us say the relevant aspects or the field conditions let us say you are going to have maximum or what we say maximum permissible drawdowns or such let us say right so, for example if you typically keep increasing the flow rate, you will typically end up with you know, greater drawdown I guess let us say, so obviously we need to be concerned with drawdown.

In that context, we had a particular formula here let us say where I guess we have different variables some of which are listed here let us say and again, here we have the well function, let us say.

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Approximations for W(u), well function

- (Abramowitz, M., Stegun, I.A., Handbook of Mathematical Functions, Dover Publications, New York, 1970)
- for $0<u<1.0$:

$$W(u) = -\ln(u) + a_0 + a_1 u + a_2 u^2 + a_3 u^3 + a_4 u^4 + a_5 u^5$$

- where:
  - a0 = -0.57722
  - a1 = 0.999992
  - a2 = -0.24991
  - a3 = 0.0552
  - a4 = -0.00976
  - a5 = 0.001079

Again for that we have the relevant aspects, how do we calculate that for different conditions right.

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- for u > 1.0

$$W(u) = \frac{u^2 + a_1 u + a_2}{(u^2 + b_1 u + b_2) u \exp(u)}$$

- where:
  - a1 = 2.334733
  - a2 = 0.250621
  - b1 = 3.330657
  - b2 = 1.681534

We have these aspects let us say, right so, based on that obviously you can calculate the well function, pardon me; are using the well function you can calculate the drawdown given that you have a particular flow rate and you know the aquifer conditions let us say right and again obviously, the time and distance from center line, radius of center line as in what does this particular variable mean?

It means let us say if this is my well let us say and this is the hydraulic gradient let us say and this is the drawdown or such okay, so r will be the distance at which let us say from the center line of the well at which I am trying to calculate the drawdown let us say, right so that is going to be r, storage coefficient, transmissivity aquifer properties let us say, again drawdown is what I am going to calculate and time since pumping began.

Anyway, so what I have is given aquifer properties let us say and I know where it is I want to calculate the drawdown, I can come up with calculating the drawdown given, I have the flow rate required but how do I get the flow rate required and such right, so now let us look at the design here. So, here let us say we have this particular case let us say as in I know my plume shape let us say okay.

For example, assume that this my plume shape and size let us say, right and now, I know the thickness of the plume here or let me draw that out here let us say this is my plume let us say, so I know the plume width for upstream and also somewhere out here let us say, right or near its (()) (09:37) let us say, right, so based upon this particular you know width, I can come up with let us say what would be the capture zone required at the wells.

And capture zone width required for upstream for that I will choose some trailers, let us say I can start with 1 or start with 2 let us say right, so I know let us say if it is 50 meters let us say and that should be the captured zone with at the width at the wells, I can equate this particular capture zone width at the wells to be equal to 50 meters, right and I can calculate the relevant aspects with being what can I calculate; I can calculate Q let us say, right.

So, what am I doing again; I am going to go with a trial design based upon the capture zone width of the or capture zone width required for that particular plume let us say, right, so based on that what do I do; I am going to estimate let us say what is the width required at the wells and far upstream right from that I am going to get the draw pardon me, the flow rate that I have for that particular number of wells.

In this context, we are looking at only one well and then I can calculate Q let us say, right so from the Q what do I do; I then calculate the drawdown right for example, I now have Q here, right and then I can calculate the drawdown right, so then I am going to see this drawdown within the relevant limits that you know I have out there in the on-site or not. If it is you know greater than or the drawdown that I am estimating would be greater than this particular drawdown which is the permissible value.

Then what do I need to do; I need to iterate again, so for example let us say I have a maximum drawdown of Z max that is available but my drawdown end up with being greater than Z max right, so what do I do; so instead of one well I am now going to have 2 wells, right say, right, so again same case if this is the flow line here 2 wells let us say, again and so on, so then again I will calculate Q, how do I calculate Q now?

Again here Q/BU will be = let us say now 50 meters now, right obviously, now Q will be relatively less hopefully here let us say, right and then I am going to get the relevant Q, right again once I calculate the relevant flow rate or you know for that relevant iteration of number of wells, I am going to you know be able to calculate the drawdown and then go along in that manner until I reach in particular set of wells that would meet both the criteria of capturing the plume width let us say.

And also being able to meet the drawdown restrictions I guess, right so that is how I can go about that typically, excel is good enough for what do we say way to go about that but obviously there are some aspects here that we need to consider as in you need to have a factor of safety right, how do I you know get to that particular aspect or where is the factor of safety coming into picture here, right.

