Environmental Remediation of Contaminated Sites
Prof. Bhanu Prakash Vellanki
Department of Civil Engineering
Indian Institute of Technology - Roorkee

Lecture – 30
Case Study: Natural Attenuation

Hello everyone. Welcome back to latest lecture session. So until now we have been discussing the relevant aspects of relevant tool, let us say, monitored natural attenuation. So in the Indian context, obviously we were looking at natural attenuation. But monitored natural attenuation is a remedial technique that is certainly by law applicable in US EPA as in if you can prove it, you can say that you are trying to get the, remediate the system or the contaminated site by monitored natural attenuation in the US area, right.

But again obviously in the Indian context too, natural attenuation as in letting the microbes to do their job is something that we can look at, right. So let us look at a case study today. Or over the next couple of sessions where we are going to analyze, let us say, one particular site where remediation of NAPL occurred or was required, pardon me. And let us look at how or why natural attenuation was one of the remediation techniques that was chosen, right. So let us have a look at this particular site.

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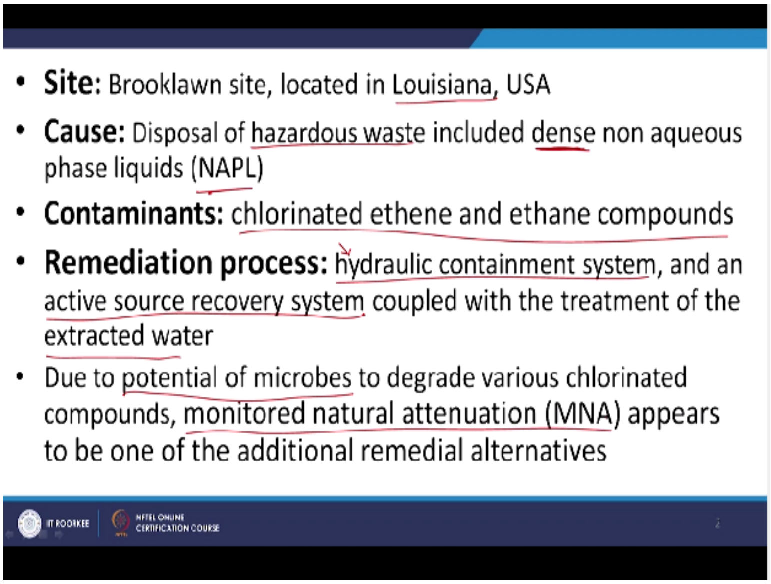

- **Site:** Brooklawn site, located in Louisiana, USA
- **Cause:** Disposal of hazardous waste included dense non aqueous phase liquids (NAPL)
- **Contaminants:** chlorinated ethene and ethane compounds
- **Remediation process:** hydraulic containment system, and an active source recovery system coupled with the treatment of the extracted water
- Due to potential of microbes to degrade various chlorinated compounds, monitored natural attenuation (MNA) appears to be one of the additional remedial alternatives

So, let us say, it looks like it is in Louisiana, right and cause was that the hazardous waste including DNAPL was spilled over, right. DNAPL and NAPL too, but certainly DNAPL by the reason why we specify DNAPL is that as you know DNAPL can, what do we say, due to its greater density, let us say, what we say, travels through this particular or travels vertically and reached the lower strata here.

That is something of an issue with the dense or DNAPL, right. So contaminant included various chlorinated organic compounds, right. And remediation process was that they were trying to contain it, let us say, as in we have not looked at it yet but maybe we discussed it in some or brief detail. As in you can either remediate it or, let us say, as part of remediation system or process, you can contain the relevant site or containment system in the sense that you prevent the transport of your relevant contaminant to a larger area, right.

So here they looked at a hydraulic containment system, right. Active source recovery as in they are also trying to remove the source from that particular site. And obviously extracted water as in your ground water is also contaminated. They are also trying to treat the ground water. So 3 prompt approach. What is it now? First, one of the major aspects obviously is remove the active source.

Then contain the relevant, what do we say, hydraulic transport and then treat the contaminated ground water, right. So let us look at what else we have. Obviously we are talking about monitored natural attenuation. So looks like based on the data, the potential for microbes to degrade the, what is it now, the chlorinated organic compounds was observed. And thus monitored natural attenuation was also considered, let us say, right. So let us look at the relevant aspects. So let us understand site first. So what do we have here? Let us understand site.

