Environmental Remediation of Contaminated Sites

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Lecture – 11
Remediation of contaminated Ground Water Plume Containment

Hello everyone, so again welcome back to the latest lecture session, so we have looked at different aspects until now, I think looking at or summarizing what we have been up to I think we looked at risk assessment in greater detail and then the relevant law and the regulations and then the aspects related to the TSDF operation and so on let us say, right and then we are now going to move on to the next major aspect.

And what is that about that is about the remediation of contaminated groundwater, right so, in this particular set of you know, lectures I guess we are going to look at how do I remediate particular contaminated or a site with contaminated ground water let us say, right, so there are different options some of which we are going to look at and such but before I go further, let us say I am a layman and I have you know, no clue about how to go about that.

And there are obviously different sources of information out there, so how do I choose from one particular method over the other when I am trying to look at remediation of or trying to choose which particular way or how do I go about remediating a particular contaminated site let us say, how do I do that?

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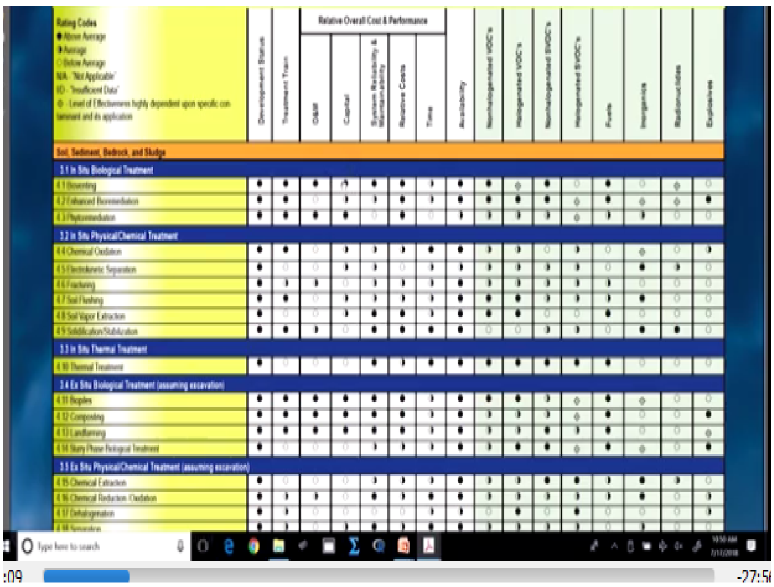

I have this particular treatment technologies screening matrix developed by the EPA if I am not wrong okay, the US EPA anyway, so this gives you an overview of the different technologies available for different kinds of contaminants let us say and in which cases or in which particular aspects does it fair better in which aspects does it fair poorly as in does it fair better in its efficiency to treat it; treat the particular contaminant of the you know in the groundwater let us say.

Or does it fair better in terms of cost, does it term; does it fair better in terms of practicality or practicality or feasibility of application and so on, so let us just try to look at that or what we have in this treatment technologies screening matrix let us say. So, here we have relative overall cost and performance operation and maintenance capital cost reliability and maintainability relative cost and timeline and also obviously, development status as in is it at mostly at the research level.

Or has it been put in practice since quite some time and so on, development status treatment trained and availability I guess and then out here, we have the different types of compounds, have the non-halogenated volatile organic compounds have the halogenated volatile organic compounds and so on, right and fuels as in hydrocarbons and so on petrol, diesel and such inorganic compounds, radionuclides, explosives and so on, right.

So, I have different classes of contaminants here, right different classes anyway and out here, I have different types of treatment techniques, so here I have in-situ biological treatment, in situ physical and chemical treatment, thermal treatment and so on, so let us say I have a particular case of you know, underground storage tank let us say as in our petrol bunks and such, I mean where do they store the petrol and diesel now.

You have this underground storage tanks lined let us say storage tanks and typically, from experience we know that they you know over time and also due to the poor quality of construction and such you know you have leaks developing in these underground storage tanks at least in Indian context, they are not detected let us say and you have consumable pollution you know of groundwater and soil let us say.

So, how do I go about choosing which particular treatment technique would be you know apt to the particular situation, so here let us say I am concerned with fuels, let us say, okay and looks like which particular technique is relatively better let us say and I guess it does say bio venting, yes and obviously, the relevant costs and such seem to be fine too.

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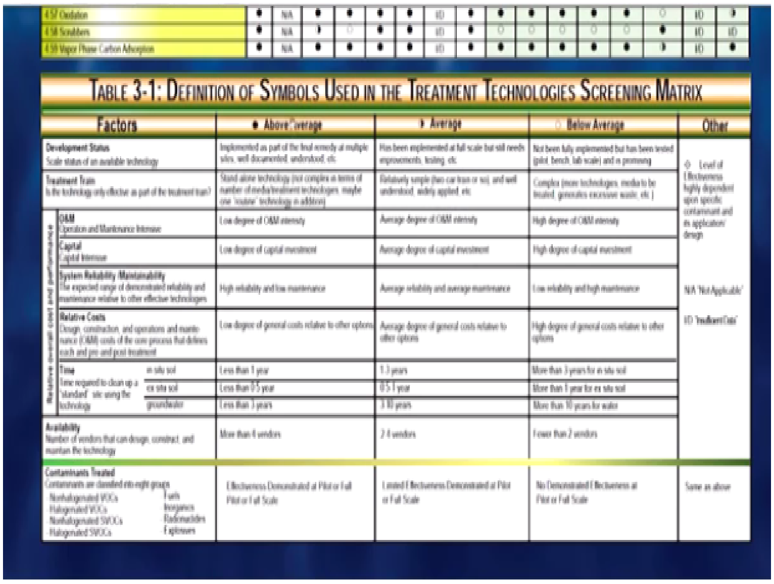

I mean cost and such to understand that I guess we need to look at the legend here right, so we have above average performance right, average performance, below average and so on and again we have the reasons why its particular, this particular method is listed as above average, average or below average, different aspects being let us say for example, in treatment train is the technology only effective as part of the treatment train or a standalone.