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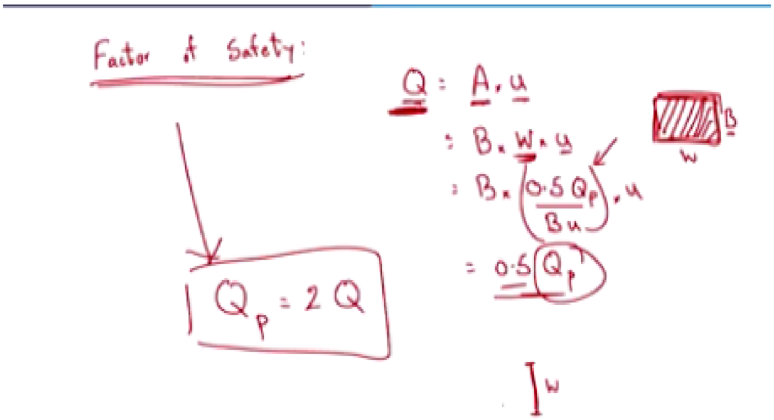

Factor of safety and one other aspect is that this these equation right, this is these equation I guess right as works well for unconfined aquifer, okay, it works well for that but for confined aquifers I guess you know, one should proceed with caution that is what I understand let us say you know, as I think it has some restrictions with respect to the confined aquifer and also the aspect here that I guess people assume or take into account is that the what is the extraction well penetrates through the thickness of the particular or relevant aquifer depending upon the scenario again so that is one aspect.

And also we assume that the flow lines are parallel; groundwater flow lines are parallel but obviously, this might not be the case depending upon the type of what do we say subsurface media out there for example, if you have clay interspersed with sand and so on, water would typically like to take the path of least resistance right, so it would like to flow around clay let us say through the sand and so on let us say or it would like to flow or it take the path of least resistance.

But anyway here we are going to obviously or you know we assume that the flow lines are parallel that is something to keep in mind but obviously, we are talking about factor of safety right so that is one particular aspect let us say we try to look at or consider for now, so I am just trying to let us say calculate let us say the flow for a given width let us say, this is the cross section let us say okay through a particular width let us say, right.

How do I get that? So, area * velocity, so it is going to be area * velocity which is the flow rate of your groundwater velocity here, so what is the area now that is going to be width and to thickness here, thickness of the aquifer let us say width * groundwater flow velocity, so how do I get this width; I can get that from here and that is equal to my capture zone width at the wells; 0.5Q/BU, let us say.

So, B * 0.5Q/BU * U, right, so what do I see, it is equal to 0.5Q, Q is the rate of pumping, so what is it that way I have looked at; we see that the groundwater flow or flow rate through that particular cross section let us say is going to be half of what we are actually pumping out let us say, so what is it that we are doing now, we are pumping out or the factor of safety lies in that if you look at the design, we are actually pumping out twice the minimum amount of water required to be able to capture the plume.

Again, how did we do that? Here, we are just trying to let us say estimate what is the flow rate through a particular cross section for the given groundwater flow velocity let us say, right and for that cross section though what did I choose; I choose the aquifer thickness and the width let us say capture zone width at the well let us say, if there were you know the relevant pumps installed and such let us say.

And from our Javendel et al, we know we have this particular set of variables to be equal to r width and I plug that in and what do I see; I see that the rate of pumping is going to be equal to twice the flow rate; ground water flow rate through that particular what do we say now, cross section or such I guess right, so here in ways are factor of safety, again right. So, what is it that we have been up to for example, the top view this is the width let us say, capture zone width at the wells.

And we have the aquifer thickness that we considered B let us say and what did we look at; we are trying to calculate or we calculated what would be the flow; actual groundwater flow through that particular, what do we say section let us say, right and we came up with the relevant aspects and tried to relate that to the rate of pumping that we would have if and when we install the extraction wells.

And what do we see again that the amount of water that we are pumping out is twice the or the flow rate anyway is twice the flow rate of the groundwater flow, right so that is one aspect to look at and consider let us say, right and here thus far we have looked at the pump, plume containment pardon me.

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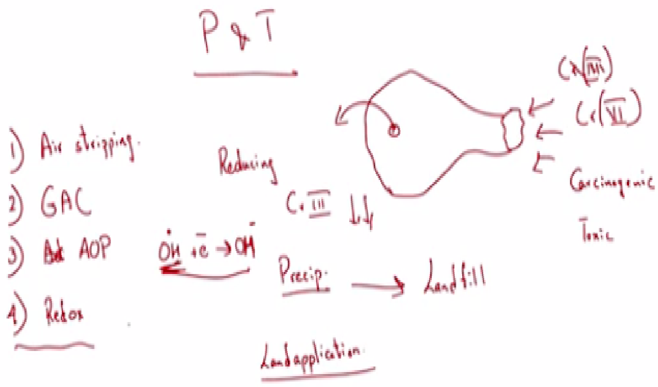

So, the next aspect would be pumping the water out and treating it right, so in this context what have we looked at; we did look at one example already, the one in the case with respect to Ghaziabad anyway, right, so what have we looked at their let us say, right or what is the scenario there; they had a source of chromium contamination; chromium 3, let us say, right and or chromium 6, pardon me, chromium 6 contamination and chromium 6 is carcinogenic let us say and it is also toxic carcinogenic and non-carcinogenic effects.

And I believe you had a groundwater flow direction in this particular direction pardon me, let us say and then the migration of the relevant plume and so on let us say, right, plume shape can vary obviously depending upon type of or you know actual conditions and the type of groundwater flow conditions that you have any way let us say you have something like this you know and what did; what were they doing?

