Environmental Remediation of Contaminated Sites

Prof. Bhanu Prakash Vellanki
Department of Civil Engineering
Indian Institute of Technology - Roorkee

Lecture 01
Introduction

Welcome to the latest lecture session on the course titled environmental remediation of contaminated sites. So this being the first lecture session, I am sure the students out there who are looking for different courses, are yet to decide upon which courses to enroll in and which courses not to enroll in, right, so obviously depends upon the matching interest and such. So to help or aid in you guys coming to such a decision, I am going to have the first 2 lecture sessions to be introductory sessions, right.

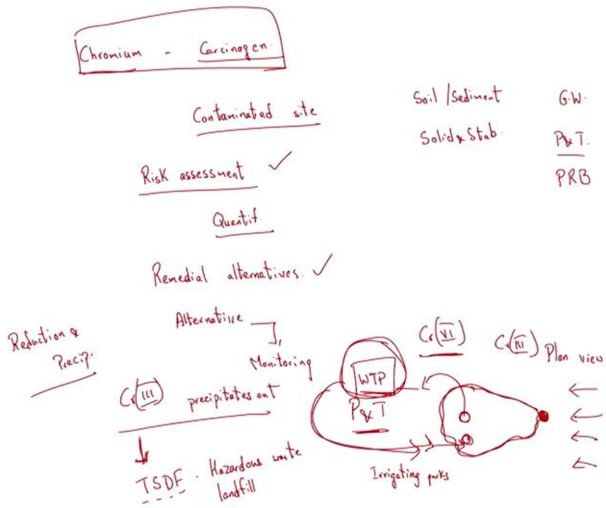
I will introduce let us say a case study, which will demonstrate the relevant aspects we are going to discuss throughout the course, right, and then in the second session I am going to talk in detail about the relevant aspects we are going to cover. Again, this course is going to be relatively technically challenging course, right, and you will have a lot of quantitative content to look at and at the end of this course you should be able to both qualitatively and quantitatively analyze and come up with the relevant recommendation let us say for a remediating a particular contaminated site, right.

So, obviously again what are we talking about here? As the name indicates, or as the course title indicates, it is environmental remediation of contaminated sites. It is slightly self explanatory, right? So here we have a contaminated site, let us say as in there has been a release or spill of a contaminant or a toxic compound or a carcinogen right into the environment, be it either into the air or land or soil or groundwater. So in this case what actions do you need to take, if you need to take any action right.

First obviously you need to analyze, let’s say, whether any action is required or not right. For that obviously what do we need to do, we need to connect risk assessment ideas I guess. Based on that, you are going to move on to look at remediating the contaminated sites. So you are going to look at different options and then we need to come up with the relevant recommendations here. So let us look at briefly what we are talking about.

So for example let us say I am going to take the example of let us say site that was contaminated with chromium.

(Refer Slide Time 02:31)



We have a contaminated site near Ghaziabad I believe right, and there we have an industrial estate and this is not uncommon. India being you know, slowly transitioning from an agricultural economy towards an industrial economy right we have more and more of these industrial clusters within proximity of human clusters or densely populated areas too.

So in general let us say the background here is that we have a lot of such industries in this particular place, Ghaziabad, and they were involved with ball bearings or such and the major industry was involved with production of fans, and in this context looks like considerable heavy metals were released into the subsurface and obviously I guess this was the case when the population density was relatively less and also the regulations, and more importantly the enforcement too was not stringent right.

But obviously with increasing population density right and also with increasing awareness let us say and also maybe due to greater contamination at that particular site, there was an outcry I believe around a decade ago and then the relevant regulatory agencies looked at the relevant aspects and they noticed that heavy metal concentrations were remarkably high, specifically for chromium.

This can also be a carcinogen to my knowledge. So we have this particular contaminated site here and what is it contaminated with, it is contaminated with chromium, so again legal battles and so on and so forth and finally I believe the court asked the major industry out there right or laid the blame on the major industry or the largest industry out there and asked them to remediate the site and go ahead with its particular remediation I guess right.

So in that context obviously what needs to be done or how do we need to go about let us see. Let us look at what needs to be done and what was done and maybe you know compare the 2 scenarios out there right. So obviously let us say you have a contaminated site right. So there has been a spill or release of a toxic or a carcinogenic compound. So in this context though before I try to remediate the particular site which obviously involves resources, time and money right, I need to first quantitatively assess if this particular remediation is necessary. So how do I go about that, I need to come up with risk assessment I guess.

