INDIAN INSTITUTE OF TECHNOLOGY MADRAS

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ECOLOGY AND ENVIRONMENT

Sustainable Water Management

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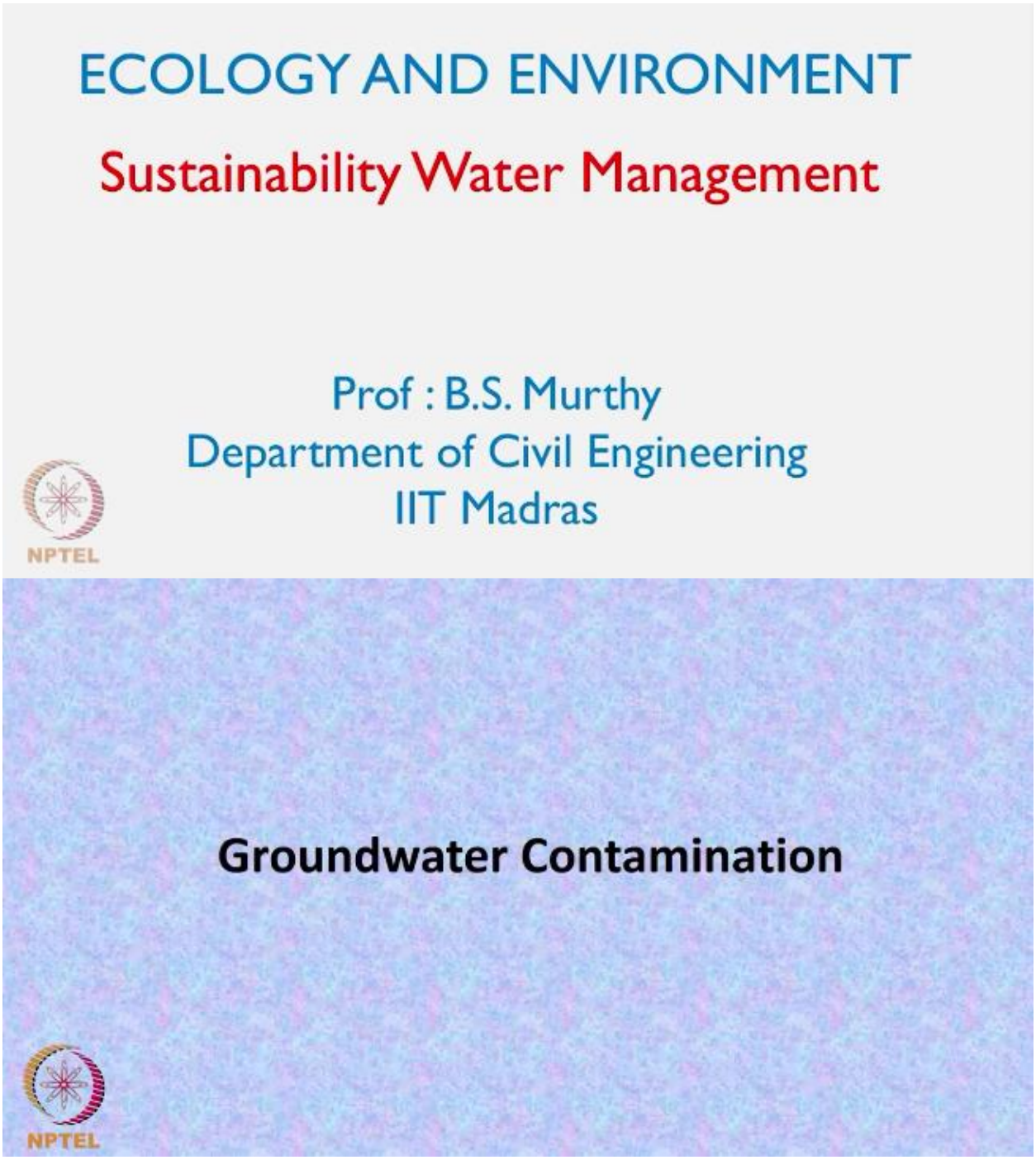
Groundwater Contamination



In this lecture, we will discuss the issues concerning groundwater contamination. As you all know we use groundwater for many purposes, for agriculture, for drinking water and so on. Before going and discussing this groundwater contamination, I would suggest to you viewing of two very nice movies; one is Erin Brockovich starring Julia Roberts, this is based on a true story.

Viewing Assignment - I

Hinkley Compressor Station (PG & E) on the natural gas pipeline connecting to the San Francisco Bay Area; constructed in 1952.

Cr(VI) is used to fight corrosion in the cooling tower.

Wastewater containing Cr(VI) from the cooling towers was discharged to unlined ponds at the site.

Percolation from ponds contaminated GW.

3.2 km X 1.6 km of area got affected

US$333 million compensation in 1996
Largest settlement ever paid in a direct action lawsuit in US history.

Source: Wikipedia

This Hinkley Compressor Station on the natural gas pipeline connecting to San Francisco Bay Area, it is constructed in 1952. And they were using Hexavalent chromium to fight corrosion in the cooling towers, the wastewater containing this hexavalent chromium from the cooling towers was being discharged into unlined ponds at the site, this was a while ago.

And since this is an unlined pond, the percolation from ponds eventually reached the groundwater, and it contaminated. It contaminated an area of 3.2 kilometers by 1.6 kilometers. And because of that contamination, a lot of other problems arose, and there was a lawsuit, and $333 million dollars compensation was given in 1996. And this is the largest settlement ever paid in a direct-action lawsuit in the history of United States. So, there is a movie about this, and I would suggest that you watch this movie.

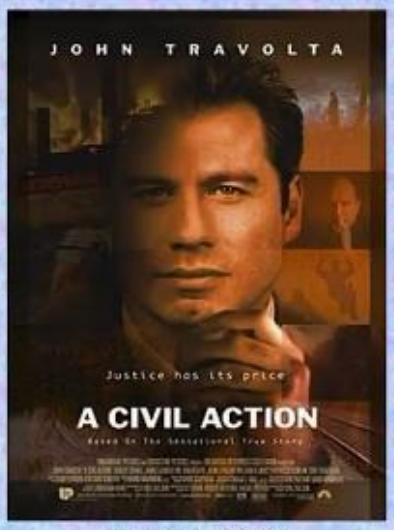
Viewing Assignment - II

Both the book / Film: A court case about environmental pollution that took place in Woburn, Ma

True Story: 1980s

Alleged that trichloroethylene released by some industries contaminated the groundwater.

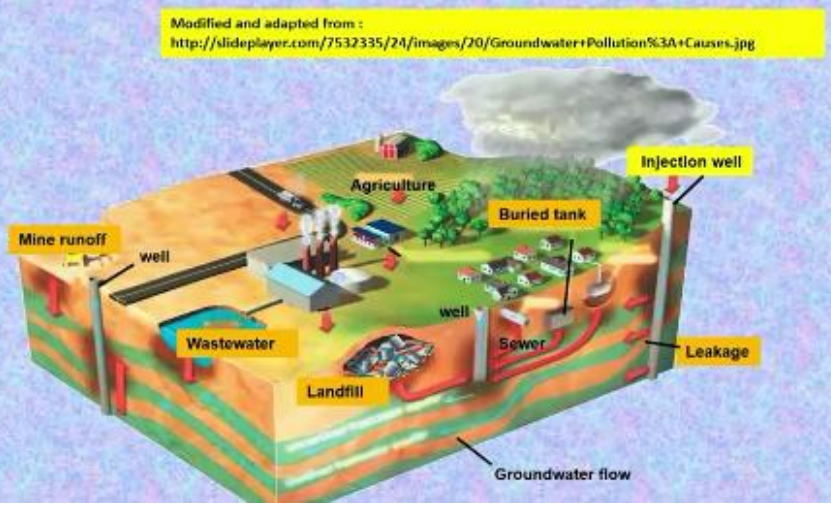
This caused fatal cases of leukemia and cancer, as well as a wide variety of other health problems, among the citizens of the town.



Source: Wikipedia

There is another movie called A Civil Action, starring John Travolta, and it is based on a book by the same title Civil Action. There was a court case about environmental pollution that took place in Woburn, Massachusetts. This was a true story that happened in 1980's; it was alleged that trichloroethylene released by some industries contaminated the groundwater and this caused fatal cases of leukemia and cancer, as well as a wide variety of other health problems, among the citizens of the town. So, there was a court case; I suggest that you watch both these movies.

Groundwater Pollution: Causes



Okay, now groundwater pollution, what are the causes? We have a lot of landfills and the landfill, the leachate from the landfill and if the liners are not working properly or if the liners are not provided then the leachate from the landfill will go down and then can contaminate any

of your aquifers. This is what we call an unconfined aquifer, that is the water table, I mean the water here is exposed to atmospheric pressure, so this is an unconfined aquifer. Whereas this part here is what we call a confined aquifer, it has a confining layer below, as well confining layer above, so this landfill leachate can go and then contaminate your unconfined aquifer. And we may be taking water from this unconfined aquifer through wells for drinking or some other purpose. So that well water could be contaminated, it is not only the landfills, but we may have buried tanks which may be carrying hazardous chemicals, and if there is a leakage from these buried tanks, the leakage of this hazardous chemicals, they can also contaminate our unconfined aquifer.