They install the pump and treat system as in they were pumping the water out taking it off site or above ground and above ground, right and then they were reducing chromium 6 to chromium 3 and chromium 3 is less soluble in water, so that is going to precipitate out, right and then this precipitate they were sending to a landfill, yes and this particular treated water they were not rejecting it but they were using it for land applications such as gardening and so on.

Again, not an ideal scenario because you still have considerable or relatively high concentrations of chromium but this is what they have been up to and also I believe they looked at introducing what we say bacterial microbes that could reduce chromium 6 to chromium 3, right and again why do they want to do that obviously, because they want to derive energy for their own needs.

Again, so here what are we looking at; we are looking at pumping the water out and then treating the water here they are looking at the redox process, so what are some of the other ways that people look at treating groundwater; they are air stripping let us say, depending upon how volatile or non-volatile the compound might be or you can have the water treated by granular activated carbon filtration as in GAC relatively what do we say, organic contaminants and such you know typically, a decent way to you know treat the water let us say.

Or you can have advanced oxidation process let us say I will call them AOP; advanced oxidation process, we call them advanced oxidation process because typically they involve the formation of let us say hydroxyl radical; hydroxyl radical which is a strong oxidizing compound let us say, why is it because it has an unpaired electron as in it wants to accept an electron and go to its more stable state which is the OH or the hydroxyl pardon me, OH – phase I guess right.

And this is what it strongly favours to do, so there is acts as strong oxidizing agent, right so at again advanced oxidation process either O3 or mean, ozonation or UV + H2O2 and so on and so forth let us say, right so again, different aspects again typical redox process to other than AOP to let us say, so different aspects here let us say.

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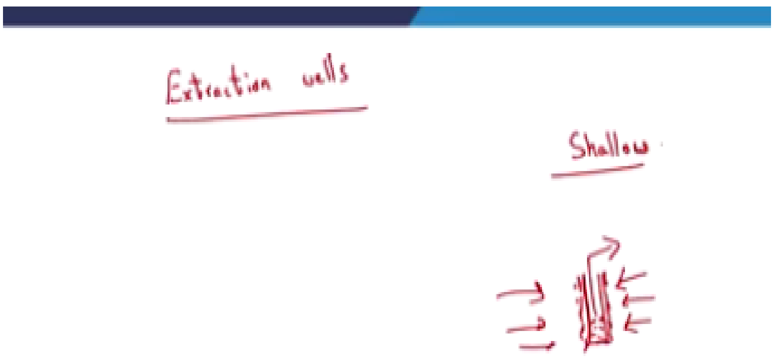

So, before I go further let us say we can also consider rather than pumping the water out extraction trenches let us say or extraction wells, so I am not going to pump water out, what am I going to do is; if I have relatively shallow contaminated zones let us say what am I going to do; let us say this is the side view let us say, I am going to dig a extraction trench let us say, I am line it with a geotextile membrane let us say at least in here if the groundwater flow direction is this way, right.

And what is that going to leave for because you know, have a trench here, the groundwater flow in that particular vicinity would be towards that particular extraction trench, I can let it accumulate here and then pump the accumulated water out and again what is the role of this geotextile membrane at the sides because if I do not have that you know smaller particles you know will seep through, right.

So, to prevent that I am going to again have a geotextile membrane to limit the transport of these relatively smaller particles say, again extraction wells, again they would work well only with at a shallow depths through but obviously, you know different what do we say, types of treatment techniques have their own drawbacks obviously, right so let us look at you know some such cases where it might it as in pump and treat might work or you know or does not work as well I guess.

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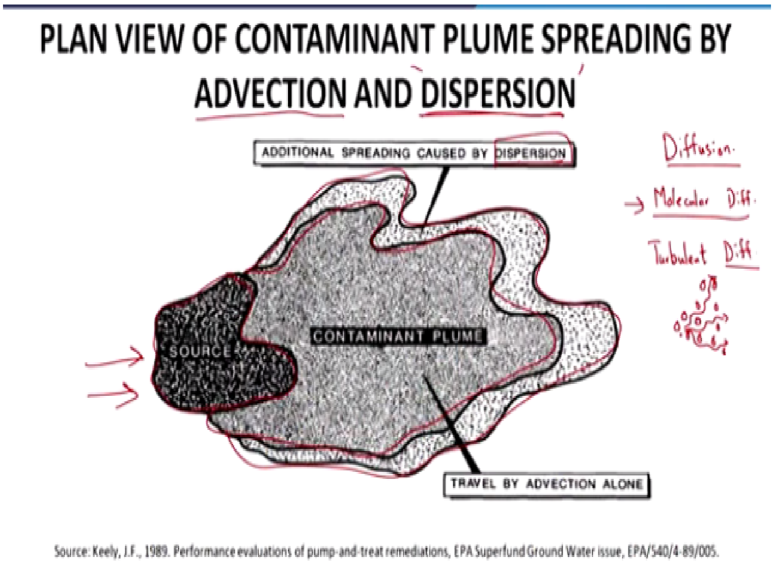

So, here we are going to look at a particular real time plume shape, so here we have a plume typically spreading by advection let us say and dispersion, before we go further I think some particular what we say, explanation is required in this regard so, typically transport of contaminants or such you know transport when you talk about transport of contaminants, we talk about 2 aspects or 2 ways by which the contaminant can be transported, we talked about advection.