I need to first conduct risk assessment as in let us say a particular manager or let us say the relevant officer out there cannot take a management decision based on let us say saying that okay, risk is high, low or not so low because they are subjective terms. So obviously he needs to have what to we say members at his disposal that will obviously provide greater clarity to him about the need for remediation and the type of remediation that is required right.

For example, there are different pathways as in is it the soil that is contaminated or is it the groundwater that is contaminated or surface water that is contaminated and if so to what extent are these different pathways contaminated and so on and then what is the risk associated with ingesting this groundwater or coming in contact with the soil through the relevant path and such let us say. What are the risks associated with ingesting the soil or ingesting the water or coming in contact with the soil or so on right.

So once you identify the risks associated or relative risks associated with each of these pathways right, you, as in the manager, can come up with choosing the best options out there depending upon the limited resources right. Obviously in an ideal case scenario you are going to have unlimited resources, but that is never going to be the case. So with the limited chunk of money out there or resources, let us say you, are going to decide let us say what is more feasible right and what is more important, and again you need to look at the timelines too. In that context, obviously risk assessment is going to help you pin down the relevant aspects and obviously cut out let us say any ambivalence on the part of the particular industry or such. As in let us say the industry personnel could, in general, they try to shirk from their responsibilities. Usually it is a polluter pays principle. Again, first you are going to conduct risk assessment right and in this context you are going to come up with quantifiable risks right and then you are going to move further.

So once I identify the contaminants or you know hazardous compounds and then quantify the relevant risks and the pathways right, I am going to choose a remedial option. So in general I am going to look at remedial alternatives and then I am going to look at different aspects right as in cost, again feasibility, right and the ease of getting these options on to the ground let us say or you know actually constructing them and implementing them, operation and maintenance cost again obviously right.

And obviously the most important aspects the level of attenuation towards these particular remedial measures or the level of attenuation that can be brought about by these remedial alternatives or measures. So based on that let us say we are going to choose 1 particular alternative and go forth with that and obviously look at monitoring from time to time, right. So in this course, what aspects are we going to cover in detail? Certainly risk assessment and then in detail analysis of what are the different remedial alternatives out there.

As in let us say we are going to look at 2 primary aspects as in contaminated soil or sediments, right and contaminated groundwater. So we are going to look at different cases right of contamination of soils and sediments in 1 particular section in the second half of the course and in the first half of the course we are going to discuss how do we remediate different scenarios of contaminated groundwater right. So there are aspects let us say like pumping and treating right.

We are going to discuss these in detail in the second session but you know I am just going to introduce the topics out here and then PRBs, permeable reactive barriers right, for example here we have solidification and stabilization right so on and so forth right. So we are going to analyze and understand each of these treatment options in great detail right. So before I go further, we are still talking about this particular chromium contaminated site.

Looks like it was spread over 3 square kilometers let us say and here let us say the source of contamination is out here right, let us say this is the plan view. This is the plan view and let us say this is the source of contamination out here and let us say this is the groundwater flow direction here. So first obviously what studies do we need to conduct here? We need to get an idea about the groundwater flow and the aquifer characteristics and so on.

So once that was done, an estimate about or model about the contaminated plume, this is the boundary of this particular contaminated plume for a particular concentration needs to be estimated or come up with based on putting in some monitoring wells. So obviously there were lot of boring wells you know that people dug in or already have for sourcing drinking water and thus they were able to come up with a relevant plume. So once they had that particular aspect though, they put in, pump and treat option in place.

So they had put up a pump and they pumped it out; take it to a water treatment plant out there and then they could have reinjected it but they did not reinject it because they were not able to treat the water to the levels that they wanted to for the groundwater standards. So I guess this being India they I guess more or less ended up supplying it for irrigation, well that I would not say is a great alternative, but again I guess considering the circumstances you know and the options that is what they have been up.