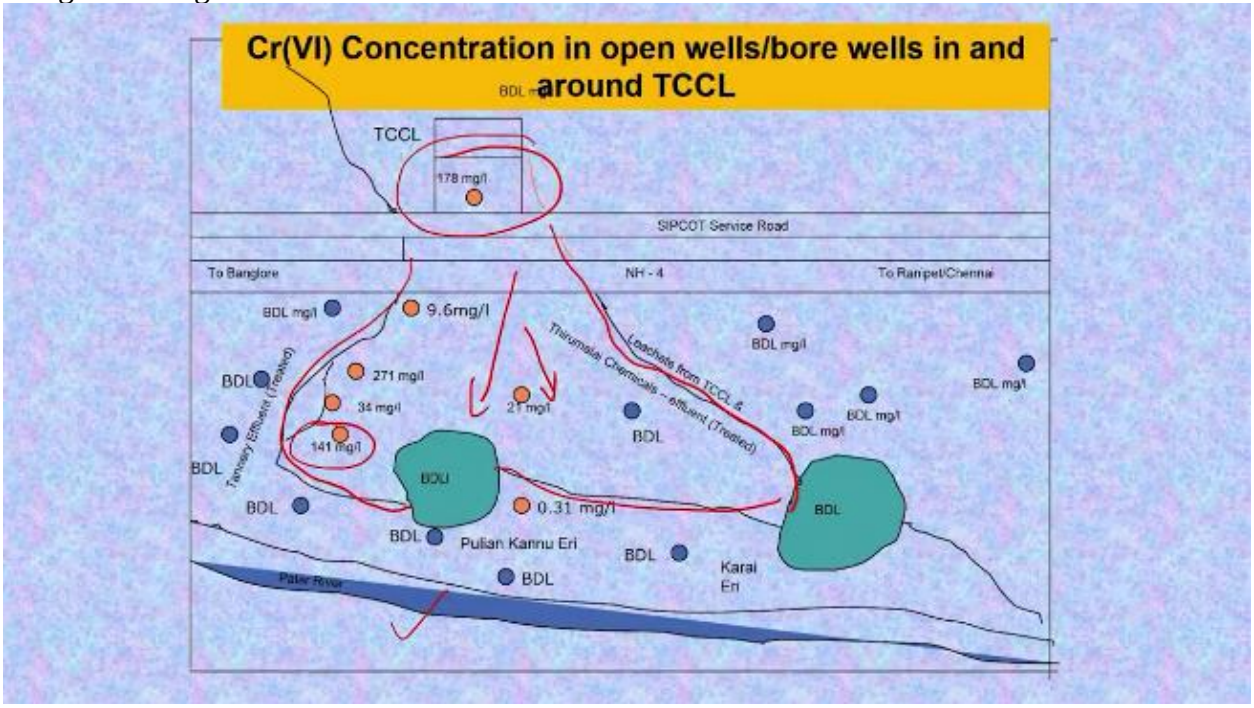
Then we have industries and wastewater from these industries if it is stored in wastewater lagoons or wastewater ponds and the leachate from these wastewater ponds or wastewater lagoons can also move down through the soil and then can contaminate this unconfined aquifer. We may have injection wells through which we maybe injecting either partially treated wastewater or untreated wastewater for groundwater storage into very, very deep aquifers. And the casing of this injection wells could be leaking, and that may leak into even your confined aquifer, very deep confined aquifers. Aquifers are water-bearing stratum, okay in the underground and your groundwater can be contaminated. Or you may have a mine runoff also if it is not managed properly, it can contaminate the groundwater. And we have septic tanks from the households; we have septic tanks, if these septic tanks are not functioning properly, the leakage or the leachate from the septic tanks can also pollute your groundwater.

And one more important source for the pollution of groundwater is the agricultural activities. For increasing the food production and for protecting the crops we may be using a lot of fertilizers and pesticides, which are nothing but a lot of chemicals, and some of them are very bad for human health. And if you use this pesticides and fertilizers without any control, without any proper attention, then along with the irrigation water or the rainwater these things can leach into the ground and then contaminate the groundwater. So, there are several causes for this groundwater pollution, because of our anthropogenic activities on the surface.

There was a case, interesting case history here, there is a Tamil Nadu Chromate Chemicals Limited, had a small factory in a place called Ranipet in Vellore District in Tamil Nadu, you can see that factory here. And the sludge is all dumped here without any proper attention, the chromium waste, the disposal area, was, or is still there, it is about 5 acres of land, over which this chromium waste is disposed, and it is open to the rains and, so whenever there is a rain then hexavalent chromium gets leached into the rainwater and this rainwater is infiltrating into the ground.

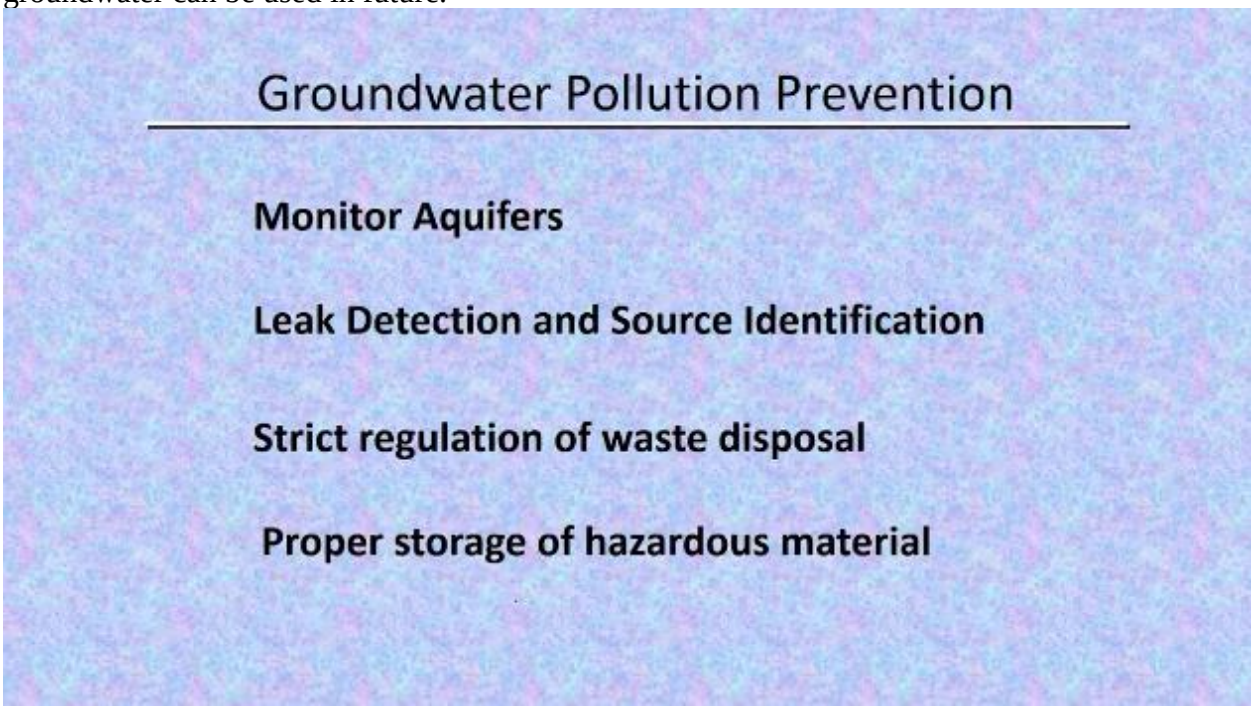
And you can see the groundwater is contaminated with chromium leachate, so you can see the groundwater which is in yellow color, this is completely contaminated with chromium leachate.

And once it gets and it reaches the groundwater table, it just does not stay there, it starts moving along with the groundwater.

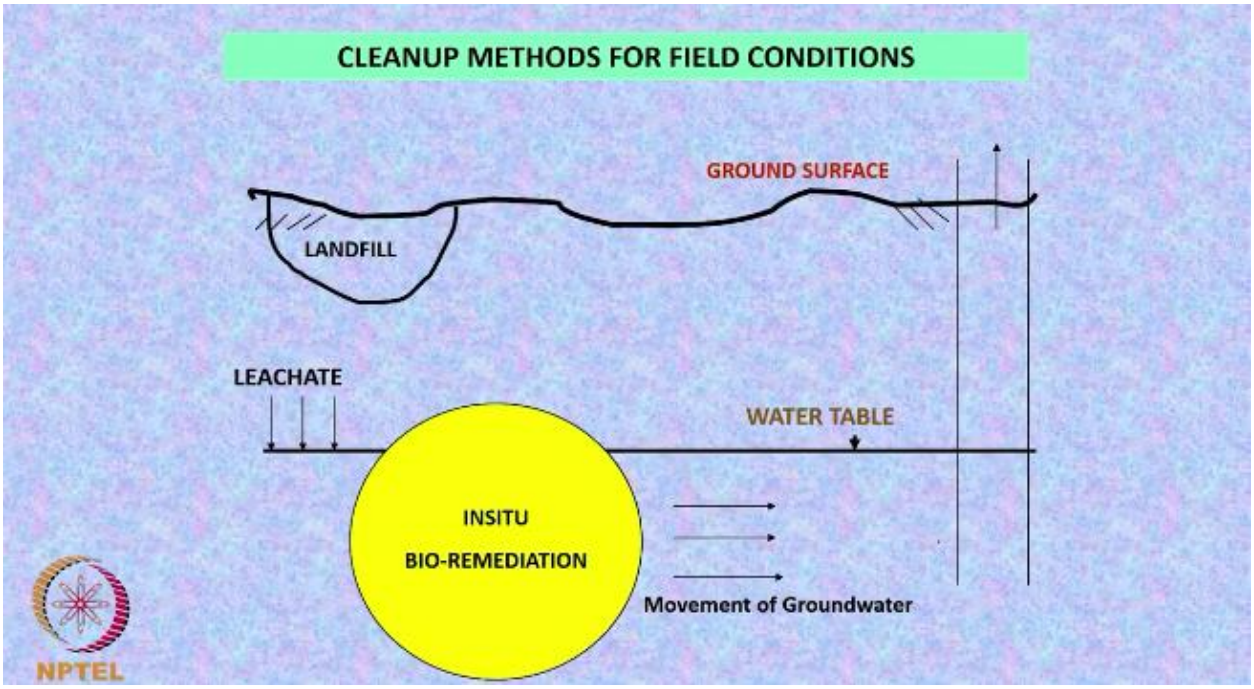


For example, this is the location of the dumpsite where one of my colleagues has gone and then measured the concentrations in the groundwater it is 178 milligrams per liter there. And Professor Ligy Philip, my colleague who measured groundwater levels along with her students in other locations also has drawn this plume shape. And here, it is around 141 milligrams per liter, and it is not just staying there, it cannot just stay there, it starts moving, and it starts moving

towards the lower water levels. And then we have a Palar river, and it has a lot of good groundwater. And once this plume reaches this Palar river, then that groundwater also will get contaminated. So, we have to be careful while we are disposing the sludge, and then we also have to think about what are the ways by which we can treat this groundwater so that this groundwater can be used in future.