For example, does it need to be set up in conjunction with other treatment techniques or does it work standalone too, so standalone not complex in terms of number of media treatment technologies maybe one routine technology in addition, right, low degree of operation and maintenance, low capital investment and so on, time required relatively less and so on availability as in there quite a few people who can you know get the job done for you and the effectiveness has been demonstrated in full or pilot-scale.

Again, we just try to look at what you know we need to understand and we have this above average classification I guess, so let us go back to what we have here, let us say and for fuels looks like obviously it does a pretty good job, right and obviously, we are going to look at why, I mean here I am just talking about bio venting or bio remediation and bio enhanced bio remediation obviously, does not or fair as well when compared to bio venting especially in the context of operation and maintenance, right.

Because it is enhanced bio remediation as in you need to put in or unit you have extraneous inputs from time to time and obviously, relevant in monitoring too and in that context your operation and maintain costs are going to be higher and also the capital costs but with respect to fuels, this particular what do we say, summary of all the available literature and knowledge bank out there says that these particular bio remediation in situ biological treatment techniques are pretty good for remediating fuels, right.

So, again one particular way to go about you know, choosing or narrowing down the relevant options, so looking at this screen matrix, you can narrow down the relevant remediation technique or screen the different remediation techniques, so once you narrow down your options to 3 or 4, you can then look at them in greater detail with respect to the actual what do we say, feasibility at that particular site as in site conditions vary, right.

So, obviously you can use this particular matrix to narrow it down to what you are looking at and then go forth for example, if I am looking at inorganics let us say or heavy metals let us say, which particular methodology seems to be better here, now? So, obviously not bio remediation not and has bio remediation and so on let us say and other level of active; I mean I am trying to understand what this particular region means I guess or symbol means.

Level of effectiveness highly depend upon specific contaminates and its application or design, so that is what it means when we have this particular symbol for bio remediation for the in organics or the heavy metals. So, which particular methods can I screen out or screen in let us say or choose when I am looking at remediation of sites contaminated with heavy metals now? I am going to look at electro kinetics operation let us say.

And also soil flushing, flushing the soil, yes that is one particular aspect or solidification stabilization let us say right and in this particular class, we are certainly going to discuss this soil flushing and certification and stabilization let us say and what else obviously, chemical extraction, oxidation or reduction, right again solidification and stabilization but this is ex situ, I believe the other one was in situ, right.

So, in thus in such a manner I can you know narrow down the relevant what do we say options that I have and once I narrowed on the relevant options then I can analyse them in greater detail to see if it is particular; if a particular technique is applicable to my particular site or not, so obviously there are different treatment techniques, what are; let us look at some of them. As we discussed earlier or you know briefly looked at them, we have biological treatments and different classifications between in situ and ex situ treatments for both the biological and physical and chemical treatment.

For physical and chemical, we have chemical oxidation, electro kinetic separation fracturing, soil flushing, soil vapour extraction, these are all aspects we are going to discuss in great technical detail now, solidification, stabilization and so on, right, so we have different such aspects out here right again, ex situ physical treatment and so on, so in particular case let us say you cannot treat it, what can you do; you can you will try to contain the particular waste let us say.

And again for that particular case, they are looking at physical barriers or deep-well injections and so on and how they fair or such compared to the other aspects out there right, so again this is a screening matrix obviously as the you know title indicates, so you can use that to screen out or screen in let us say the techniques that you can consider I guess.

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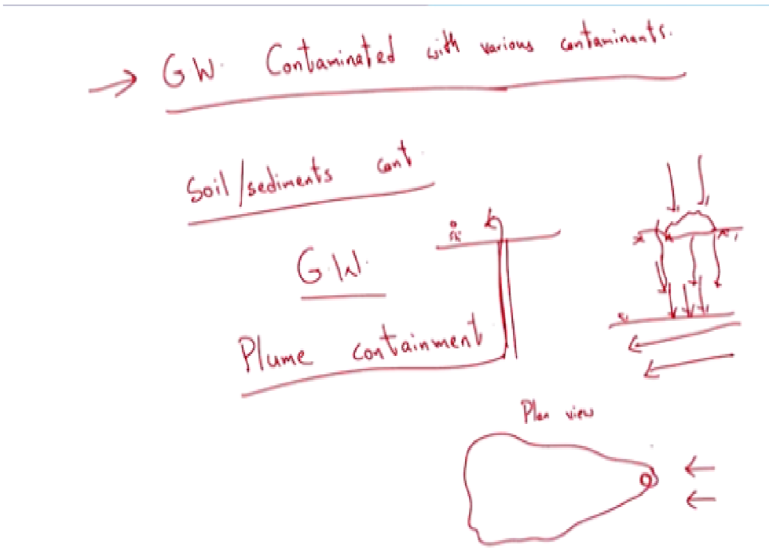

So, moving on let us say, we are now going to obviously start looking at the relevant aspects with respect to contaminated or sites contaminated with or groundwater contaminated with various contaminants, right and then once you are done with this particular set of aspects, we are going to look at soil and sediments which are contaminated and how do I remediate those particular contaminated sites which have what we say now, soil and sediments contaminated I guess, right.

So, 2 different cases or classifications that we are going to try to look at; 1 is when we have groundwater contamination, how do I remediate the site and the other one is when I have soil or sediment contamination, how do I remediate the site so, in that context obviously we are going to look at groundwater contamination let us say, so in that context groundwater contamination let us say, we are going to primarily look at plume containment initially, right.