So this water rather than being re-injecting, they are now supplying it for parks and such in the vicinity so that they can water the lands and so on. So here the principle was I believe chromium VI is the oxidation state at which it was existing in the groundwater right and I think chromium VI is pretty toxic; chromium in its oxidized state of VI; so they had to reduce it to chromium III and that is what they were doing in this groundwater treatment plant first reducing chromium VI to chromium III with a reducing agent, I think they were using sulfite, to reduce this particular chromium VI and then chromium III usually precipitates out.

So then they are removing chromium III from that particular water so obviously here kinetics and equilibrium these are the aspects that are involved here right as in how fast the particular reaction of chromium VI with sulfite goes through, what is the stoichiometry involved and so on and then obviously you know it is again with respect to precipitation again, even though you are going to precipitate chromium III out, you are still going to have some chromium III in the solution because it is in equilibrium, you are never going to remove it (chromium III) entirely.

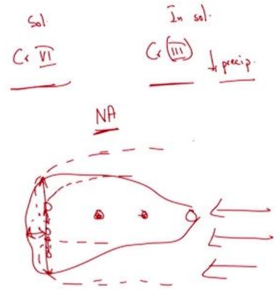
So again after that removal, what are they going to do, they are going to send this water out for irrigating the parks, while chromium III, they are sending it to TSDF for hazardous waste landfill. So this is a treatment storage and disposal facility (TSDF), so typically we have one such TSDF per state in general that is how it works in the Indian context and this was one way that they were treating the contaminated ground water.

And all this time obviously resident still needs to be able to access drinking water, so what is the relevant company up to? They are now providing tankers to the whole locality as an alternative for drinking water and also other than this particular aspect of reduction and removal by precipitation, what have they also been looking at? So looks like few other people from different institute, I believe, IIT Madras, they isolated a few strains of bacteria from different locations where the concentrations of chromium VI were pretty high.

These particular microbes are used to very high chromium VI concentration. So, again it's the principle of survival of the fittest, so those microbes that were isolated from those particular areas where chromium IV concentration was very high showed a tendency to reduce chromium VI to chromium III. Why would microbes do that? Microbes want to survive too. right? So they were trying to use it as source of energy.

Again as we know microbes either in waste water treatment, what is the principle here, we know redox reaction, they (microbes) act as catalyst more or less. So here again looks like those particular microbes that were thriving in those localities where chromium VI concentration was high showed a remarkable ability to reduce chromium VI to chromium III and so these strains were again introduced in the groundwater here.

(Refer Slide Time 15:50)



What is happening out there in the groundwater, chromium VI which is more soluble, chromium oxidation state 6 is more soluble, chromium III can precipitate out right. This is more soluble, this is insoluble. So they were trying to introduce these microbes or colonies into the groundwater out there in that locality from time to time and they did observe considerable levels of removal from chromium VI to chromium III, which is the more insoluble form.

You know by this again they are trying to reduce the concentration of this carcinogen, chromium, in groundwater. It was a two-pronged attack on the relevant aspect. Here again you can say it is natural attenuation or you know it is not natural but may be engineered attenuation, attenuation by microbes and such. One aspect I guess that could have been improved upon, as we are talking about, was choosing the location of these pumping wells.

As we are going to discuss later, to be able to capture the width of the plume and the total volume of the particular plume based on aquifer characteristics and let's say groundwater flow direction, right. You have, based on Javendel et.al.'s work with respect to relevant modeling, particular locations where you need to place these pumps or extraction wells. Here, to my knowledge that was not done, but maybe I might be mistaken, but to my knowledge, the data that I have collected indicated that such an analysis was not done.

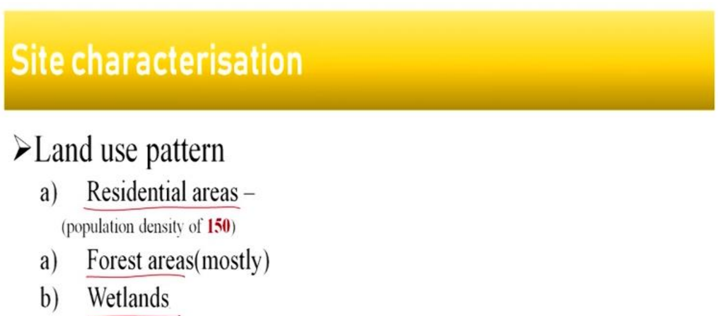
So if you are able to place these wells according to the relevant scientific estimates, the chances of the wells capturing the contaminated plume would be remarkably high. If you do not place the wells or extraction wells that are pumping out the water at the relevant locations, you risk a chance of the plume flowing around the relevant flow paths that are captured by the extraction wells.