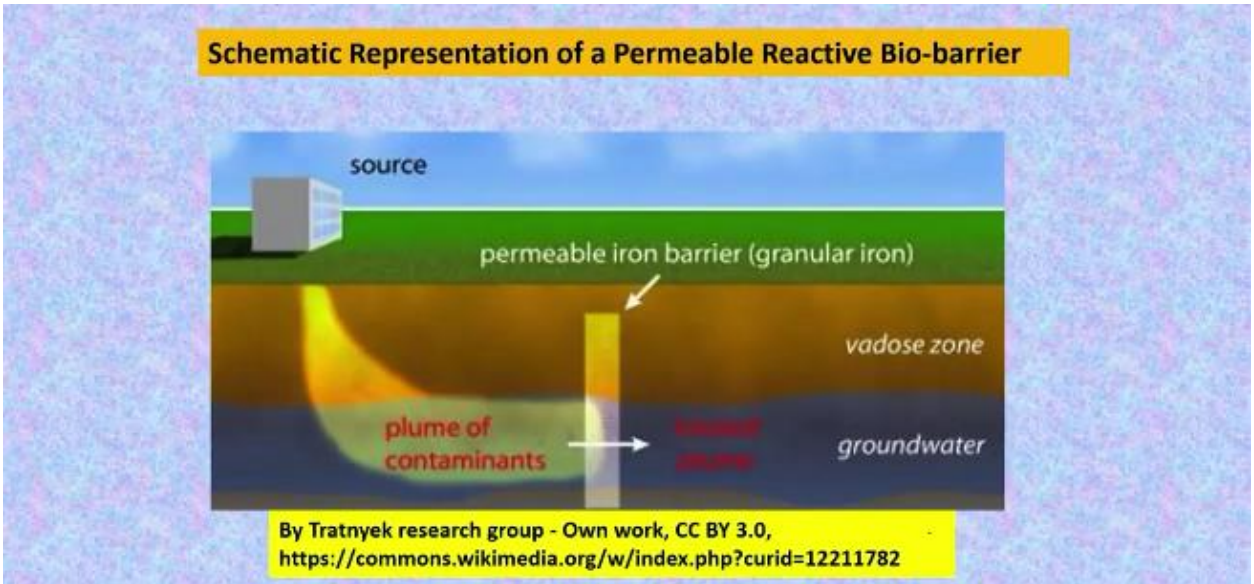


What are the different ways of preventing the groundwater pollution? First and foremost thing, we need to monitor the aquifers, that means we have to take the water samples at frequent intervals and then, analyze this water samples for any possible contamination. So, we have to monitor aquifers, so that we would know, what is the level of contamination and how far the plume has moved the contaminant, contamination has moved, what is its transport, what is the fate of this contaminant, for all that we need to monitor the aquifers. Then we also have to worry about which are the places, where the leaks are occurring, or the spills are occurring. So, we have to have a leak detection system and a source identification, or environmental forensics is also very important. Once we detect that groundwater got polluted, we need to find out where this pollution is coming from, so the source identification is very important, and it is not also very easy, but it is very important in terms of groundwater quality management.



We need to put very strict regulations on waste disposal. And we need to have proper storage of hazardous material. One of the ways by which we can treat the contaminated groundwater is what we call pump and treat. That is you pump out the water from the ground, and then you send that water through proper treatment plants and design the treatment plants according to what kind of contaminants we have. We can use either biological methods or chemical methods for treating this contaminated groundwater in the treatment plants and then put that treated groundwater back into aquifer through what we call recharge wells. This is what we term as pump and treat methods.

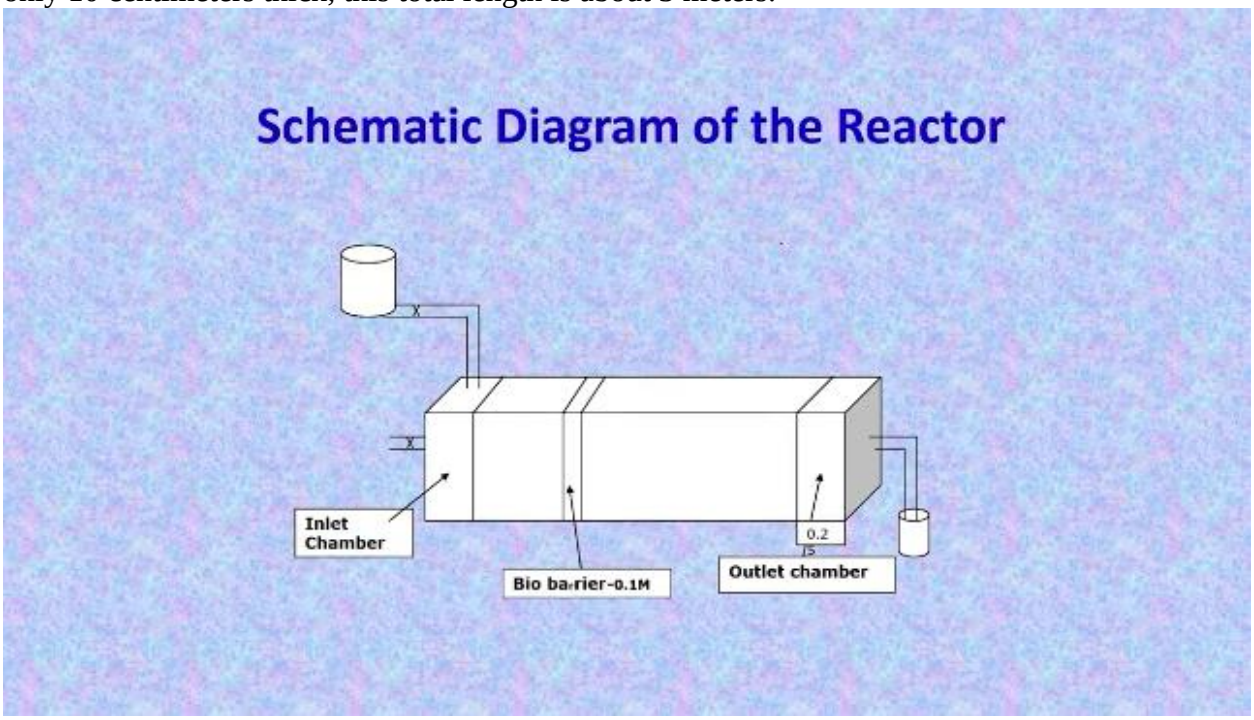
But we can also have in-situ treatment, that is what schematically shown here in this picture. Let us say we have a landfill here, and this landfill is leaking, and the leachate from the landfill has come to the aquifer, and there is a pumping well here, which is pumping the water for some beneficial purpose. And because it is pumping, the groundwater will flow in this direction, as the groundwater is going in this direction the contaminant also moves along with this, this leachate which has come here, it will also start moving into the well, and eventually we get contaminated water from this well. So, what we can do is between this location here and this well, we can have what we call an in-situ bioremediation. We can introduce a very special bacteria like chromium reducing bacteria, in this location and this chromium reducing bacteria can convert hexavalent chromium to trivalent chromium, whose solubility is less, and then it will precipitate out, and it will get fixed on to the solids. So, whatever the water that comes towards the downstream side will be free of hexavalent chromium. So, this is what we call an in-situ bioremediation technique. And for this, we can have permeable reactive bio-barriers or permeable reactive barriers.



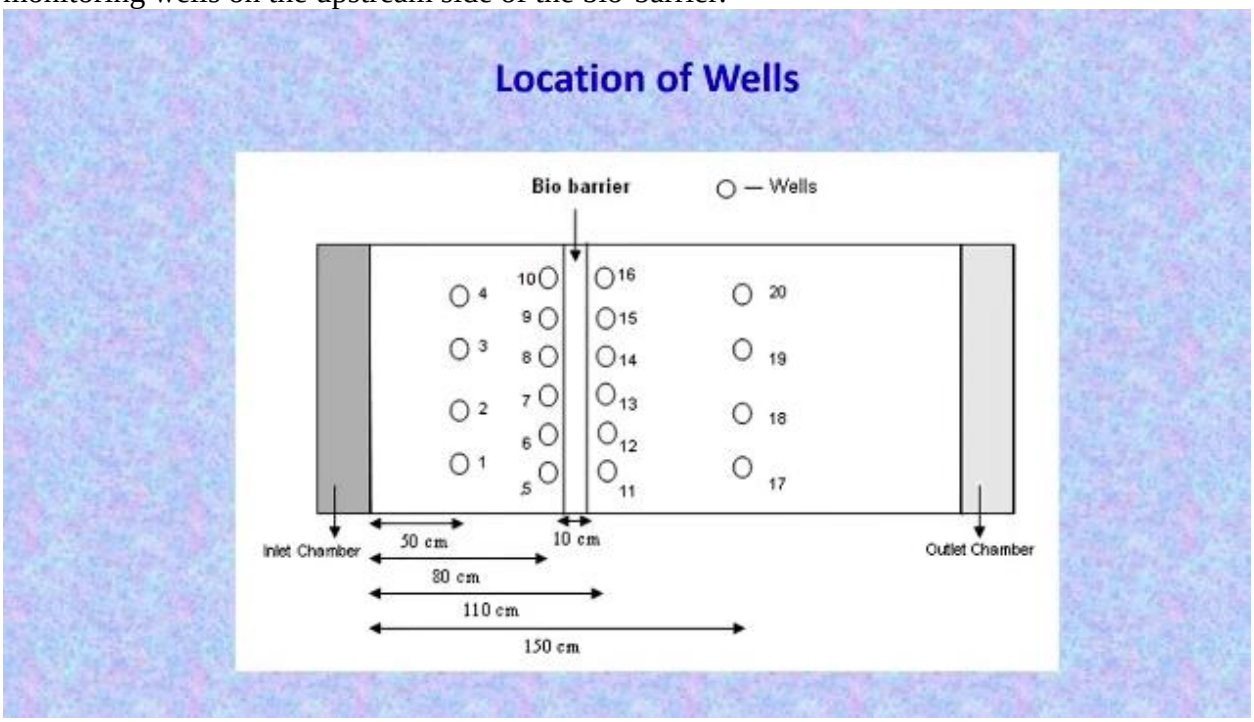
Here, this is a barrier where we have introduced the appropriate chemicals or bacteria, and as the plume is moving towards this direction and it moves through this permeable barrier, the reactions will occur in this permeable barrier and then either the contaminant is degraded or contaminant is transformed to less harmful substances, like in case of hexavalent chromium, there is a bio, you can use biotransformation to trivalent chromium and then clean water comes out on this side. This is the barrier, permeable reactive barrier technology which we can use for in-situ treatment.