So, again there are different examples wherein you can have what we say contaminated groundwater let us say, right and in that context I think we also looked at one example at the start of this particular course as in we looked at a particular case in Ghaziabad where I believe we looked at a case where the ground water was contaminated with chromium and there was constable outcry out there, after constable time anyway and health effects, adverse health effects were observed by the relevant population.

And only then, did I think the political and the bureaucratic machinery you know try to you know set the what do we say, trade in motion such that they looked at remediation of that popular contaminated site again, we looked at groundwater contamination in that particular scenario and I think there the case was that we had some industries that looked at what is our involve heavy metals in their particular manufacturing process.

And they did not dispose them in a proper manner or hold them in a proper not proper, scientific manner and thus you had contamination of this particular groundwater with the landfill, I believe whenever you had rainfall and you had what do we say permeation of this particular contaminant what do we say, rainfall with the particular, not rainfall I guess rainfall after contact with the contaminated soil reached the groundwater.

And then you had contamination of the groundwater, right so, for example I believe they had just the chromium piles out here on the surface let us say, land surface and here you have the groundwater let us say and you had rainfall let us say and then through the subsurface and then contact with this particular groundwater, right so, you have contaminated groundwater here and you had the affected population out here let us say.

And they were obviously had boring wells to drain have the water out and they were ingesting the contaminated groundwater and so on and the relevant issues there I guess right, so again moving on we had we did look at one popular case, where they were actually pumping the water out, treating the water and then disposing it in different ways but here before we look at pump and treat, we are going to look at containing the plume as in I have a contaminated what do we say plume.

As in here if I am looking at the plan view, so here is the source of my contamination and groundwater flow in this direction and let us say if this is my contaminated plume let us say, ground water contaminated plume, so rather than treating it or you know pump and treat is one option, I am just going to try to contain it let us say, so that it does not spread to you know larger area and thus leading to what do we say contamination to a wide direction, I guess.

So, I am trying to limit the extent of damage, you can consider this particular case as trying to limit the extent of damage, so how do I go about that or you know look at plume containment I guess right.

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So, if I go through to the next slide here, I have an example of what they were up to; they here their case, it is a case of pump and treat but in the first context, we are going to look at plume containment, before we move on to pump and treat, again this is pump and treat, they are pumping the groundwater out you know treating it or using a reducing agent I think, sulphide to reduce the chromium from oxidation, it is 6 to 3 at chromium at oxidation 3 precipitates out let us say.

And thus they are able to you know remove this particular chromium from that particular ground water, you see this is all the groundwater that they pumped out and this is the treatment train and this particular direction let us say, yes and I think here they were adding increasing the pH I believe maybe and then adding the reducing agent and here coagulation and flocculation out here and so on.

So, we are going to look at the relevant videos in the next lecture but for now I am just trying to give a picture of what you know or what are some of the aspects involved, so once they removed that chromium again, they were dispersing it on land I believe because they could not treat it to the extent that they could re-inject the water into the groundwater, right or into the subsurface.

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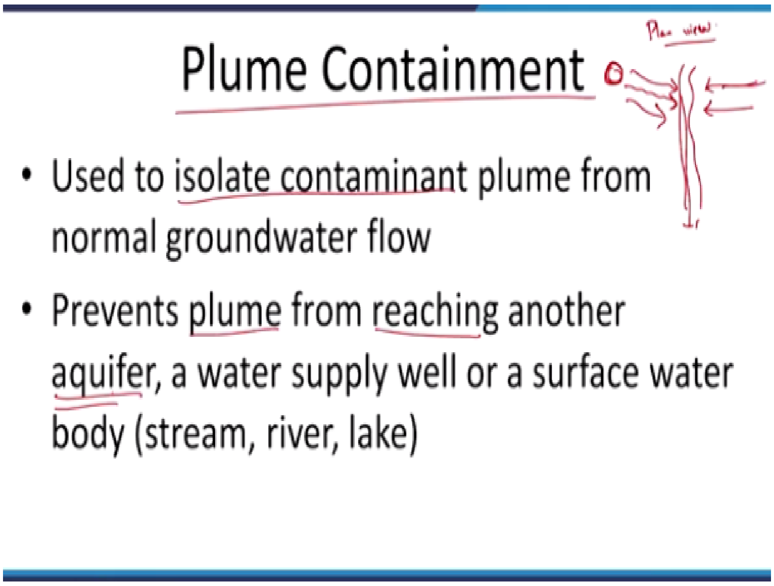

But here we are now looking at only plume containment for now, right so again, what are some of these objectives for plume containment obviously, I am trying to isolate the containment plume from the normal groundwater let us say, if they release, if I observed this particular contamination relatively early let us say, what am I going to do; I am going to try to isolate the contaminated plume from the particular groundwater let us say.

And also prevent the plume from reaching an aquifer as in let us say, if there is a stream nearby let us say, right in general, how is it going to be the case, so if I have a stream here and it is flowing in this direction and if I have a contaminated site here, this is the plan view again, plan view or top view let us say, typically groundwater flow direction would be towards that particular aquifer let us say or the stream permits surface water body.

I am just trying to look at try to understand how you have your particular what do we say digital elevation model out there let us say, so here I am trying to what would happen if I let this contaminated groundwater reach this particular or reach of this surface water body, then I would have you know the containment traveling over a wider extent of area let us say or distances, pardon me and then contamination over a wider extent let us say, right.

So, in that context obviously I want to prevent this particular plume from reaching another aquifer let us say or water supply, well or surface water body in this context we looked at the stream I guess right, so there are different objectives in mind when you are looking at plume containment.