Let us try to illustrate this particular aspect. Here I have this particular plume and this is the plan again. This is the groundwater flow direction. Where do I place this extraction well? Is it here, here or so ?. If I know that plume is out here, then I need to choose number of extraction wells, the spacing between the wells and the distance from the edge of the plume and the width that can be captured here.

So, then the extraction well flow path lines are gong to be something like this and the entire plume will be captured. There is some scientific basis behind this, obviously these are aspects that we are going to discuss later on too. This is one particular example from the Indian context but data on this particular aspect was relatively limited, so we are going to move on to another particular case study where we have rather more data.

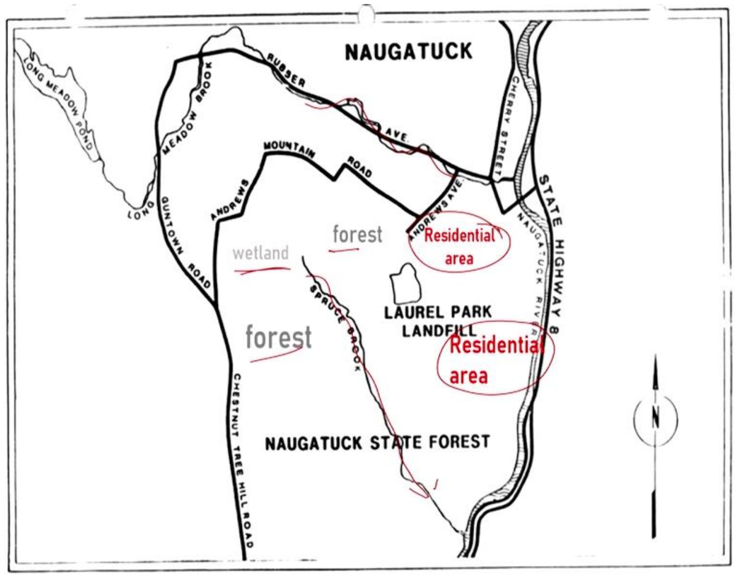
The study here in this case is a landfill in the US, and we are going to try to understand that particular case and see what is usually done. So, let us move on to that particular slide.

(Refer Slide Time 19:20)



Obviously first its site characterization; so before we go further, obviously we need to understand what is the site about and so forth; so obviously there are we need to identify residential areas which are affected, forests, and then obviously wet lands, I guess, ecologically sensitive areas too. Here we have the relevant site out here.

(Refer Slide Time 19:39)



So here is the landfill that was typically used both for municipal solid waste and some industrial waste, considerable waste rather from a plastic manufacturing and I believe a tyre manufacturing company. This was the landfill out here, okay and we have I believe in this particular slide relevant aspects. We have wet lands here, forests and residential areas in the vicinity. Though it was not densely populated, they were in close proximity to this particular landfill which is located on a hill top. So let us try to understand what the system is. So obviously it has highway here, we have some streams out here right and again one other one out here.

Anyway, I am not going to go into the details at this stage but we will cover such details during the course of the class; so I believe the crux of the issue is that heavy metals are leaching from this landfill which is on a hillock at a higher elevation part and you have leaching of these heavy metals from the landfill into the relevant, either groundwater or surface water streams and there is a potential obviously for contamination of ground waters that are relied upon by these residential areas or these residents for their drinking water supply.

So here let us say, if this is the scenario and this is the contaminated site. So the course is going to look at let us say how do I go about it and what are the best alternatives that one can choose now. So in this context obviously what needs to be done, we need to look at the risk assessment again, that is going to be looked at in detail during the semester. We are going to spend I believe a week or so about it and then we are going to move on to look at 2 major aspects as I mentioned: ground water and contaminated soil.

How do we remediate them and what are the options? So obviously different options are going to be depended upon what kind of contaminant and what kind of aquifer we have. For example, let us say, heavy metals, depending upon the type of heavy metal, if it is relatively more soluble, it is not going to be absorbed on to the soil, there might be some but usually it is going to be relatively less depending upon the type of heavy metal.