My colleague, Professor Ligy Philip has conducted some experiments, a pilot scale experiments in the laboratory, where we introduced hexavalent chromium laden water here you see the yellow color, and it is moving in the ground along with the groundwater towards the downstream

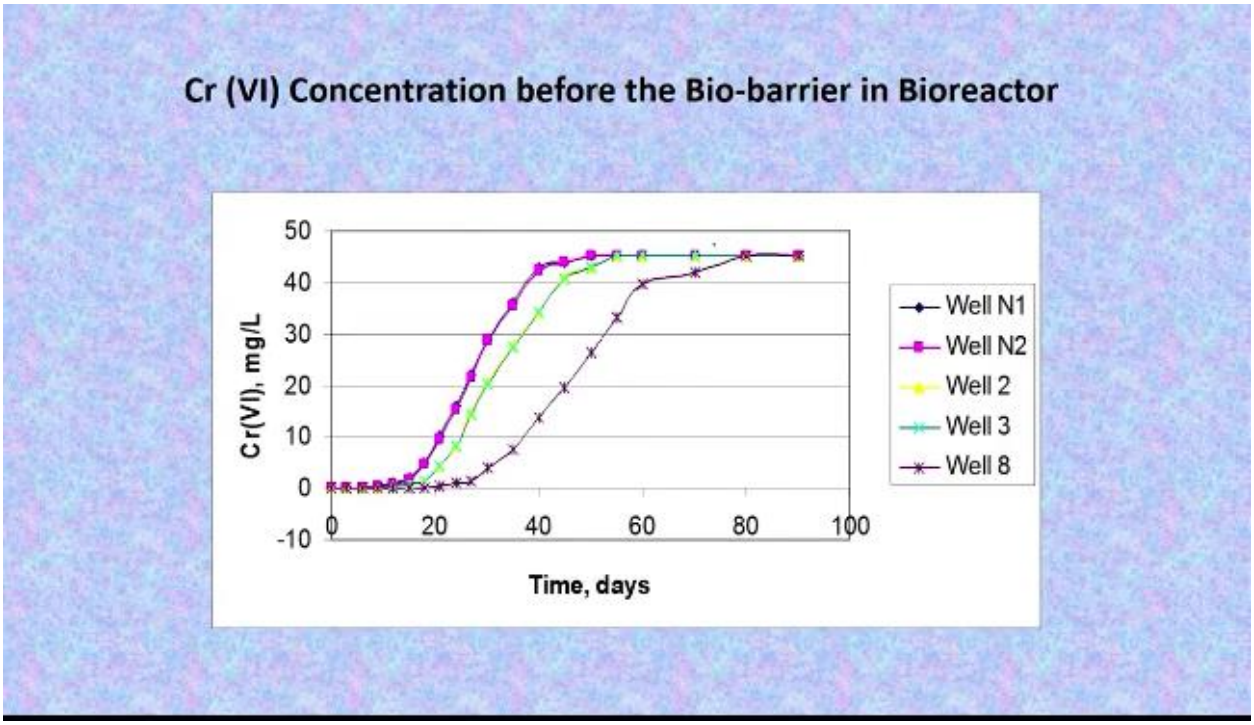
side. And here you put a permeable barrier and introduced the chromium reducing bacteria that she and her colleagues have isolated and enriched, and this chromium reducing bacteria converts CR6 to CR3. This is the schematic diagram, is an inlet chamber here, there is a bio-barrier. It is only 10 centimeters thick, this total length is about 3 meters.



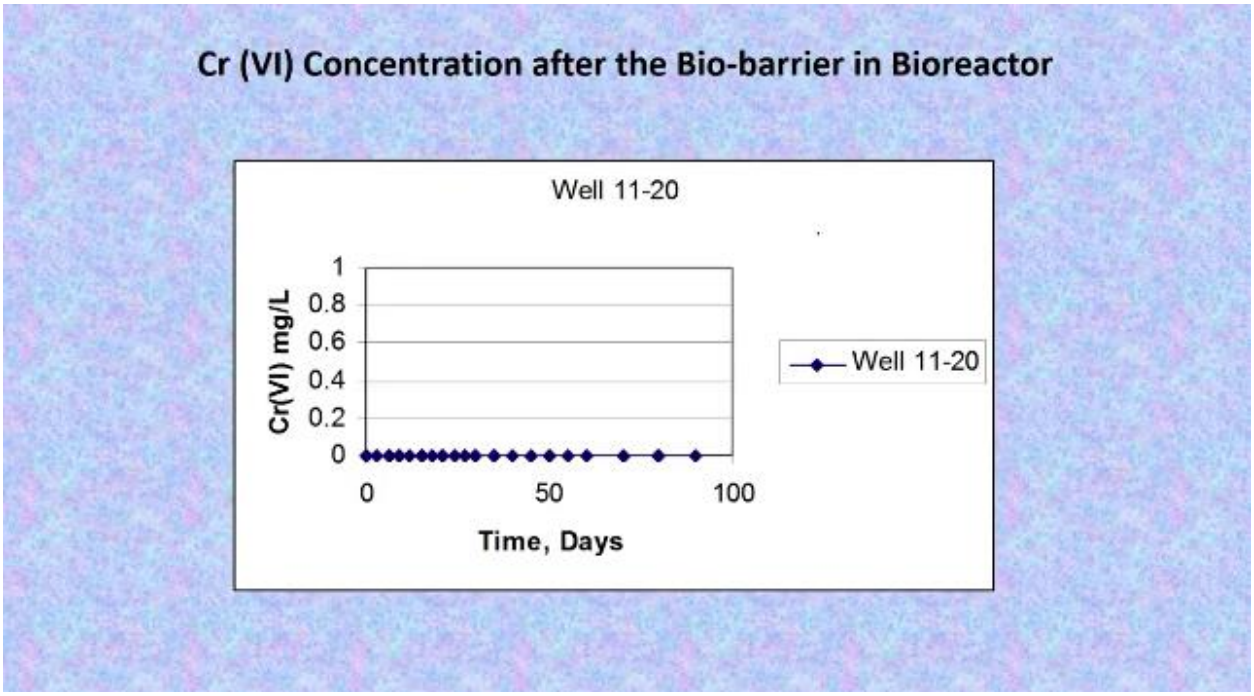
And there is an outlet chamber, and then you have a lot of this monitoring wells, 1, 2, 3, 4 to 10 monitoring wells on the upstream side of the bio-barrier.



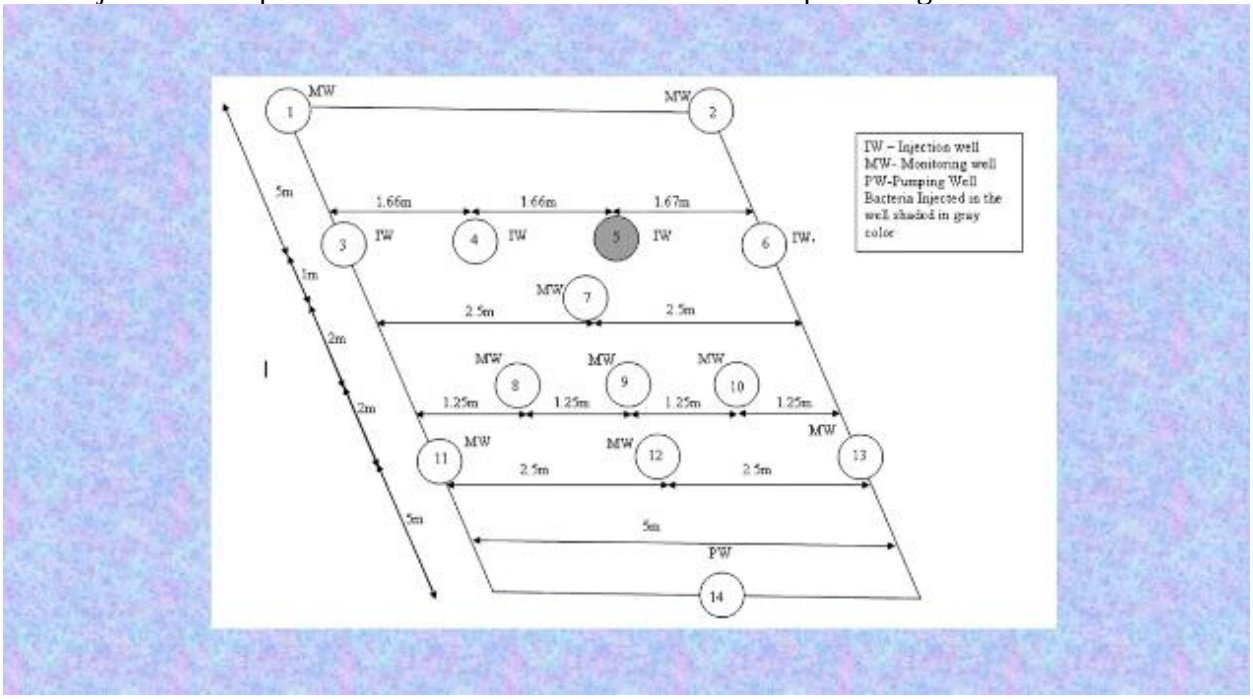
And then 16 to, I mean 11 to 20 the monitoring wells on the downstream side. We had taken samples from these monitoring wells and then analyzed for the presence of hexavalent chromium or what is its concentration.