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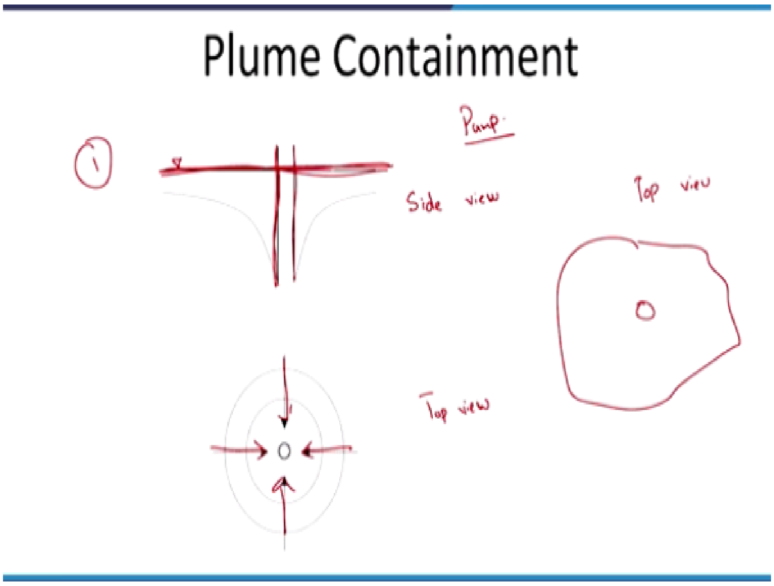

So, in that context let us look at what we have here, so how do I contain a plume you know there are different aspects as and I can put in barriers that is something we are going to discuss later, as and I can have barriers around that particular, if feasible around that particular contaminated area and so on, so that there is no transport of the contaminant from that particular site to the groundwater and so on.

But for example, I have a particular contaminated plume and did not want to let it you know migrate further, so what can I do; I can pump it out let us say and what is the issue here let us say, so here let us say this is a particular case we are going to look at and this is an ideal case obviously this is the what do we say groundwater level let us say, right and here is my pump let us say or well let us say and this is the drawdown obviously that I see here.

And I am going to pump the groundwater out and this is what you would observe here, this is from the side view obviously, right and here I have the top view, so here I have the top view and obviously, if this; for this case all the groundwater would obviously you know flow towards the particular well, so as and if this is my contaminated plume, I can just plug one in the center and start pumping water out, this is again the top view let us say.

I can start pumping water out and over time let us say or after a certain period of time depending on the rate of your pumping let us say you are going to you know capture the entire plume but if you take a couple of seconds to try to look at this particular scenario and try to understand what the issue is; I guess you will see that it does not obviously reflect what would be the case out there in on the field or in the nature let us say, right.

Why is that? Obviously because you know groundwater in this particular case as we see here let us say if I look at the hydraulic gradient you know it is not going to be obviously flat let us say, right, you are always going to have a gradient now, right again you have a terrain; natural terrain right of the subsurface or earth let us say and your ground water flow obviously direction typically tries to follow that particular terrain let us say depending obviously upon that particular aquifer characteristics and so on let us say, right.

Thus, what we are trying to understand is that there is a ground water flow which is not the case that we considered here and there is going to be hydraulic gradient, right so that is what we have here.

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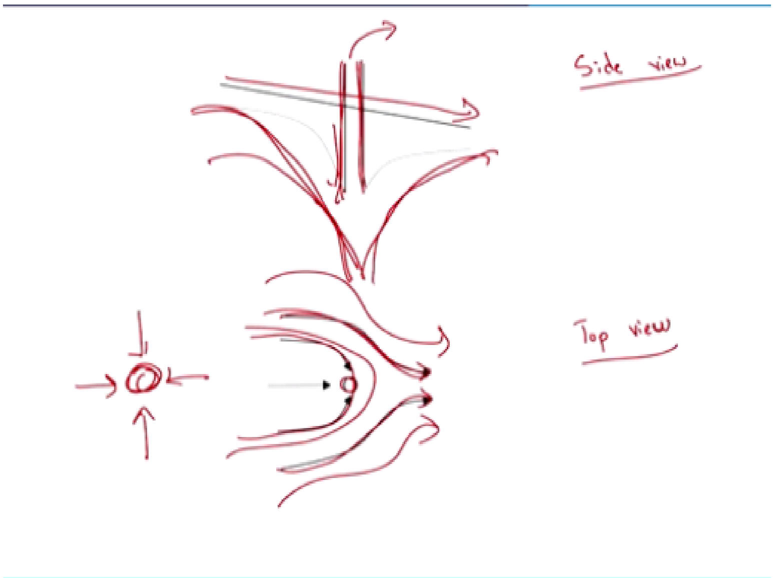

So, obviously if this is the hydraulic gradient let us say and now my ground water would flow in this particular direction let us say, so now if I plug my pump in now let us say and this is obviously the side view and this is the top view, right so, if I plug it in now, let us say or plug my pump in now and start pumping it out, so unlike the previous case let us say where you have symmetrical what we say draw downs and such that is not going to be the case here.

And especially, the relevant aspects will be captured when I look at this particular top view, so when compared to other case, where all the plume was going to travel towards that particular pump, you are going to have flow lines that are not going to be captured by this particular pump here, right so, there is only a particular zone of influence for that particular pump let us say and there are constable flow lines that will not be captured by this particular pump let us say, right.

So, what are the different aspects that I need to consider now; I need to consider first how many pumps do I put in let us say, what are the locations of these pumps let us say and what is the spacing between this pump and finally, what is the rate of pumping from this particular pump let us say, so these are the aspects that there are particular design for and we are going to go forth and look at that.