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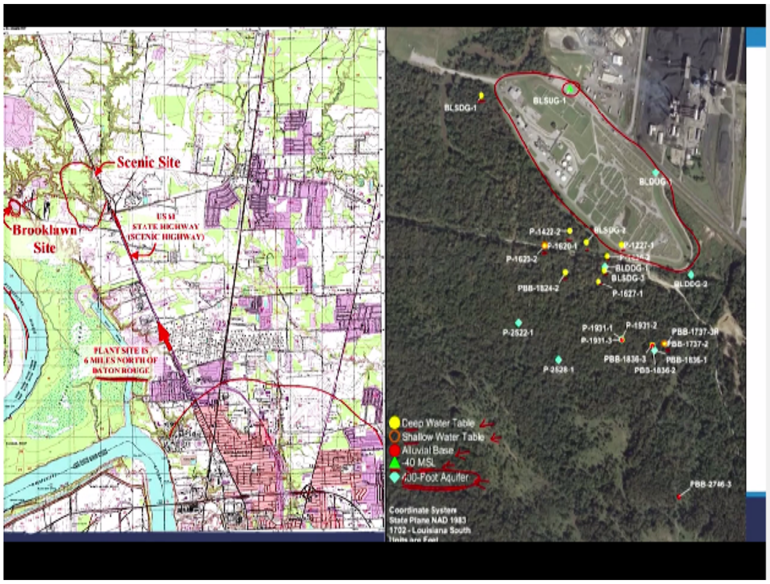

So this is in Louisiana. This is I believe Baton Rouge, right. This is industrial, not industrial, a thriving city, right. And again the plant is around 6 miles north, not far off from the thriving, what do we say, city. State highway here and is a scenic or area of natural beauty out here or a scenic site and this is our site of, site that needs to be remediated here, right. So out here, yes. So let us try to understand site.

First that it is relatively near to a, what is it now, a huge, thriving city, right. It is also near a tourist attraction, yes. And more importantly as you can see or sense from this particular site map, it is near a particular river, a major rive that too, the Mississippi River, right. So that is one particular case. And again here, you see that it is marsh land probably here, right. So it is at a remarkably critical location, right.

Again let us look at the site here. So this is the site, okay where they were storing different LNAPL and DNAPL or different non-aqueous phase goods. This was the storage site, right. And again before we go further, let us understand some of the site characteristics here. So first that this is marker for -40 mean sea level, right, -40 mean sea level. Anything else? So again -40, so what this gives you an idea about that is that it is remarkably low lying area, right, that is one thing to look at.

So they have deep water tables here, remarkably deep water tables throughout that particular site, the deep water table. Obviously, not obviously, also shallow water tables too, shallow water tables, yes. And more importantly this is something that we need to keep in mind, there is a 400 foot deep or thick aquifer now, right. Obviously you do not want your contaminant to reach that 400 or such huge aquifer because once it reaches that aquifer, the contamination is going to obviously be spread over a wide area and also because, what do we say, considerable aquifer.

It is probably the source of, what do we say, ground water, let us say, for major or considerable parts of that particular state. So the key aspects are that, we have both deep and shallow water tables and obviously alluvial base because you have a river running around here, right, near the site and that it is a very low lying area and that you have a huge aquifer out there, right. So that is something to keep in mind, yes. Let us move on.

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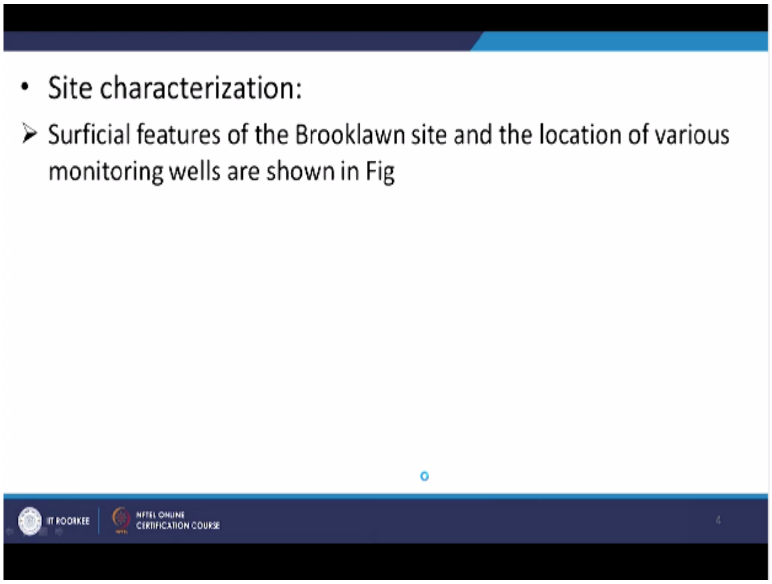

- Site characterization:
  - Surficial features of the Brooklawn site and the location of various monitoring wells are shown in Fig

So surficial features, we can look at that in the relevant site.