Advection in the sense let us say if there is a net flow of fluid either gas or liquid let us say in net flow of fluid in any particular direction and then obviously, you are going to have the contaminant being transported due to this net flow of fluid along with you know in some direction let us say, then I am going to call that particular transport you know of the containment advection, I guess right.

So, again one particular example let us say obviously what is it now, I have a stream let us say, so in the stream you have; you do have a net flow of a fluid or in this case a liquid in one particular direction, so if there is a contaminant release at a particular point, so obviously along with the water flowing in the stream let us say, you are going to have a containment transport and that I am going to refer to as advection.

Or for example let us say if there is wind blowing in one direction let us say consistently let us say and I have let us say a source of air pollution, let us say chimney out there or someone burning a pile of garbage or such and if that particular you know, air pollutant is being carried along with the wind which again as a stress is flowing in or has a net flow in any particular direction let us say.

Then, I am going to call that to be advection let us say but again, what would I refer to as diffusion let us say or when would I you know refer to a particular transport as being diffusion let us say for example, let us say you know if I open a scent bottle here let us say, right and I have the windows, doors and everything closed in this particular room and if there was a person sitting at the far end of the room, after some time he can still smell the particular you know scent let us say.

How can he sense it now let us say, as in there is net flow of fluid; no, none here, how is it that he can sense that particular compound let us say or smell it rather right, even though there is no net flow of fluid now, how was the contaminant traveling from here to the person who might be sitting at the far end of the room now, right how is that going to take place through diffusion now and here the driving force obviously is that you have a concentration gradient as in at this location, the concentration of the relevant compound is high compared to the you know that particular location out there, at the far end of the room.

So, thus you are going to have a random what do we say, transport of a randomized transport of the relevant molecules let us say right, so as in all the directions and what is the driving force or what does it drive towards; it will drive towards such a state when the concentration in that particular system is going to be the same let us say, for example initially the concentration is high and low at some other place.

Diffusion will drive the system such that the concentration is the same at all the particular or concentration is the same in that system, right so when concentration is high at one location and lower at another location, so you are going to have molecular diffusion from this particular location to the other so again, that is how I am describing diffusion as let us say, right but another example would be again what we have discussed would be molecular diffusion, right.

Molecular diffusion and that is something remarkably slow you know it remarkably slow, right but let us say if again I am going to consider the same case I have all my doors, windows closed and then I have open up the scent bottle, how can I see to it that say that he can; he or she at the end of the room can sense this or detect this compound faster, I can turn on the fans right, so what conditions would I be creating in this particular room then?

I will be creating turbulent conditions let us say, so in that case you know you will have a different diffusion coefficient which is relatively higher I think maybe two orders of magnitude higher typically and I will have turbulent diffusion as in what one aspect that people need to understand here is just because I turn on the fans, it does not mean it is going to be advection, why is that?

Let us say you have 4 fans or so here let us say and I turn them on, I am not going to have net flow of the fluid in any particular direction, so it cannot be advection, right but still I am considering or creating turbulent conditions and again still going to be diffusion but now, rather than molecular diffusion, it is going to be turbulent diffusion, right again that is different aspect we are going to talk about these in greater detail relatively later on.

So, in the context of groundwater though you come across the aspect or the term called dispersion, right and here we have 2 aspects; one would be diffusion and also the what do we say, dilution of this particular contaminant let us say due to the different tortuous paths present in let us say a different paths that your molecule can take. Let us say here you have different particles, soil particles let us say, right.

So, a containment entering here has different paths to take it, can either be and appear and appear and appear or such let us say, so to this particular case which I am referring to as dispersion let us say you will again have what do we say, dilution of your particular contaminant here, so here again what are we looking at; as you see here we have the source, this is the source of contamination let us say.

And due to groundwater flow in this direction, this is the contaminant plume due to advection; advection as in here we have ground water flow in one particular direction as we see here and so this particular containment has travelled over a certain area let us say or to a certain extent because of its transport by that particular net flow of fluid let us say and here they you do still see additional what do we say, dilution but not much let us say and that is relevant or depend upon dispersion, let us say, right.

Some of the aspects of which we have looked at here, so again dispersion typically or diffusion pardon me, diffusion is not of great consequence in surface water bodies, why is that; because the surface water flow velocities are relatively high right, so the transport, what do we say, contaminant transport by these particular surface water streams is going to be due to advection anyway.

It is going to be much higher compared to the transport due to diffusion let us say, it is remarkably slow, so for surface water bodies though you can thus neglect diffusion, right because advection is so high compared to diffusion now but in groundwater though the groundwater flow velocities as you know are remarkably slow let us say, right, a few meters per year let us say, right.