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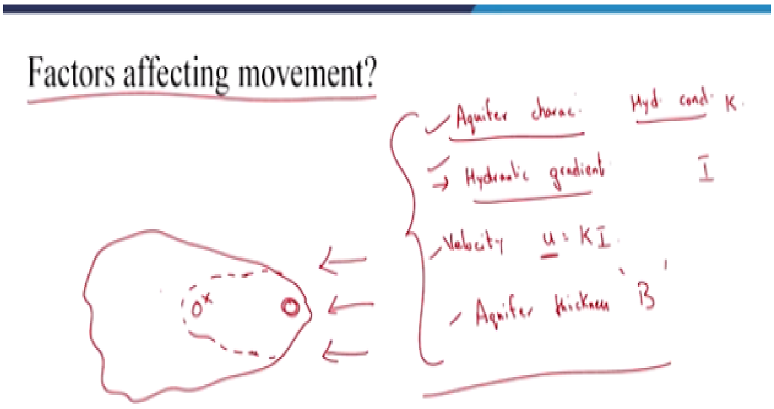

Again, before we go further there, we need to look at what are the factors affecting the movement of this particular contaminated groundwater now, let us say, what are they now? So, obviously aquifer characteristics let us say, characteristics let us say and typically, we are considering what do we say we are considering hydraulic conductivity I guess let us say, right, we consider hydraulic conductivity let us say, right.

And we are consider with the energy or the hydraulic gradient let us say or the energy gradient let us say, right and we are considered with the slope, pardon me not the slope I mean, slope is considered out here obviously, we are considered with the speed let us say that = KI, speed of groundwater flow let us say, groundwater flow velocity and we are also concerned with aquifer thickness I guess, right.

So, typically these are the factors that would what do we say affect your; you know, movement of the particular contaminated plume again, what are the hydraulic conductivity? Again ease with which let us say you know your particular water let us say, or contaminated water can flow through a particular media let us say and then hydraulic or energy gradient or the slope of that gradient let us say or a slope energy slope I guess, gradient is slope.

And velocity which is K times I and then aquifer thickness let us say, these are the aspects which we typically need to consider here. So, how do I go about you know using this information and try to come up with an estimate about let us say the placing of the wells, number of wells and so on let us say, for example let us say, you after looking at or considering a different number of monitoring wells have this particular what do we say piece of information.

As in you know that your contaminated plume is this and your particular groundwater flow direction is this, you have the relevant aquifer characteristics, hydraulic gradient, velocity and aquifer thickness but how do I know where to place the rest obviously, not in the center, let us say, why is that because then I might not end up capturing all this particular portion, I might only capture only this particular portion, I might not capture all this plume.

So, the key is to understand let us say or try to come up with a way to be able to scientifically come; what do we say, determine the number of wells, location of wells, spacing between the wells and the rate at which you are going to pump out the relevant water from these wells, right so, in that case obviously you can look at groundwater or develop groundwater models, mathematical models but typically that is time consuming and such let us say and is resource intensive.

So, there are obviously there are other what do we say time tested metals; methods, pardon me that people look at.

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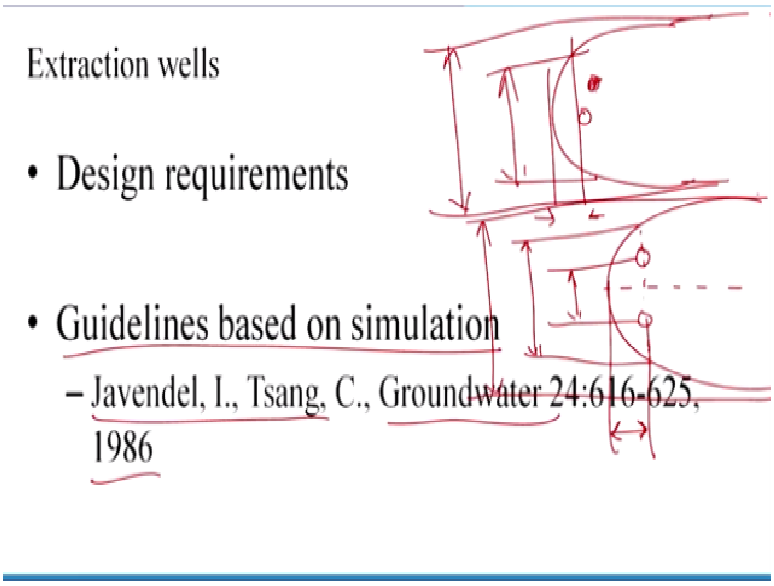

So, one approach is obviously the guidelines based on simulation from Javendal et al and published in I think groundwater volume page number and year let us say right, so let us just I try to look at what they have here and let me see where that is that is out here.

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Capture-Zone Type Curves:
A Tool for Aquifer Cleanup

by Iraj Javandel and Chin-Fu Tsang[a]

Javendal et al; so what did they look at capture zone type curves, a tool for aquifer clean up.

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Major questions to be answered for the design of such projects include the following:

1. What is the optimum number of pumping wells required?
2. Where should the wells be sited so that no contaminated water can escape between the pumping wells?
3. What is the optimum pumping rate for each well?
4. What is the optimum water treatment method?
5. Where should one reinject the treated water back into the aquifer?

The purpose of this paper is to introduce a simple method for answering four of the above questions which are of hydraulic nature.

First, we shall develop the theory and give a series of sample type curves which can be used as tools for aquifer restoration. Then, the procedure for application of the curves will be given in answering the above questions.

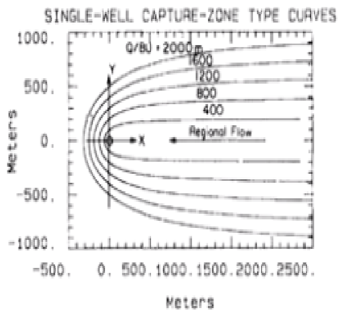

Fig. 1. A set of type curves showing the capture zones of a single pumping well located at the origin for various values of (Q/BU).

equation (1) is the ratio (Q/BU) which has the dimension of length (m). Figure 1 illustrates a set of type curves for five values of parameter (Q/BU).

So, they looked at simulations for this let us say and this is what you know I guess, this is one of the particular cases, so here we have a set of type curve showing the captured zones for a single pumping well located at the origin for various values of Q/BU let us say, Q is the flow rate, B is the aquifer thickness, U is that velocity of groundwater flow and let us say this is the groundwater flow direction.