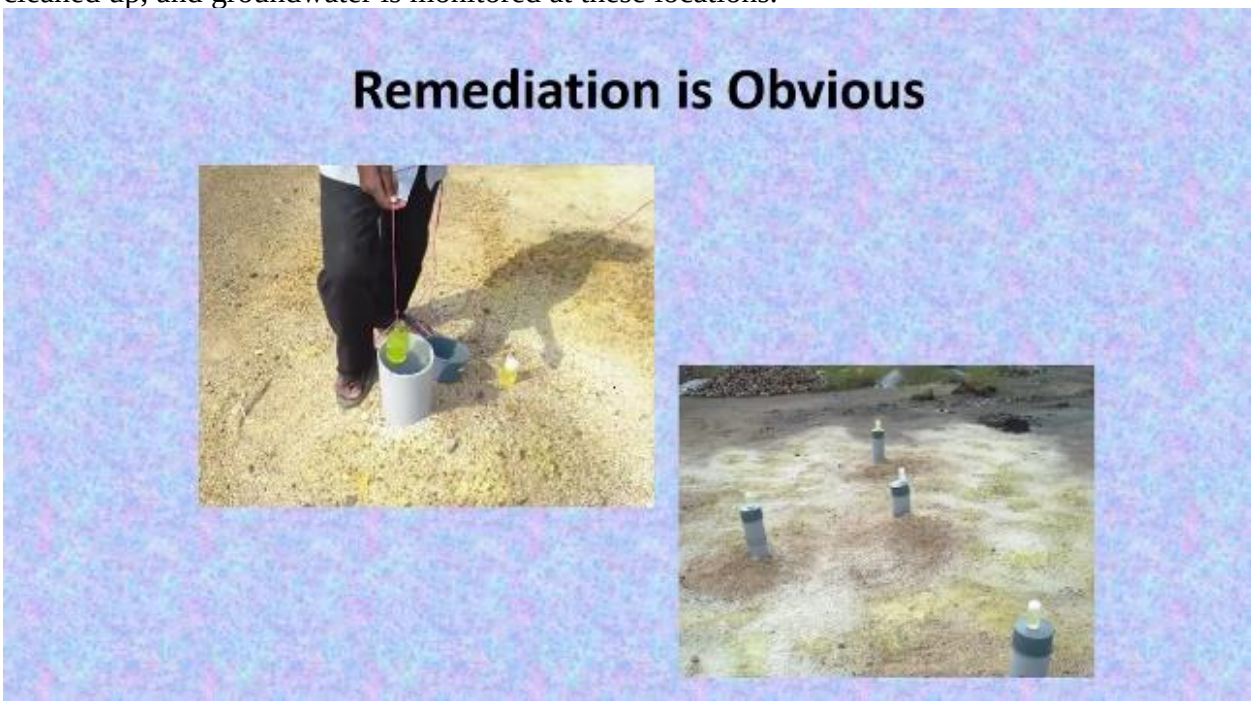
And their experiments have shown that upstream of the bio-barrier there was an eventual breakthrough of, the hexavalent chromium has reached these monitoring wells, and the concentration was as high as 45 milligrams per liter. Whereas on the downstream side, in the wells 11 to 20, there was no hexavalent chromium, that means all the hexavalent chromium got converted to trivalent chromium in the bio-barrier.



This is just an example of how one can do in-situ treatment of polluted groundwater.

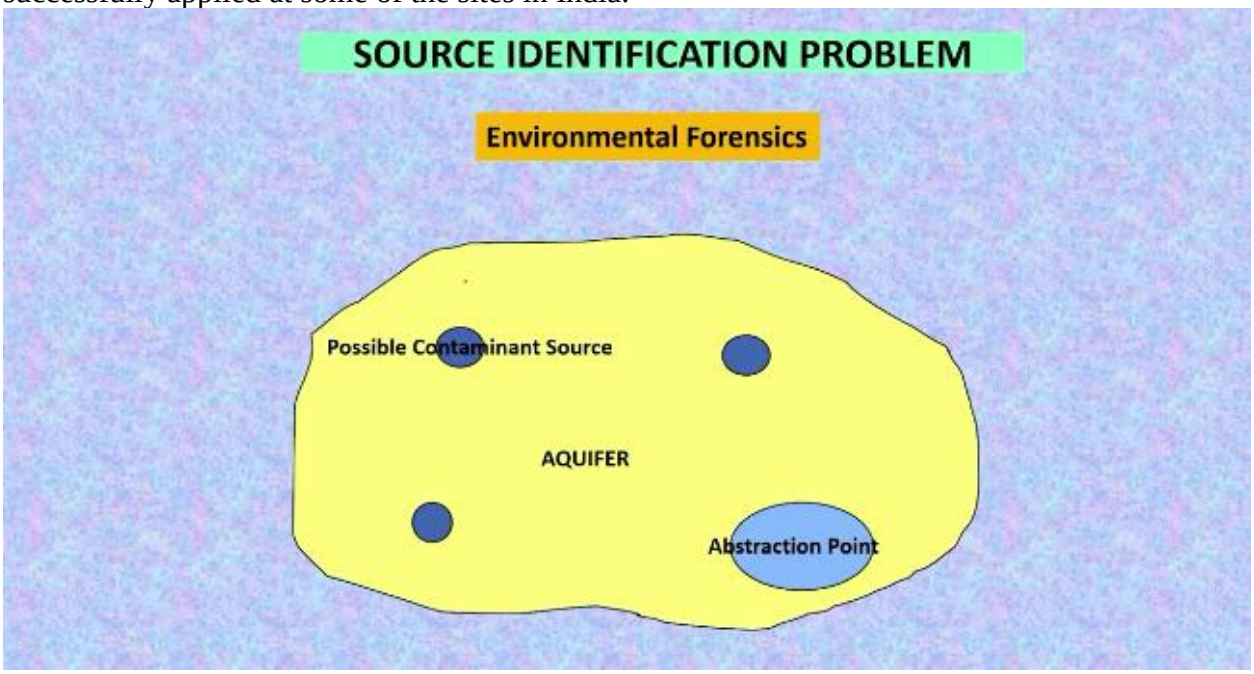


Then this experiment was conducted in the field, you had four wells, this is in the same site that I have shown earlier, Ranipet. Through these wells, the chromium reducing bacteria as well as the substrate for their growth, a carbon source, they have been introduced into the groundwater through these recharge wells. And then created reactive zones around these wells. So, when the chromium-contaminated water, groundwater moves through these reactive barriers, it gets cleaned up, and groundwater is monitored at these locations.



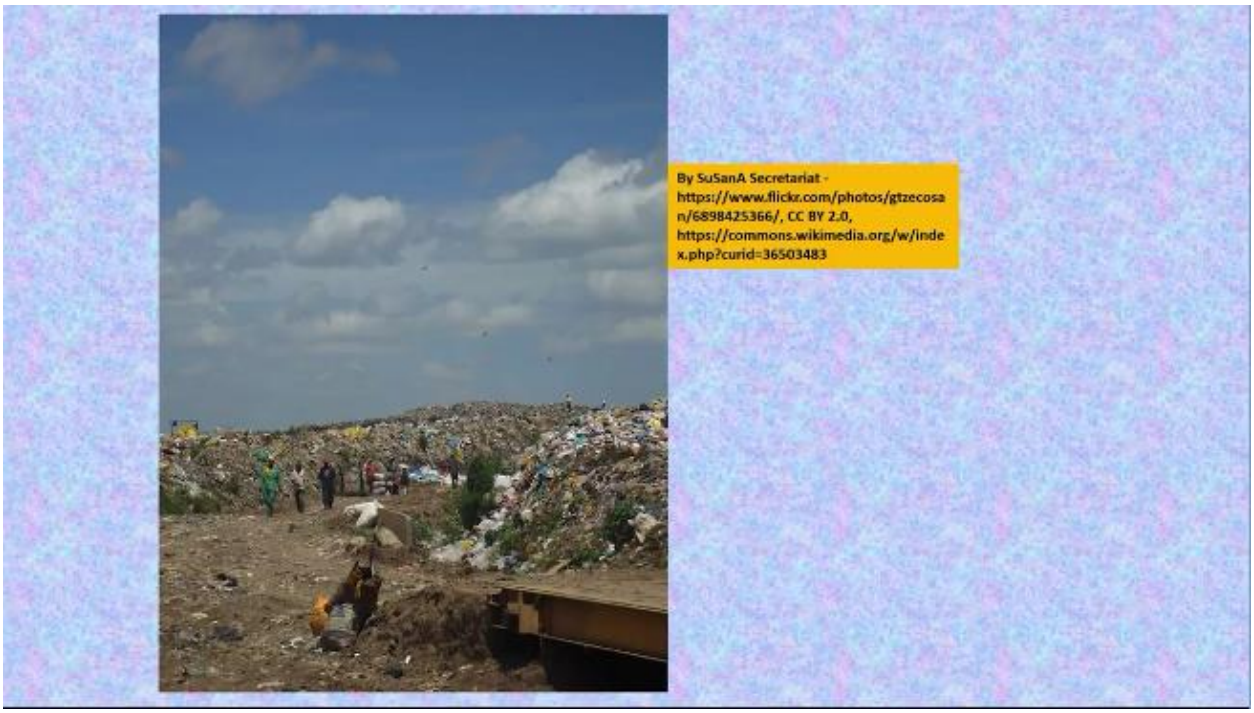
And we can see that on the downstream side we have water, the groundwater is quite clean whereas on the upstream side you have chromium-contaminated water. This was done for a

small site as a pilot study, and later on, it has been, the technology has been transferred and successfully applied at some of the sites in India.



As I mentioned, for groundwater contaminant management, source identification is very important, I would just explain to you what the problem is, what the source identification problem is. Let us say, this is the aquifer, and this is my abstraction point from where I am drawing water from the wells, and then I find one day that this water is contaminated and I analyze the water, and I know what are the contaminants.