So, in that context though diffusion or you know contaminant what so we say transport due to dispersion is what do we say important to and that is something that you can visualize out here too right, so again something here this is one aspect that we need to look at.

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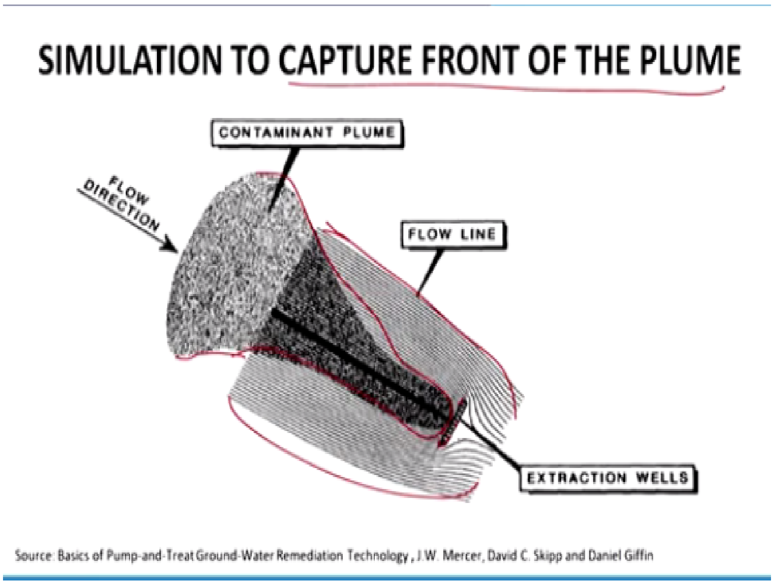

And where we going to look at that; we are going to come back to that so, here let us say again simulation to capture or the front of the plume let us say different aspects, so here let us say we have extraction wells, flow lines that can be captured you know those that cannot be captured we looked at the design and such but here we have relevant aspect here let us say as in what is the relevant aspect here that we are assuming that the plume is going to behave or you know flow in this manner, right.

And obviously, because now I am going to start pumping out this is what you know the behaviour is going to look like and that we assume or presume for these conditions that we are going to capture the relevant plumage let us say, right.

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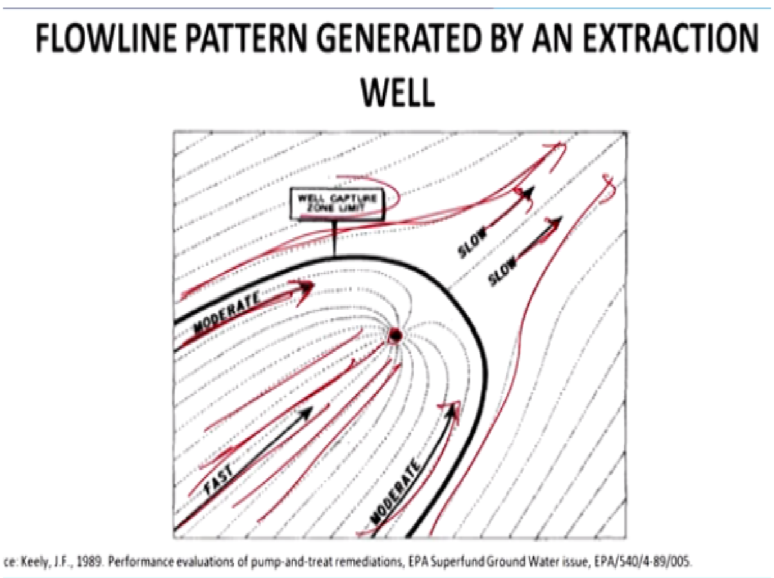

So, moving on again top view let us say, so we have a relevant well here, you know relatively fast, the flow lines approaching that particular well but those at the periphery, relatively moderate and those flow lines that are not affected by this pumping well obviously, there will be at the groundwater flow velocity or they will be relatively slow, right say, right, so you have moderate on the periphery fast along center or near the center let us say, the center line of the well and slow outside the capture zone limit, right.

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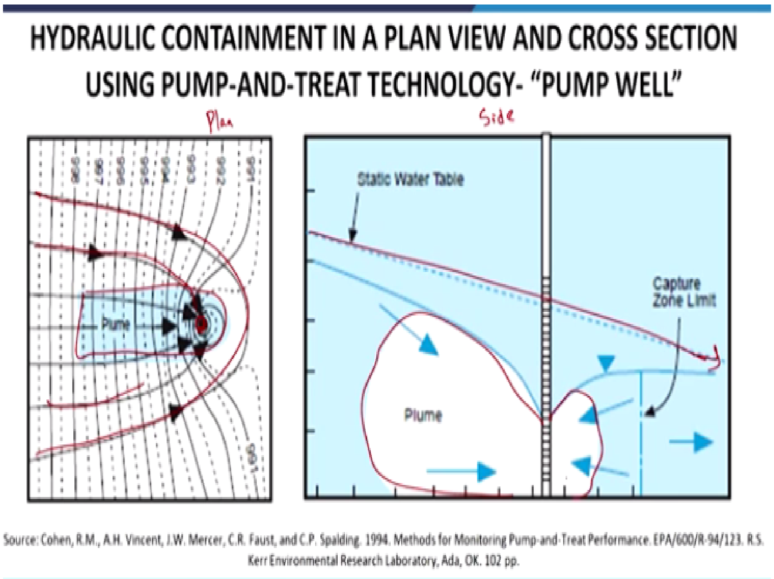

Again, general aspects, so in this context let us say, we are going to look at different aspects here or two particular examples here, so here we have the plan view and here we have the side view let us say, so here you have the plume and here you have the extraction well and factor of safety let us say, they are taken in such that it is going to cover a wider area and same case here we see that from the side view here you have the extraction well upstream obviously.