And so, they say that they can come up with a weight to estimate these particular capture zone or this particular capture zone.

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are interested in separating the capture zone of those wells from the rest of the aquifer. We shall start with n = 1 and expand the theory for larger values of n. The following development is based on application of the complex potential theory (Milne-Thomson, 1968)

Case 1, n = 1

In this case for the sake of simplicity and without losing the generality, we shall assume that the pumping well is located at the origin of the coordinate system. The equation of the dividing streamlines which separate the capture zone of this well from the rest of the aquifer is

$$y = \pm \frac{Q}{2BU} - \frac{Q}{2\pi BU}\tan^{-1}\frac{y}{x} \qquad (1)$$

where B = aquifer thickness (m), Q = well discharge rate (m^3/sec), and U = regional flow velocity (m/sec). One may note that the only parameter in

where y_D = BUy/Q, dimensionless, and

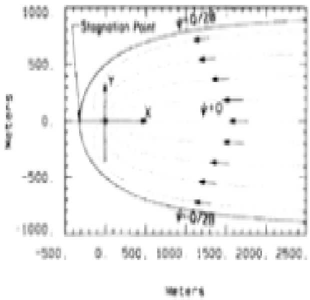

Fig. 2. The paths of some water particles within the capture zone with (Q/BU) = 2000, leading to the pumping well located at the origin.

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So, let us see what they have here let us say, right and obviously, they have this particular stagnation point right, if this is my pumping well or location of my pump let us say or the well, I am going to have a stagnation point out here yes, I am going to have a stagnation point, so this particular boundary is my particular or determines the extent to which the contaminated plume can be captured by the well placed at this particular location.

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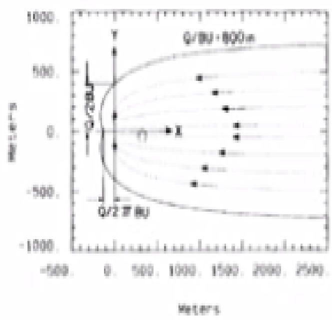

Fig. 4. Capture zone of two pumping wells properly located to prevent any leakage from the space between the two wells.

$$\phi = Ux + \frac{Q}{4\pi B}\left(\ln(x^2+y^2) + \ln[x^2+(y-d)^2] + \ln[x^2+(y+d)^2]\right) + C \qquad (13)$$

$$\psi = Uy + \frac{Q}{2\pi B}\left(\tan^{-1}\frac{y}{x} + \tan^{-1}\frac{y-d}{x} + \tan^{-1}\frac{y+d}{x}\right) \qquad (14)$$

Here also, when d is large, fluid will escape between the wells and three stagnation points will be formed, one behind each well. Keeping the rate of discharge of each well constant and reducing the distance between each pair of wells, eventually a position will appear where no flow will pass in between the wells.

Again, to find the position of the stagnation points one must set the derivative of W in equation (12) equal to zero:

$$\frac{dW}{dz} = U + \frac{Q}{2\pi B}\left[\frac{1}{z} + \frac{1}{z-id} + \frac{1}{z+id}\right] = 0 \qquad (15)$$

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So, how do I go about you know getting that things done or you know getting my particular aspects again different aspects, so here we look at a different case when I have two wells I guess and the spacing needs to be Q/2BU, let us say not spacing by guess from the or width of the capture zone let us say from the center line Q/BU and from the and where does it need to be located; it needs to be or this center line between these two wells needs to be located at distance of Q/2 pi BU let us say, let me try to put that up in here I guess, right.

So here they looked at different cases, one for one pumping well they came up with that particular zone of influence let us say, right and they calculated relevant distances, this is one particular distance that they calculated and also this captures zone width and also capture zone width for downstream I guess, right so, these are some of the aspects that they you know came up with or simulated I guess.

And then they also looked at simulation for what do we say two wells and if this is the center line here and then again, they were able to calculate the spacing required between the two wells, the capture zone width at the center of the wells, spacing from the center line to the stagnation point because that is how you know where to locate the wells and again, capture zone width for upstream of the or for downstream of the particular contaminated plume I guess, right.

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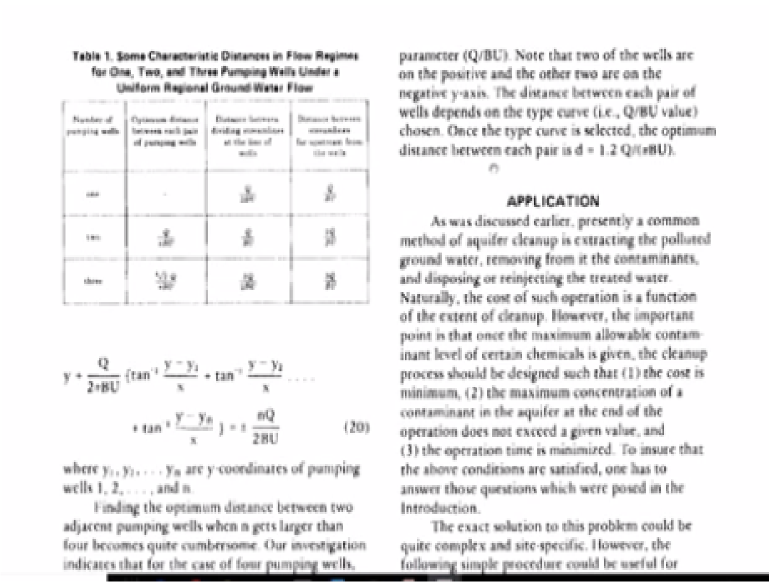

Table 1. Some Characteristic Distances in Flow Regimes for One, Two, and Three Pumping Wells Under a Uniform Regional Ground-Water Flow

Number of pumping wells	Optimum distance between each pair of pumping wells	Distance between dividing streamlines at the line of wells	Distance between streamlines for upstream from the wells
one	-	[illegible]	[illegible]
two	[illegible]	[illegible]	[illegible]
three	[illegible]	[illegible]	[illegible]

$$y + \frac{Q}{2\pi BU}\left(\tan^{-1}\frac{y-y_1}{x} + \tan^{-1}\frac{y-y_2}{x} \ldots + \tan^{-1}\frac{y-y_n}{x}\right) = \pm\frac{nQ}{2BU} \quad (20)$$

where $y_1, y_2, \ldots y_n$ are y-coordinates of pumping wells 1, 2, ..., and n.