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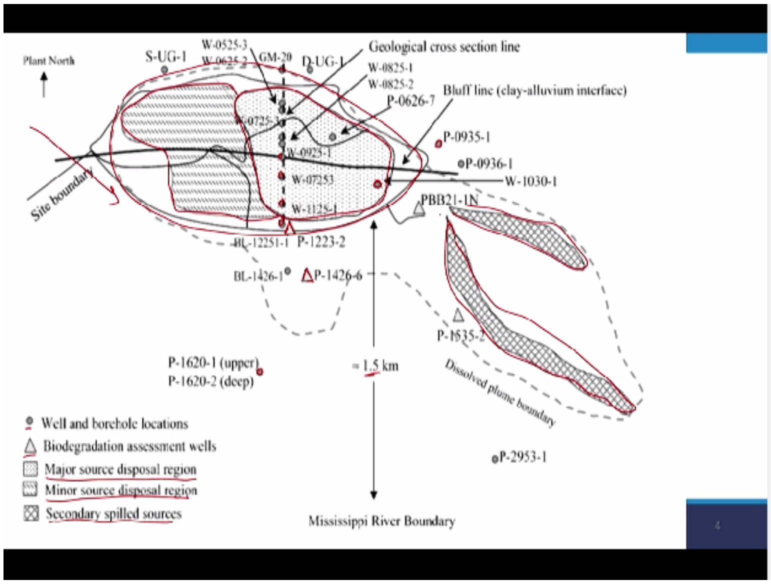

So this is the relevant site. Again as we discussed or just saw that earlier, this is the relevant site, yes. So as we see it is around 1-1/2 km from that particular river boundary, not far off, right. And let us look at this particular legend here. So we have different wells and borehole locations, right. Different wells outside the zone of contamination, inside the zone of contamination, right and along the zone of contamination, right.

So different locations, either some outside because you want to get the background data, some inside or at the source because you want to know what is at the source. And some along the flow path because obviously you want to look at how it is, how the system is changing or such, right. So what else? So biodegradation assessment wells, so they are looking at biodegradation assessment wells.

I will come back to this. So here we had to have 2 cases. Two cases of source disposal regions required. So after the spill, here you have a major source disposal region and minor source disposal region. So this is the major source disposal region, right. And then the minor source disposal region. So they were disposing NAPL, DNAPL or NAPL here, either storage or disposal.

And then there was flood event and the levee broke. They had levee protecting this particular site. Again as we know this site is remarkably low lying, right. And during the flood, the levee could not do the job or failed and then the site was overrun due to floods and the flood, let us say, and you had spill of all this NAPL and DNAPL, let us say, into the shallow region, let us say, right.

We will come back to that. So again what else do we have? So key aspect is that this is the major source disposal region and minor source disposal region. And obviously after the flood, all this was also contaminated now, right. So obviously again the ground water was actually flowing in this direction, I believe. We will look at that later. So here we have this secondary spilled sources. So these are the primary spilled sources and after secondary as in, we have them out here, let us say, right. So the secondary spilled source is here.