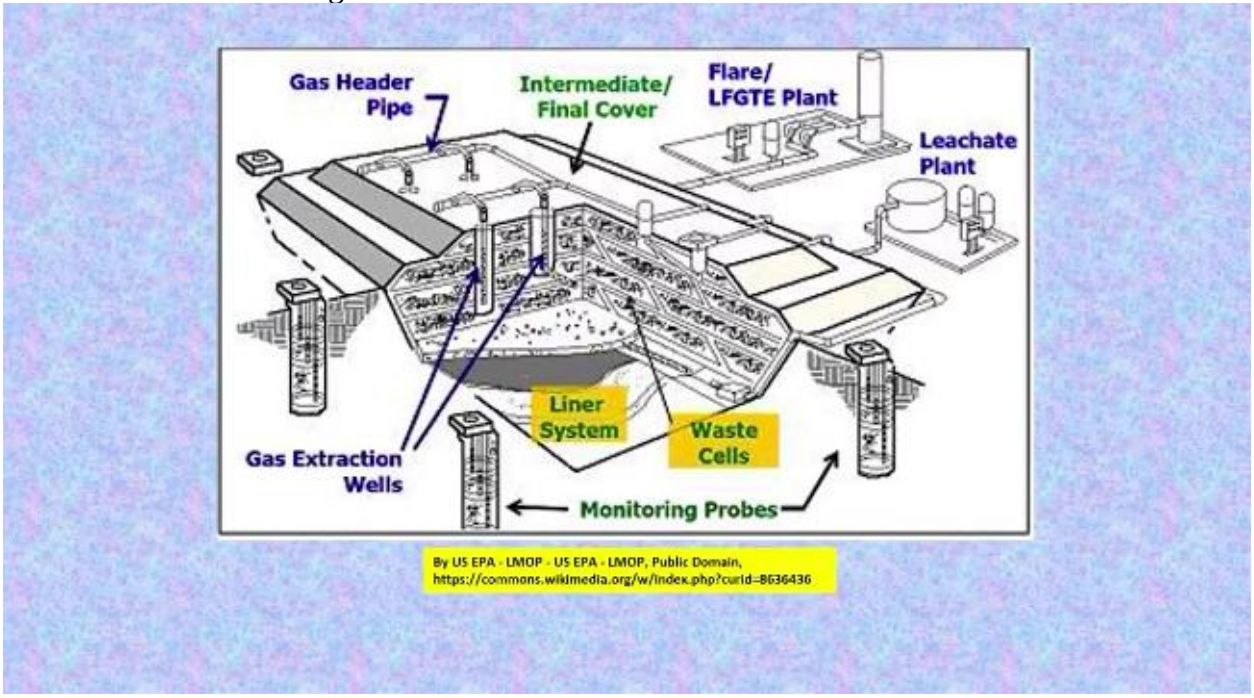
Now to control this contaminant coming into the well, I need to know where it is coming from. So that I can go there and then stop the contamination at the source. So, I have to identify the source, that is not easy. If I have only one source for that particular chemical to come, there is only let say only one factory or one point source then looking at the signatures of the chemicals here and the possible source, we will be able to tell where it is coming from. But then there could be many sources of this, many possible sources for this contaminant, it may be originating here and then moving like this, it may be originating here and moving like this, or it could be originating here and moving like this, and not only that, what the contamination that I am finding here now might have originated long ago at some location. Let us say at this location, it had originated long ago, it had taken for this contaminant to move here some time, if I go now and inspect this particular source, the leaks might have been plugged already. So, by just inspecting the source currently, I may not be able to say that, that is not a source of contamination. Might have originated while ago. So, when we talk about the source identification problem, we have to make analysis, maybe some field investigations, historical investigations, and then modeling. We have to bring all the tools together and then try to see where this contaminant has originated and when. That is what we call source identification problem, or this belongs to the subject of environmental forensics.



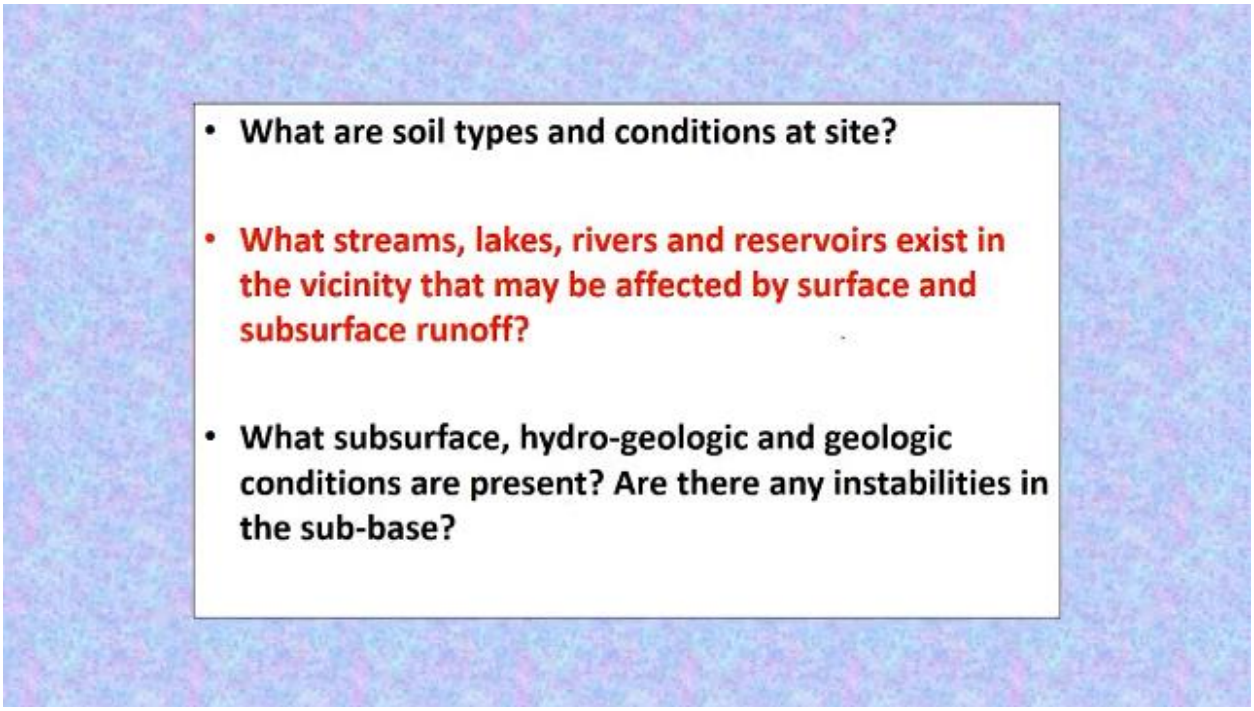
I would give a small example of, how, when we try to do some solid waste management problems, we have to consider what is its effect on groundwater pollution. As I mention one of the sources for groundwater pollution could be the solid waste dumping sites, one such site is shown in the figure here. I would like to explain this in the context of a case study in Chennai city. It is easy to see, how the siting of the dump site is very important in the context of protecting groundwater.

All the solid waste collected from Chennai city, there was a proposal for taking this solid waste and then creating an engineered landfill site in a place called Kuthambakkam. But then there

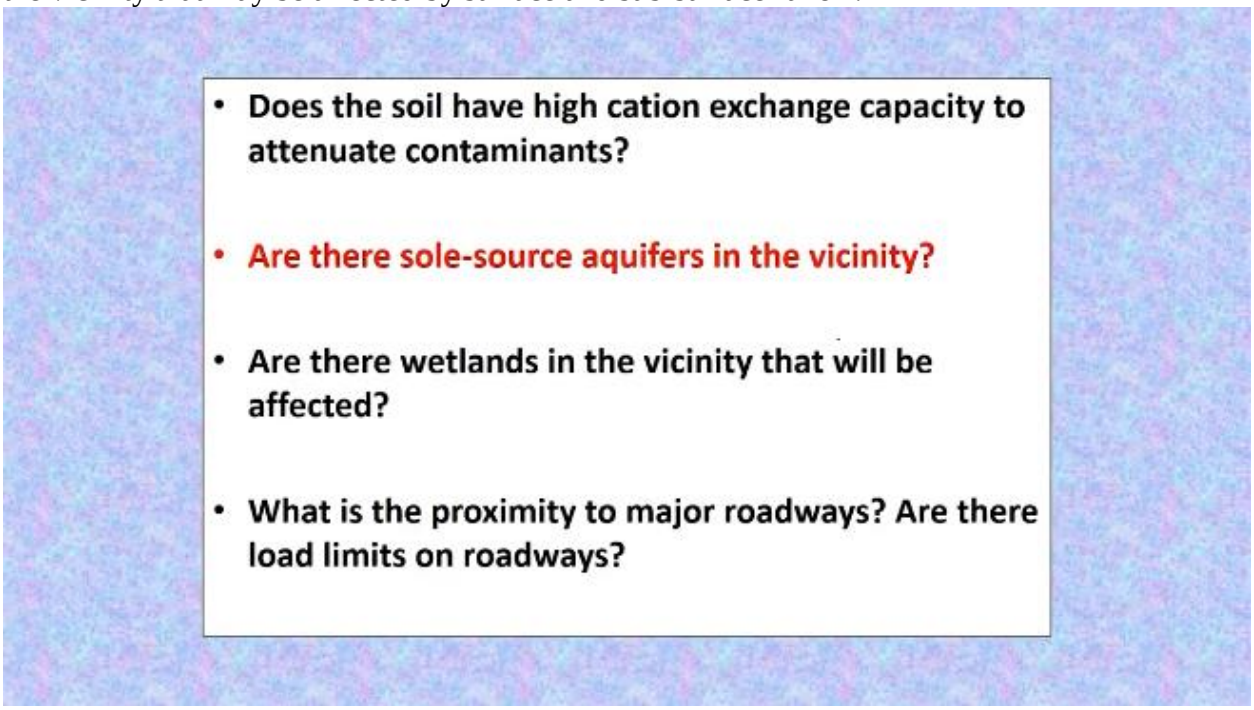
were concerns by the local people regarding whether that is a good idea of taking all the solid waste there and then siting the landfill site at that location.



Now there are many technologies for this engineered landfill site, I mean landfills. It is just a, I mean it is a pit dug into the ground, but then you have to prevent the leakage or the leachate going into the ground by putting appropriate liner systems, and then you have to put an appropriate cover for this landfill. And then whatever the leachate that is generated in this landfill site, you have to collect and then treat the leachate plant, in the leachate plant. And then you can also collect the gas that is coming out of this landfill; you can extract the gas, use it for, you know useful purpose, this is in a simple terms, what is an engineered landfill is. And we also put all these monitoring probes or monitoring wells, and we keep taking samples and then see whether the groundwater, any leachate is coming out of this landfill site.