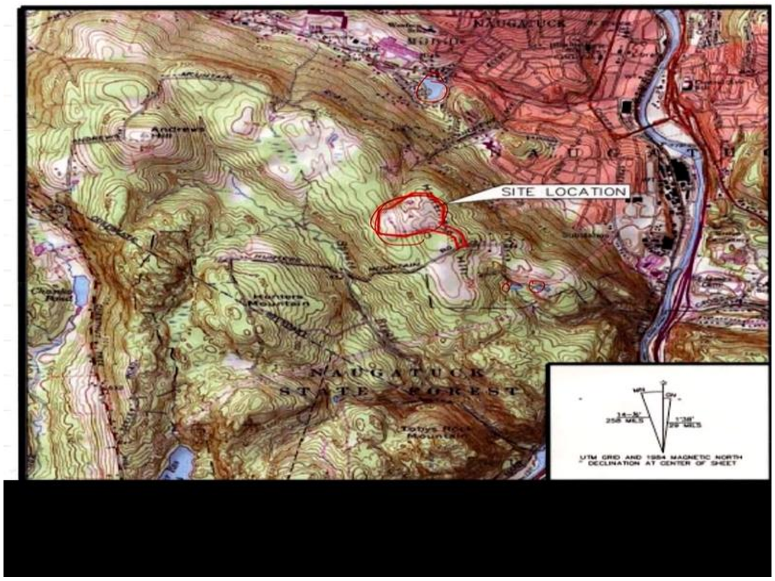
But let us say if its hydrophobic compound, let us say hydrocarbon or let us say chlorinated solvent. Chlorinated solvents are used as industrial solvents now. Let us say there is considerable number of contaminated sites mostly in the western world and certainly in the Indian context too, because the regulations usually are not strictly enforced here, of these chlorinated solvents are carcinogens or toxic compounds.

Unlike let us say soluble compounds like some of the heavy metals let us say, here the case is that these chlorinated solvents are remarkably hydrophobic right. So the key here is that you need to be able to understand that any action that would only try to treat the groundwater would not be satisfactory in this case. So then you need to look at different techniques, let us say could it be soil washing or natural attenuation or so on and so forth or could it be a passive treatment technique and so on, right.

So in general again we are not going to come up with only one alternative. We are going to understand different alternatives and then come up with a set of alternatives that would in general be technically feasible, right. So that is something we are going to go into. So again we are going to briefly go through this particular site in this session and then depending upon the time, we are going to again look at this particular site in the next session and then go through the relevant aspects we are going to cover in the class in greater detail.

So from these 2 sessions I assume you will have enough information to decide whether this course is of relevance to you or not. So let us move on. So here is the site location and again as I mentioned it is on hillock here that is what is visible from this particular site.

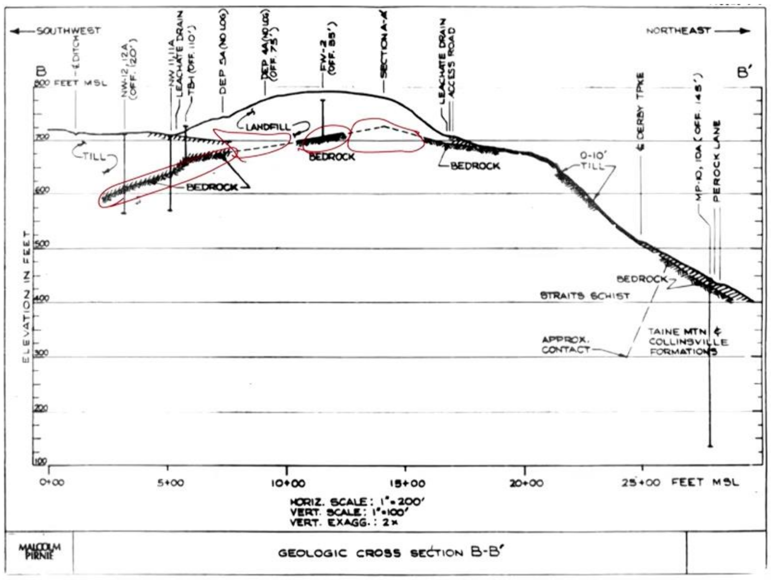
(Refer Slide Time 23:52)



So here we have a few surface water bodies out here, again obviously we need to look at groundwater models and such. I am not going to go into that in detail at this particular point in time but we will certainly do so during the course.