Because you have a slope here, right, they have a slope here that is why you see this phenomena obviously this is something we have talked about and again I think it is self-explanatory out here, greater capture zone area downstream and upstream relatively less I guess right, so that is something we have here.

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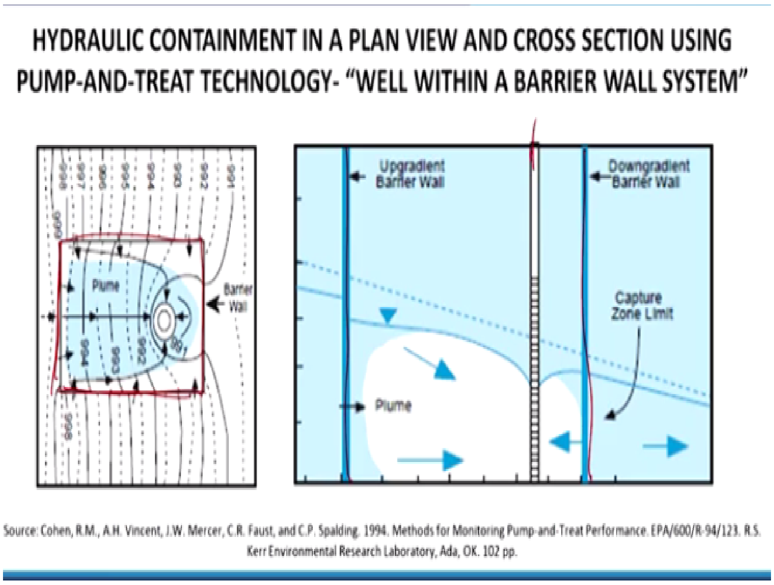

And again, this particular case of plume treatment, pump and treat pardon me, can also go hand in hand with different techniques, you can also have barriers let us say for example, this is my plume, so I am immediately able to put them, what do we say a barriers that would restrict the hydraulic conductivity or decrease the transport due to advection let us say for example, let us say, the spill is relatively recent or I detected the spill relatively recently.

So, what can I do; I can put in a barrier along the what do we say or I can create a perimeter of a relatively impermeable barrier, right say, right and then I can start pumping the water out and that is what you see here, so in the side view you see that barrier walls and then the relevant extraction let us say, right.

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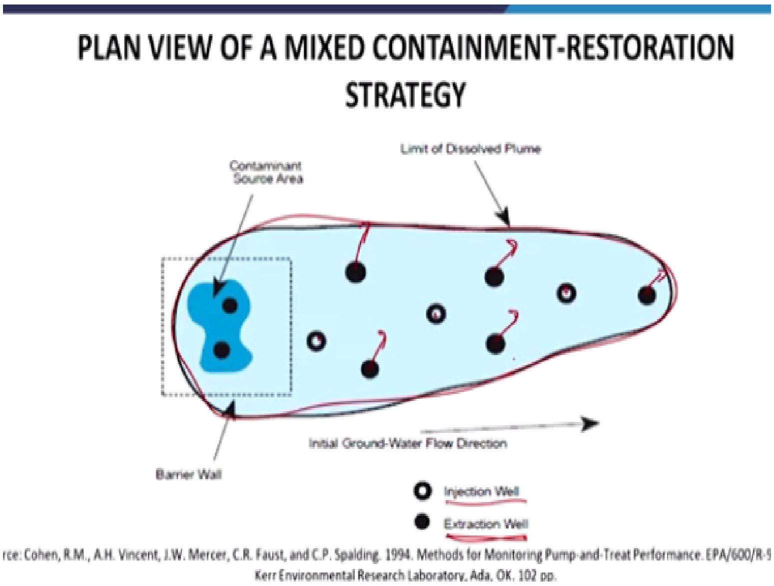

And then moving on obviously, if I am going to have an extraction I need to do something with the water that I treat out so, typically you have injection wells going along or hand in hand with extraction wells, so here you are pumping water out let us say and here you are rejecting the relevant water let us say and this is your obviously contaminated plume again, there is some science or there is science behind or you know there is logic behind how or where to place these you know injection wells for optimal what so we say are you know for greater efficiency.

Again, it depends upon stagnation zones let us say, groundwater flow velocities and the type of aquifer characteristics I guess again that is for a different case maybe.