Finding the optimum distance between two adjacent pumping wells when n gets larger than four becomes quite cumbersome. Our investigation indicates that for the case of four pumping wells, parameter (Q/BU). Note that two of the wells are on the positive and the other two are on the negative y-axis. The distance between each pair of wells depends on the type curve (i.e., Q/BU value) chosen. Once the type curve is selected, the optimum distance between each pair is d = 1.2 Q/(πBU).

APPLICATION

As was discussed earlier, presently a common method of aquifer cleanup is extracting the polluted ground water, removing from it the contaminants, and disposing or reinjecting the treated water. Naturally, the cost of such operation is a function of the extent of cleanup. However, the important point is that once the maximum allowable contaminant level of certain chemicals is given, the cleanup process should be designed such that (1) the cost is minimum, (2) the maximum concentration of a contaminant in the aquifer at the end of the operation does not exceed a given value, and (3) the operation time is minimized. To insure that the above conditions are satisfied, one has to answer those questions which were posed in the Introduction.

The exact solution to this problem could be quite complex and site-specific. However, the following simple procedure could be useful for

So, again moving back here, so again three wells, they considered three wells again similar cases, so based on that they came up with the general case and here we have the relevant information and what do we have here, we have the number of pumping wells; 1, 2, 3 and number let us say, optimum distance between each pair of pumping wells distance between the pumping wells, distance between dividing streamlines at the line of the wells let us say or the central line.

Distance between stream lines for upstream from the wells let us say, so let us try to understand this and in our context let us say.

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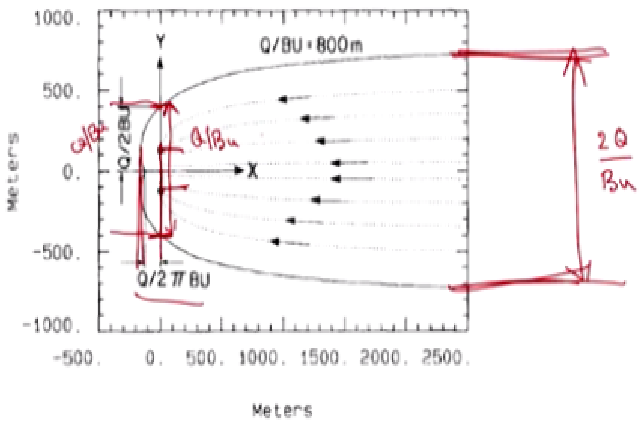

So, here we have the case for 2 wells, so what do we have here; we have the distance at the center line let us say of the wells from the center let us say and this is Q/2BU, so obviously this particular distance will be Q/ BU and we also have spacing for these two wells that is also given and also we have the spacing from the center line to this popular stagnation point that is Q/2 pi BU and also we have this particular width, pardon me, we have this particular width and the capture zone of this particular width.

This is called obviously captured zone for downstream or upstream let us say depending on which context you are looking at so, capture zone for upstream I guess let us say, so obviously these are the 4 major aspects.

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Guidelines

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	1.17 Q/πBu	0.5 n Q/Bu	n Q/Bu

Let us look at the table, so the spacing between the wells for 1 well, 2 wells, 3 wells, 4 wells and n number of wells; Q/ pi BU and so on let us say, 1.26, 1.2Q by and 1.1 n Q / BU, I guess let us say, right or 1.1 pardon me and here capture zone width at the wells 1.5Q/BU and let us try to understand that and Q/BU for two wells, as we looked at that here the capture zone width at the wells is this particular distance, captured zone width at this particular center line I guess.

And then capture zone width for upstream and that is this particular case and what is it for two wells; its 2Q/ BU I guess, so again this is based on 2Q/BU and here this distance is Q/BU let us say, so how will this help me; so I can understand let us say not try to understand, pardon me try to analyse a particular contaminated plume and then try to look at the number of wells that are going to be looked at what do we say required to be able to capture that plume line.

And again, for this though I need to be able to look at the threshold drawdown that I am going to look at as in how do I decide let us say if I should place just one well at a high rate of pumping or 2 wells with relatively lower rates of pumping and so on and so forth. How am I going to be able to determine that particular aspect let us say, it is going to be determined based on the acceptable level of drawdown.

As in there is a maximum drawdown that is you know you can live with as in you are starting pumping here let us say you know, you have particular drawdown here obviously, right and if I increase the rate of pumping obviously, my drawdown is going to be higher let us say, I mean I guess I am you know relatively poor in my drawing, so obviously at a particular pumping rate this is my drawdown and at higher pumping rate, this is my drawdown, right.

So, obviously there are thresholds to this particular drawdown as and if it is a confined aquifer or let us say depending upon groundwater regulations in that area let us say, you do not want to affect the groundwater movement such that the other people will be affected, so you are going to have to consider those aspects and take that into account let us say, so to get that into account I need to be able to estimate the what do we say draw down.