So again let us move on. Here we have the cross section of a particular location. Here is the land fill right.

(Refer Slide Time 24:25)



At some cases, we have bedrock which is relatively impermeable and as I mentioned that this particular landfill is on hillock, it is at a particular elevation or at a higher elevation compared to its surrounding areas, thus exacerbating the transport of the relevant contaminants.

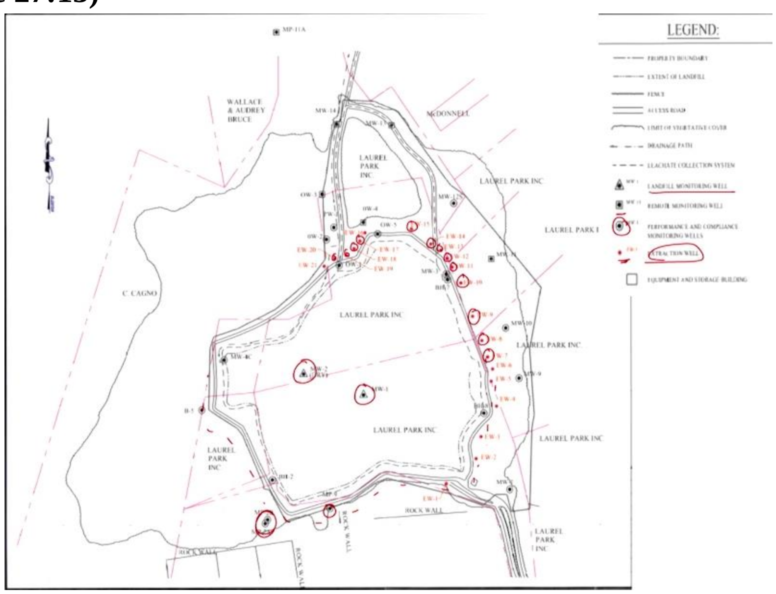
The key issue here was, I guess, that initially they had no impermeable layer beneath the landfill, right. So why do we need an impermeable layer in the first case? So obviously again, in general you are going to have anaerobic conditions in these particular landfills. There is no access to air or oxygen out there. Anaerobic conditions lead to formation of acids and acids again come in contact with heavy metals which are in solid form and then that will lead to dissolution of the heavy metals, and then leaching of the heavy metals right over time; so the leachate comes through right.

So if I have no impermeable layer here, so what is going to happen? Depending upon the soil characteristics here it is going to contaminate the groundwater here or depending upon the elevation it can lead to contamination of the surface water too and obviously contamination of the soil here. So that is one particular aspect here that needs to be looked at. So in general though we need to have an impermeable layer and above that a leachate collection system and so on.

So again that is something we are going to discuss in the context of landfills, soils and sediments and so on but for now obviously we need to have a scientifically designed landfill. So initially there was no landfill and then it looks like a committee was set up and they suggested putting up a landfill, but to my knowledge it was not successful. Again different cross-section here I guess. Again you see the relevance of these bedrocks which are impermeable but you see there is considerable area out there that is relatively more permeable allowing for the leachate to permeate through the soil.

So, again different characteristics as in slope and such but we are not going to go into that in great detail. So that is the particular aspect out there. So now obviously once there was an outcry from the residents or once the regulatory agency detected the contaminants at a relatively higher level, what did they do? They obviously needed to come up with different monitoring wells right. So here they looked at extraction wells, monitoring wells and so on.

(Refer Slide Time 27:13)