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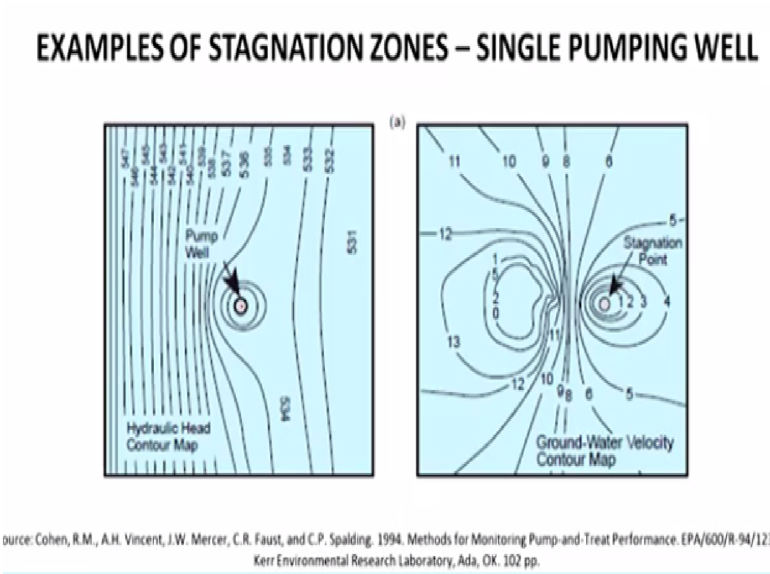

So, in this context again this particular case, we have different stagnation zones and you know we have relevant pumping wells.

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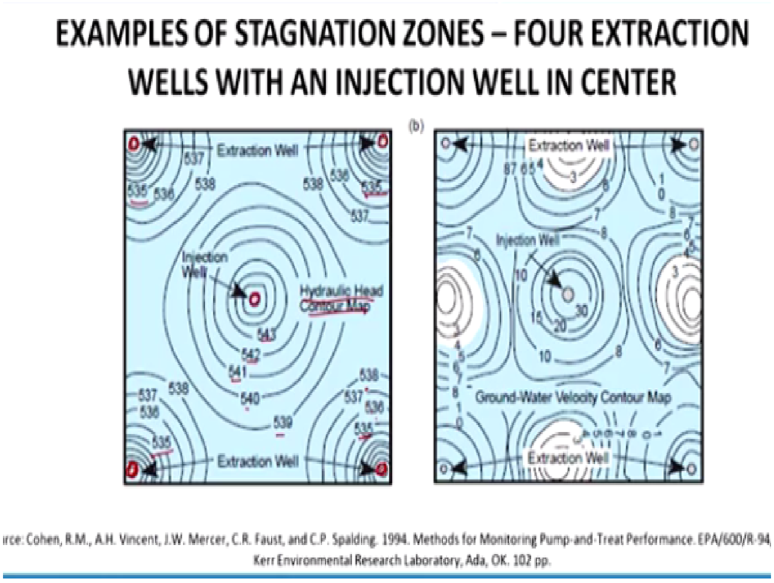

I believe it will be much more apparent in this picture, so what do we have here; we have the hydraulic head contour map here for example, 543, 542, 140, 39, decreasing towards 535, let us say, right, 535, 535, 535, so what do we have here; we are going to have extraction wells here let us say or the stagnation zones let us say towards which the groundwater is typically flowing and an injection well here where you have relatively higher head let us say, right.

So, what is it that I am trying to promote; I am trying to put in water where it would naturally flow towards the extraction wells again, thereby you know taking the contaminant along with it let us say, right, so again in this case we have the velocities but again, typically you know looking at the heads and such and then obviously, groundwater velocities or the contour maps will let you know where to place the injection wells and the extraction wells let us say, right.

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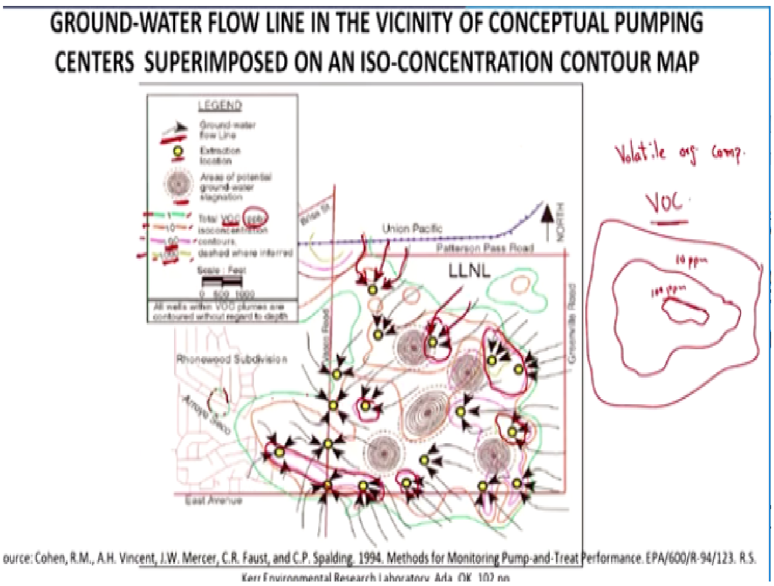

So, here we have an actual scenario and that yeast which is contaminated by volatile organic carbon; volatile organic compounds not carbon, pardon me which we refer to as VOCs, toxic and sometimes carcinogenic too depending upon the type of compound, so here we have 3 or 4 cases we need to look at before we understand the figure, here the flow line; groundwater flow lines, we have the extraction well locations.