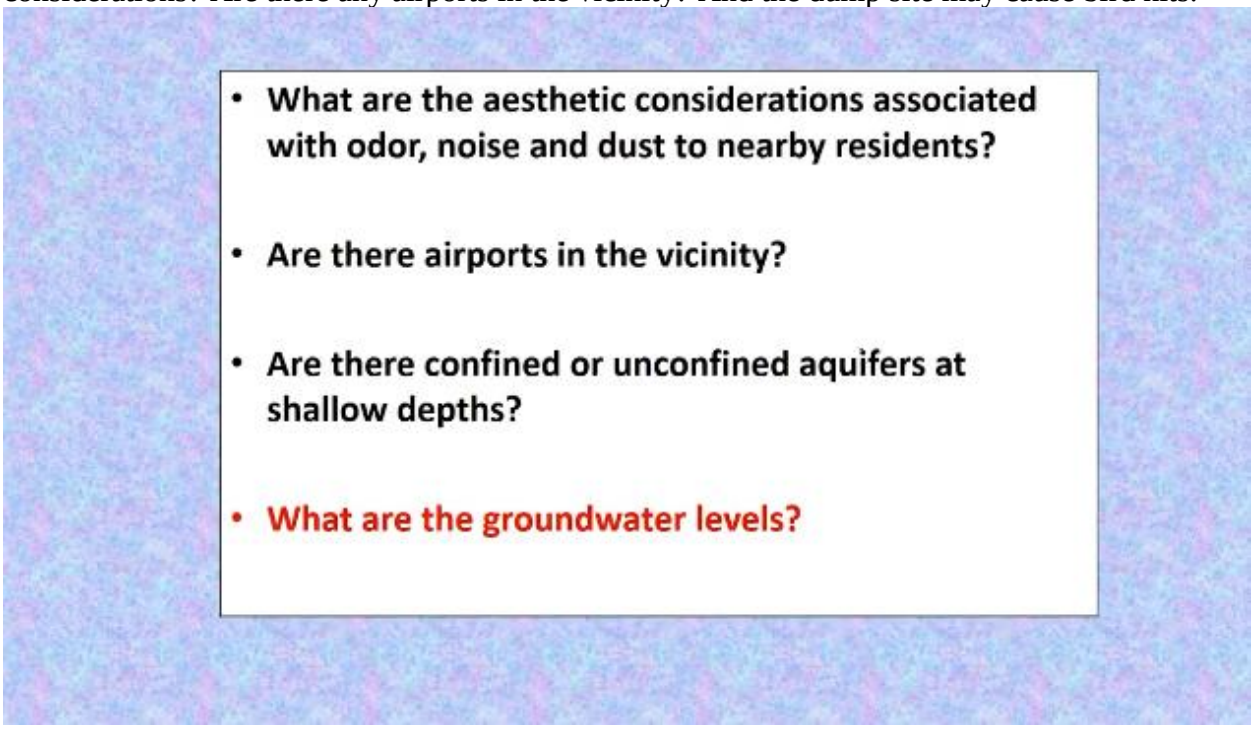


Now there are certain questions we have to ask before we siting the landfill. What are the soil types and what are the conditions at the site, what streams, lakes, rivers, and reservoirs exist in the vicinity that may be affected by surface and sub-surface runoff.



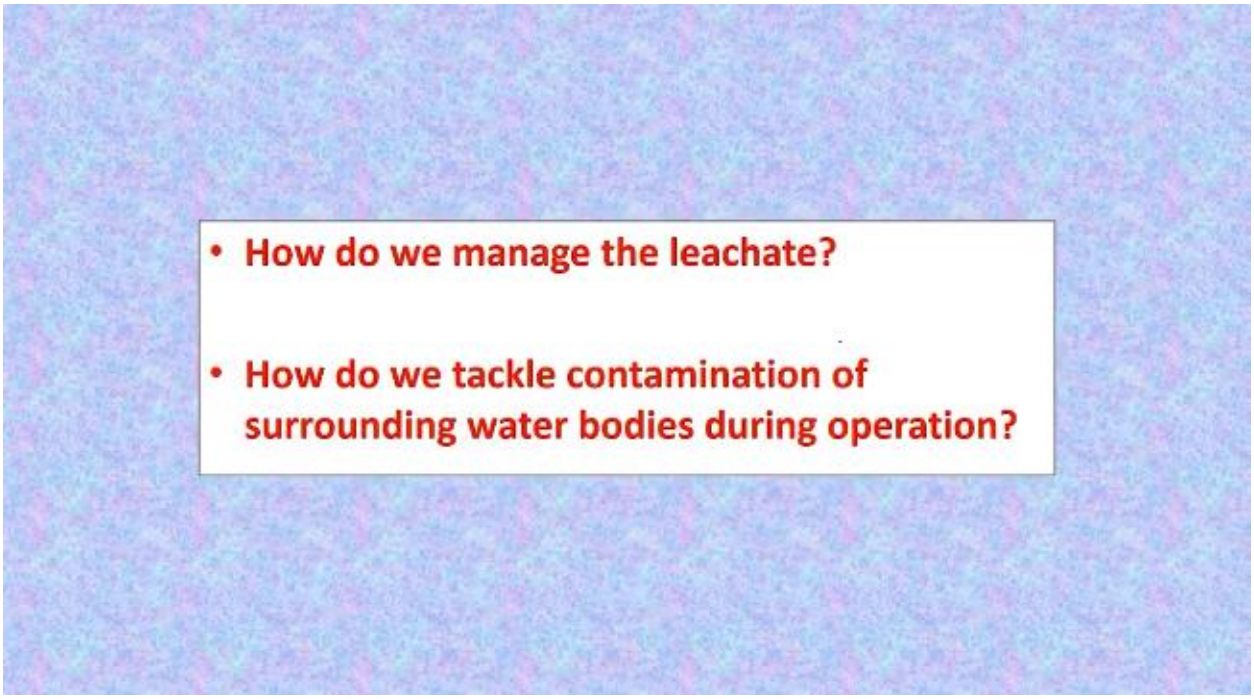
What hydro-geologic conditions are present, are there any instabilities in the sub-base, does the soil have high cation exchange capacity to attenuate contaminants, attenuate contaminants means as the contaminant moves through the unsaturated zone or saturated zone, its concentration keeps coming down that is what we call attenuation.

Are there sole-source aquifers in the vicinity? That means if there is any source of water either surface or sub-surface and that is the only source of water that you have, source of the water which can be, I mean the water from that source can be used for drinking after some treatment. So, are there any sole sources in the nearby? Are there wetlands in the vicinity that will be affected? What is the proximity to roadways? Are there any load limits on roadways, aesthetic considerations? Are there any airports in the vicinity? And the dump site may cause bird hits.

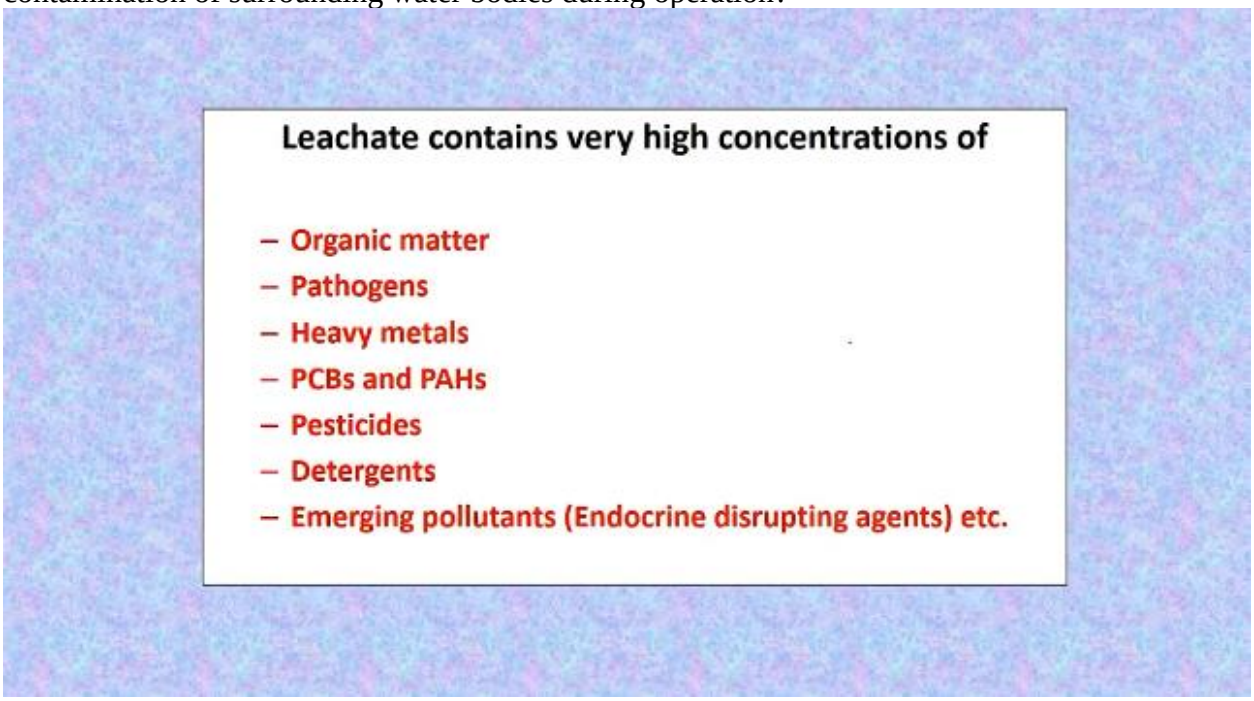


Are there confined or the unconfined aquifers at shallow depths, because if the aquifer is at the shallow depth, then the risk of contamination to the aquifer will be very high.