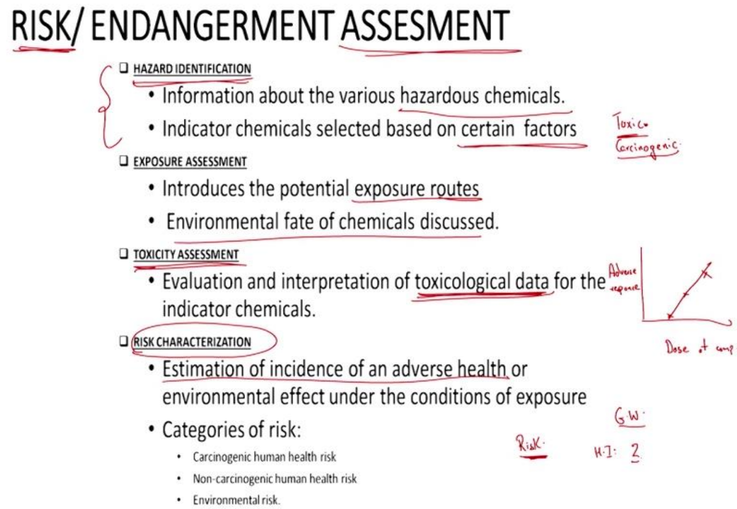


So landfill monitoring landfill wells and here they have the extraction wells and then these were set up later obviously right to extract the leachate that was going through as you see they are set up around the periphery of this particular landfill right and obviously you have the performance and compliance monitoring wells; so once you set your particular alternative or once you come up with an alternative, obviously you can't just shut shop.

You need to obviously have monitoring wells that are going to look at the performance of your particular chosen alternative over time; so that is what you see out there. Obviously the location of these extraction wells depends upon the kind of alternative that they looked at and I guess we are going to look at it in a bit more detail but the alternative that they chose was pumping out the leachate and treating it at a different water treatment plant right either onsite or offsite.

So that is something we are going to discuss in greater detail right. So let us just skip through. So risk assessment as in I need to know right.

(Refer Slide Time 27:50)



That is the level of risk posed by this particular contaminated site to either the residents or to the ecologically sensitive areas out there. So let us look at what are the major steps: I need to identify the hazards.

As in what are the various chemicals and how are the chemical chosen. They are chosen based on either their ability to be toxic or carcinogenic and we have standard data for these particular aspects so that should be relatively easy. So obviously hazard identification is the first step and then exposure assessment as in what are the different routes or pathways and where does the chemical end up.

As in we discuss a few, we are going to highlight a few chemicals here from this hazard identification. So then we need to look at what are the different pathways as in is it groundwater that is leading to transport of the contaminant to the affected or sensitive areas or is it through the air or through soil or so on and obviously what is the fate out there. So moving on, then we need to calculate the toxicity.

Again we have the standard toxicological data for these chemicals and that is something that we are going to look at again. These are typically developed from the dose of this particular compound, and what is the adverse response observed. That is how this toxicological data is calculated in general. So how do you define a particular compound to be toxic or not?. So you are going to conduct the test on in general, rats or mice, and then you are going to try to extrapolate that data to human.

So there are different ways, but in general obviously the crux of the issue is that you are going to expose the relevant laboratory animal to higher concentrations of that compound, look at the adverse response as in let us say could it be tumor, carcinogenic tumor, hair fall, lesions on the skin, so on and so forth and going to come up with the dose response curve. Depending upon the type of compound dose and response and from that you are going to come up with toxicological data.

So obviously we know we have relevant data for almost all the compounds but we need to know the relevant background to understand the uncertainties involved when we are conducting the risk assessment. So moving on, this is the major aspect here, risk characterization: as in I need to put a number for the risk that is posed to the relevant affected area due to different pathways.

So we are going to have to estimate the incidence of adverse health or adverse effects and obviously put a number; as in I can’t just say it is high or low, because it is subjective. So obviously if I say okay risk due to exposure to drinking water at their usual levels is around let us say 2, I am talking about here for non-carcinogens or toxic compounds, which is the hazard index, is 2.

Usually the cutoff we look at or threshold is 1 and let us say from some other pathway it is 0.001, so that will help me understand, for example, from taking in groundwater, the hazard index comes out to be 2 or from ingestion of or coming in contact with soil, the hazard index that is calculated or the risk characterization comes out to be let us say 0.01 and the threshold or the hazard index is daily intake of the relevant compound divided by acceptable daily intake or reference dose.

Anyway, we are going to look at these aspects in greater detail later on. So let us say from here I clearly understand that drinking of the groundwater poses much greater risk than coming in contact with soil, so let us say depending upon the resources that I have, I am going to put in more resources towards remediating the contaminated ground water right. So I guess I am out of time for this session.

So we will continue looking at this particular site in the next session, right and then we will look at the topics specifically that we are going to discuss in great detail throughout the course, we are going to skim through that and I guess with that I am going to end today's session and hopefully I will see most of you back for the next session and thank you.