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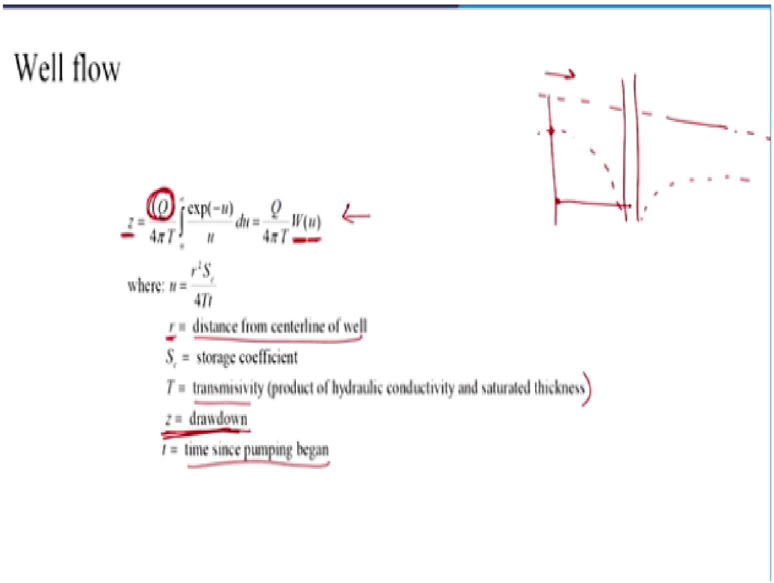

And for that I have particular again what do we say, set of calculations, so let us look at that so, I have draw down here that is going to be calculated based on a particular flow rate right, so what am I going to do; I am going to assume or how do; what is the approach here let us say, I am going to assume let us say a particular case as and I am going to start with one well and I am going to assume particular flow rate and then go ahead and calculate the relevant drawdown and see if that is acceptable or not let us say, right.

So, here I have Q let us say and then I can calculate drawdown accordingly, what are some of the other aspects I need to have though, I have r; distance from centerline of the well to the location at which I am considering as in if this is my particular well and this is my drawdown let us say, groundwater flow is in this direction obviously, so r would give me an idea about what is the distance from the center line of the well to the point at which I am considering this particular drawdown I guess, right distance from center line of the well.

And storage coefficient again act for property, transmissivity, product of hydraulic conductivity and saturated thickness, right and drawdown which is what I am trying to calculate and time since pumping began and this is the well function, I think people in hydraulics should be you know should hopefully try to recognize that.

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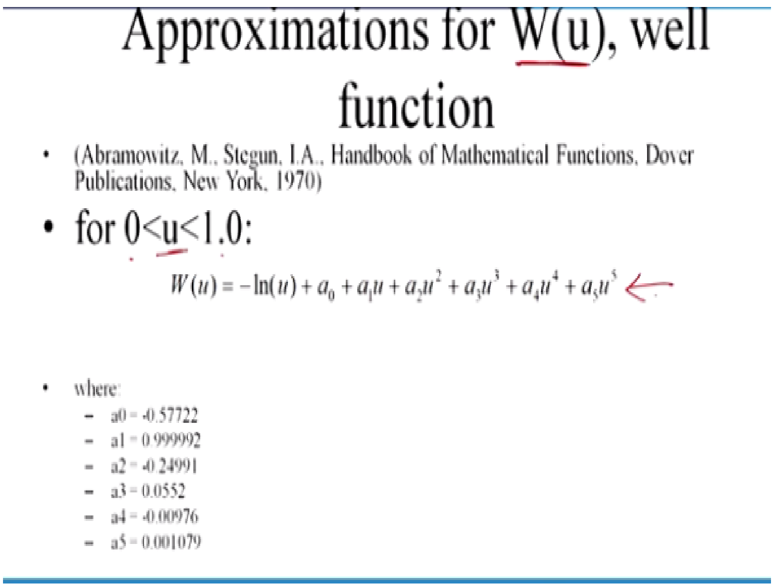

And well function obviously, again with what do we have here, approximations for well function, if u is between 0 and 1; we have a particular way to calculate well function.

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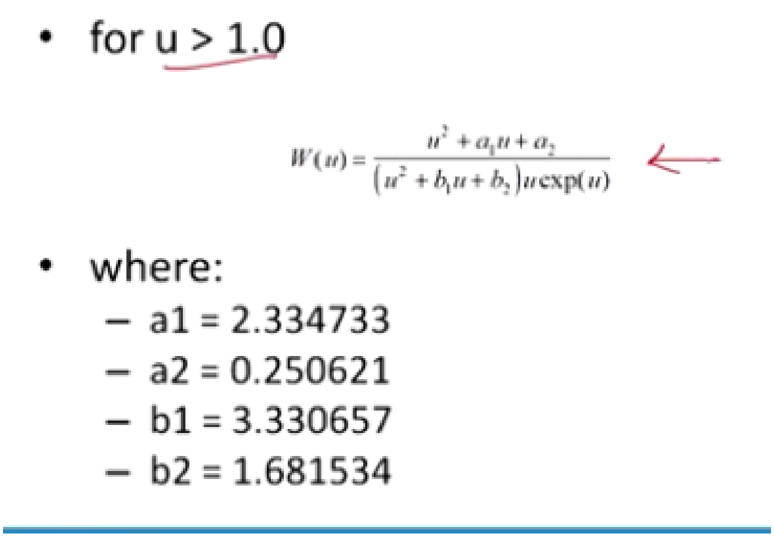

If u is > 1, we have another particular way to calculate well function and then we can more or less obviously calculate the drawdown I guess, so if this drawdown is within the acceptable limit, what would we do; we should say that the particular scenario is what we say meeting the relevant what do we say thresholds with respect to drawdown the plume captured boundary and so on.

But if it exceeds or does not meet one of these criteria obviously, I need to increase the number of wells and then what do we say again look at the relevant flow rates and so on and then go ahead and calculate the relevant aspects I guess, so I guess I am running out of time, so I will wrap it up for today and then we are going to look at the relevant aspects in greater detail and maybe an example in the next session I guess, right and thank you for today.