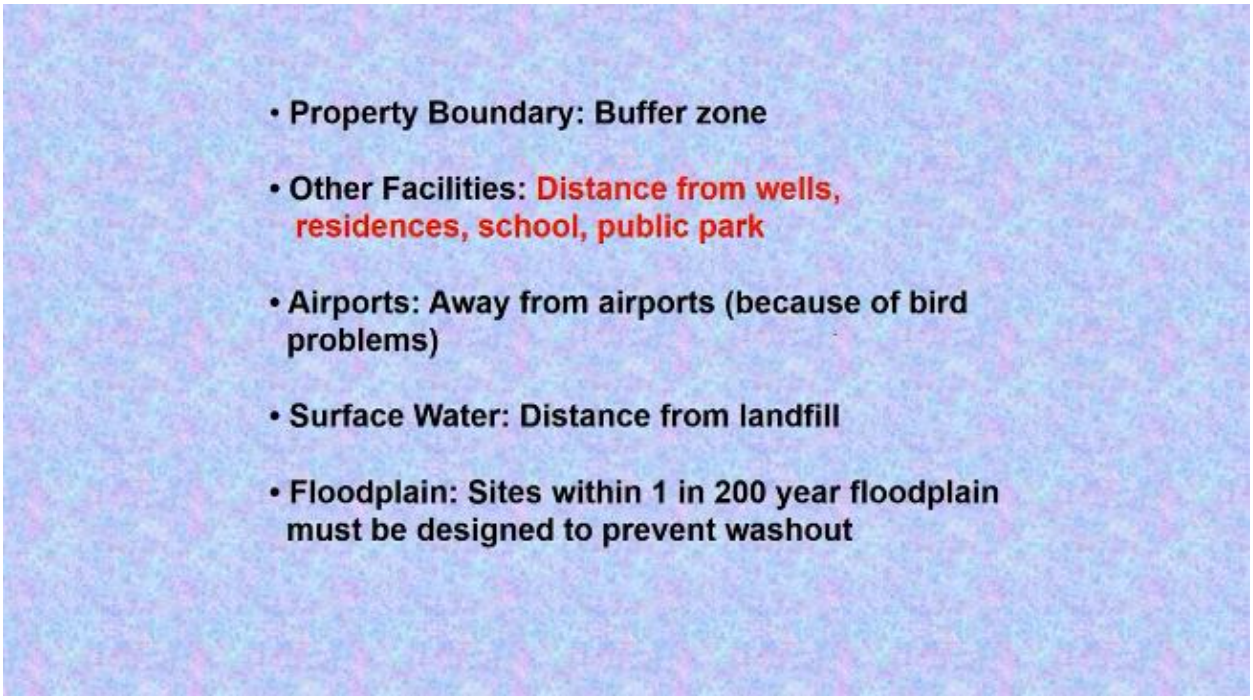
What is the groundwater level? Is the groundwater level going to be above the base level of your landfill or its very, very deep, and what are we doing to manage the leachate, whatever the leachate?



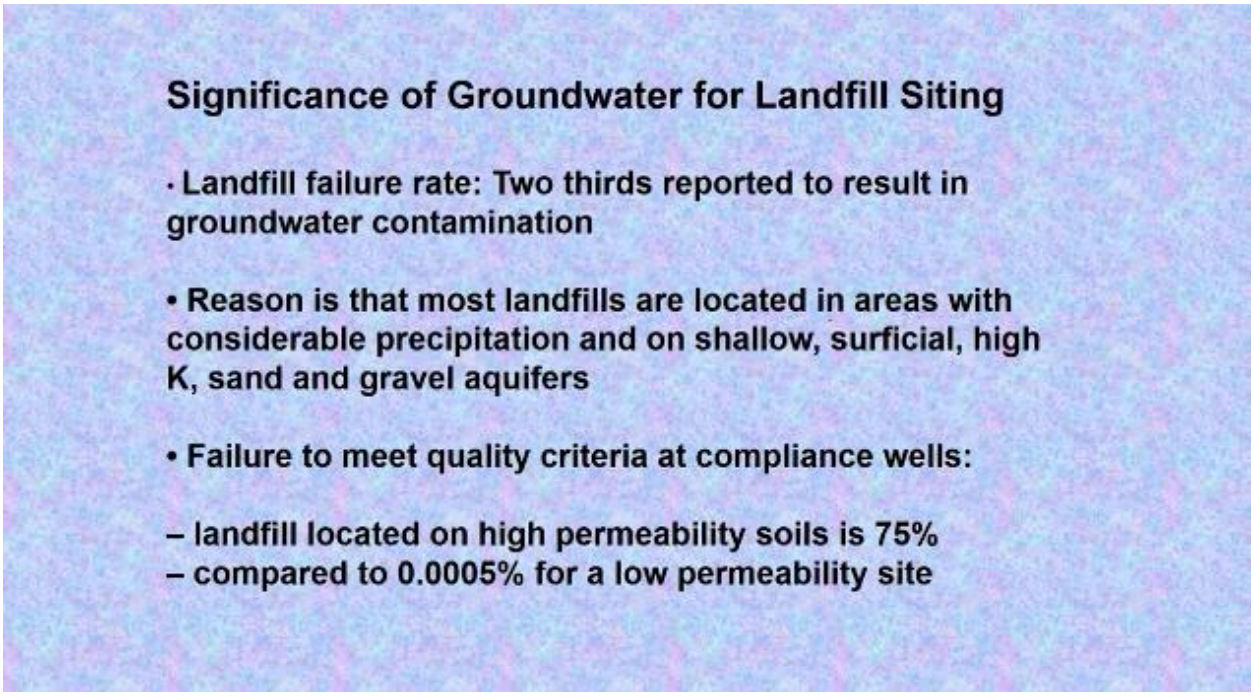
It is contaminated with any high concentrations of hazardous chemicals. So, how do we tackle, contamination of surrounding water bodies during operation?



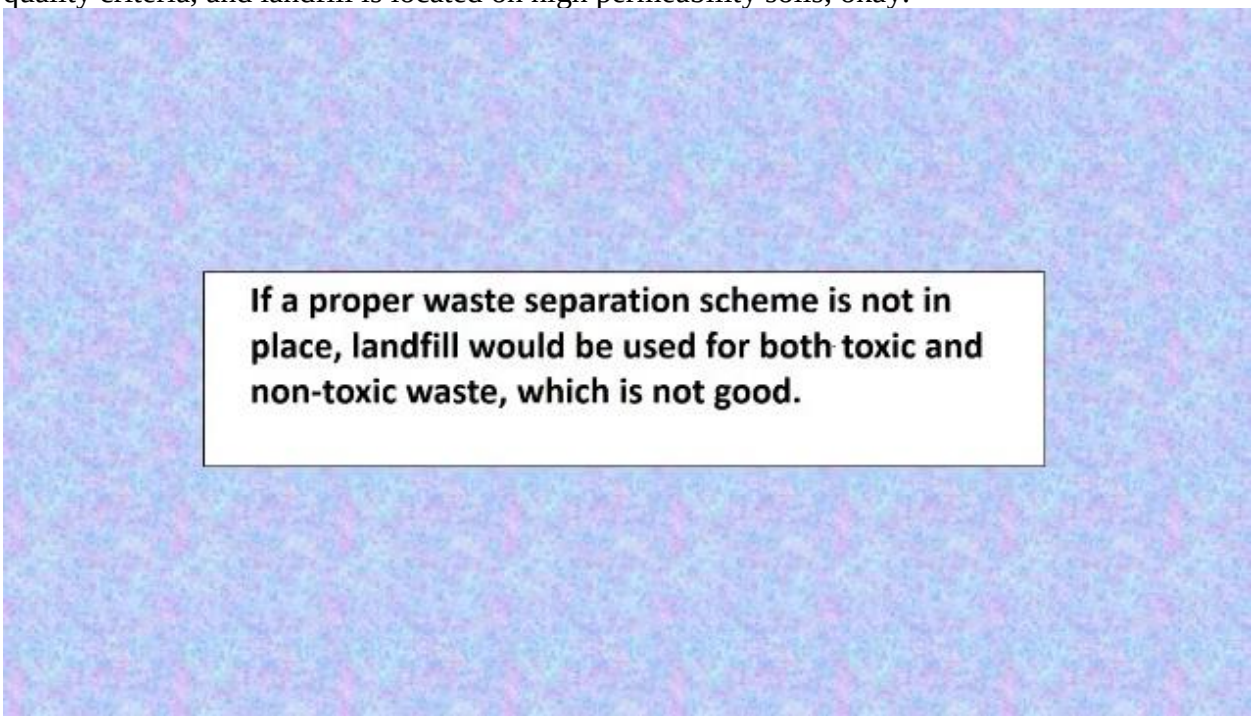
Like for example, the leachate contains high concentrations of organic matter, pathogens, heavy metals, PCB's, PAH's, pesticides, detergents, and emerging pollutants etcetera. So, what are we doing to manage this leachate, are we collecting the leachate properly and treating it properly, and then disposing it off. What is the leachate management that we have for the landfill? That is very important.



Are there any property boundaries? Are we following within the buffer zones? What are the other facilities? Distance from wells, residences, schools, public parks. Then surface water, what is the distance from landfill to the river or tank or lake, are we siting this landfill on floodplains. Like sites within 1 in 200-year floodplain that is flood whose probability of occurrence is 1 in 200 years is going to come to this particular locations, if that is the case then we have to design the landfill to prevent washout. So, all these issues one needs to consider before we go and then do the siting of landfill. But landfill itself is required very much as a part of our solid waste management. And if we do not do proper solid waste management, then also we will be polluting our water sources. So, you can see how all these issues are interconnected, solid waste management, water resources management, public health, economy, and of course, the social acceptance, people would not like to have a dump site in their backyard. So, everybody says not in my backyard. But if everybody says not in my backyard, where are we going to take this garbage too, how are we going to dispose of, so you can see the issues of sustainability, how they are very important in this case.



To summarize significance of groundwater for landfill siting, the two-thirds of landfills are reported to, I mean failures are reported to result in groundwater contamination. Most of the time wherever this has occurred they were located in areas with considerable precipitation and on shallow surficial, high permeability and sand and gravel aquifers, and they were failing to meet quality criteria, and landfill is located on high permeability soils, okay.



So, if proper waste separation scheme is not in place, landfill would be used for both toxic and non-toxic waste, which is not good for landfill operation. So, all these issues have to be considered.

Thank you.