We have what do we say potential ground water stagnation zones let us say and here we have the plume limits let us say for example, until now we have typically looked at let us say only when we talk about plume boundary, we looked at only one particular boundary or such but obviously, when we talk about boundary, we are talking about a plume you know which contains let us say concentration of compound or a certain concentration of compounds.

So, for example if I want to; if this plume pertains to 10 ppm concentration, 1 ppm concentration will obviously plume will obviously cover a wider area and 10 or you know 100 ppm or such a relatively lesser area, right so that is something that we have here again and that we have a plume boundary for 1, 10, 100 and 1000 ppm I guess you know and what we have here now?

So, here you have different zones of contamination with respect to the green line which is only for ppm let us say and then orange, pink and again let us say light green, so here typically the way that these particular extraction wells have been set up, they have been trying to limit what do we say or extract water relevant to the 100 and 1000 ppb I guess pardon me, not ppm, ppb or parts per billion contaminated VOC groundwater I guess.

So, as you see here what are the major areas that we are trying to look at; this particular area and certainly with this particular light green here, let me locate that here I guess, here we have that particular light green area and again this 100 ppb contours I guess right, so we are trying to design our particular or design our particular extraction system let us say in such a way that I am capturing all the contaminant plumes that would be pertinent to a relevant to 100 and 1000 ppb.

And thus as you see here as would typically be the case you have localized groundwater flows let us say, here you see this pathway for the groundwater flows and here again you see this different particular pathway here right, so depending upon site conditions let us say and the extent to which you have what do we say non-homogeneous contamination let us say which is the case here, we need to go for what do we say a relatively more complex, what do we say kind of placement of the system rates that is something that we see here that is one particular drawback.

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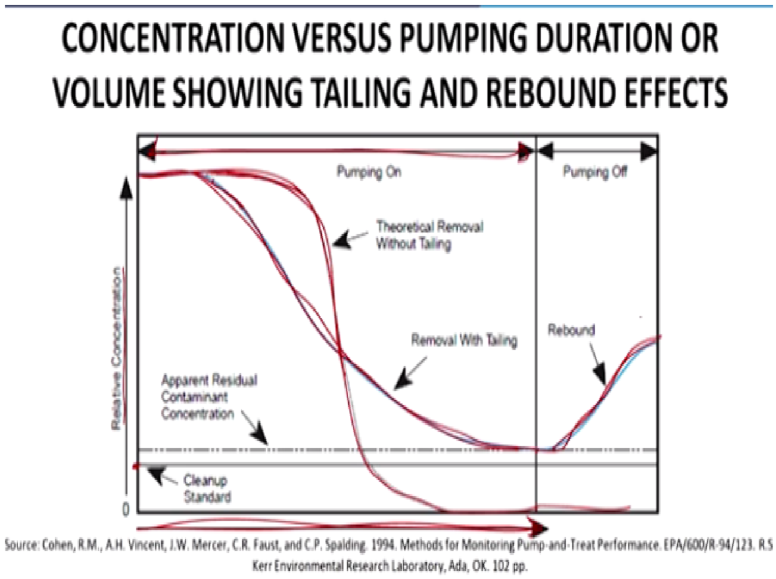

And the major drawback here is that you know the profile that we are going to view which is what we are going to look at now due to some particular cases let us say is going to be widely different from one compound or the other and one kind of aquifer media to the other and let us look at what we have here. So, this is what we have here in the sense that we have on the y-axis we have relative concentration of the compound.

And we have the standard to which we want to treat it and we have the extent of what do we say time required here let us say or time on the x-axis let us say, so what is the ideal behaviour let us say; ideal behaviour would be such that I turn on or start pumping, I start pumping water out and once all this containment plume is removed, the concentration of the relevant compound in the water should be almost 0 or you know within the standard.

So, where is that particular theoretical removal that is what I have here, so this zone we have pumping on let us say, so almost all the contaminant has been removed let us say at this phase and then the contaminant concentration in the water should be almost 0, let us say and here pumping off you know you should not see any further contaminant concentration in the groundwater but that is not going to the case.

You are going to have first this kind of a behaviour, you are not going to have sharp decrease here, you are going to have this kind of a tailing behaviour let us say, tailing behaviour and then even after stopping the pumping, you will increase; you will again see an increase in the conditions or the ground water contaminant concentration, I guess right, so why is that and how does it affect the efficiency of your pump and treat?

This is; these are questions that need to be asked, then again looked at before you choose the option for pump entry, so this is an aspect we are going to talk about in a bit more detail in the next class and do some or look at some math in this regard I guess, right, so with that I will end my session for today and thank you.