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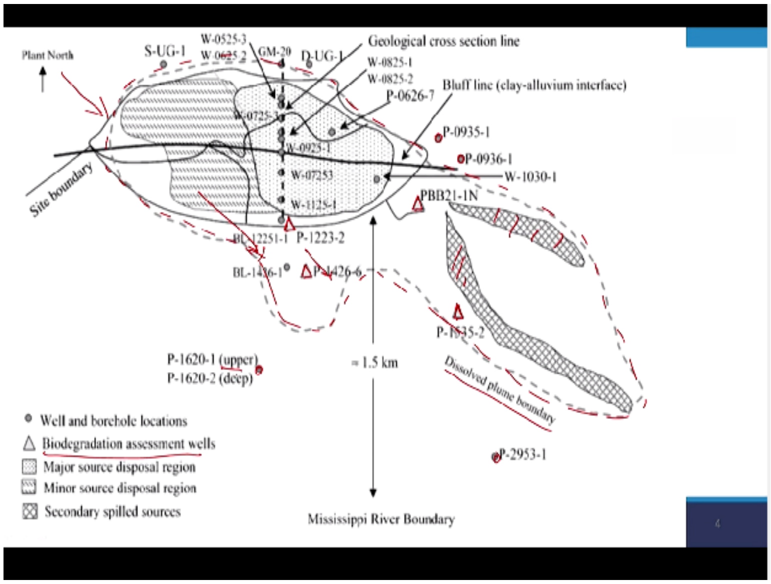

And more importantly if you look at this particular dotted line, and this is nothing but this huge area has this contaminated plume, right. So you have the major source, what do we say, locations, right. So 1 and 2, major and minor and then another secondary spilled sources, right. And obviously you have DNAPL and that is going to percolate through your particular soil, let us say, right.

And you are going to have ground water at relatively high, what do we say, levels because of the river being close by, right. So you are also going to have contamination of your particular ground water, let us say, or the relevant, what do we say, ground water near the river anyway. And thus you are going to have a plume and this is the relevant boundary as you can see, right. So anything else that we have out here?

I think, okay. So here as you can see now, let us say, this is the major source region and as I mentioned as we are going to look at it, the ground water is flowing in this direction now, right. So here to understand if remediation is taking place or not, they dug some biodegradation assessment wells, right. That is something that you see, right. Because now the plume is moving in this particular direction.

They dug some wells in the downstream of the source, right. That is something to keep in mind because we are going to come back to that. These are the downstream locations. As you see, they also dug wells outside the contaminated zones to understand the background data, both at upper and deep levels, let us say, right. At shallow and deep levels, right. So that is something to keep in mind. So lets us move on. So geological data.

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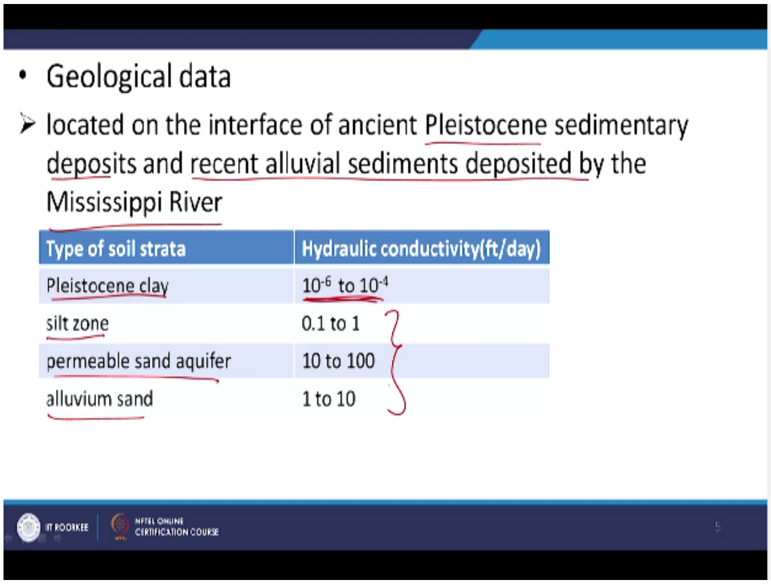

- Geological data
  - located on the interface of ancient Pleistocene sedimentary deposits and recent alluvial sediments deposited by the Mississippi River

Type of soil strata	Hydraulic conductivity(ft/day)
Pleistocene clay	10^{-6} to 10^{-4}
silt zone	0.1 to 1
permeable sand aquifer	10 to 100
alluvium sand	1 to 10

So looks like they have an ancient Pleistocene sedimentary deposits and recent alluvial deposits from the Mississippi River, right. Alluvial deposits, right. So that is something to keep in mind. Let us look at that. Obviously the ancient clay layer, hydraulic conductivity is relatively less, right, 10 power -6 to 10 power -4.

So silt zone and permeable sand aquifer and alluvium sand, obviously as you would expect, the hydraulic conductivity is remarkably high, right, as you would expect again, right. So the hydraulic conductivity is remarkably high for this particular zone but obviously we need to look at the strata now, right. So let us move on.

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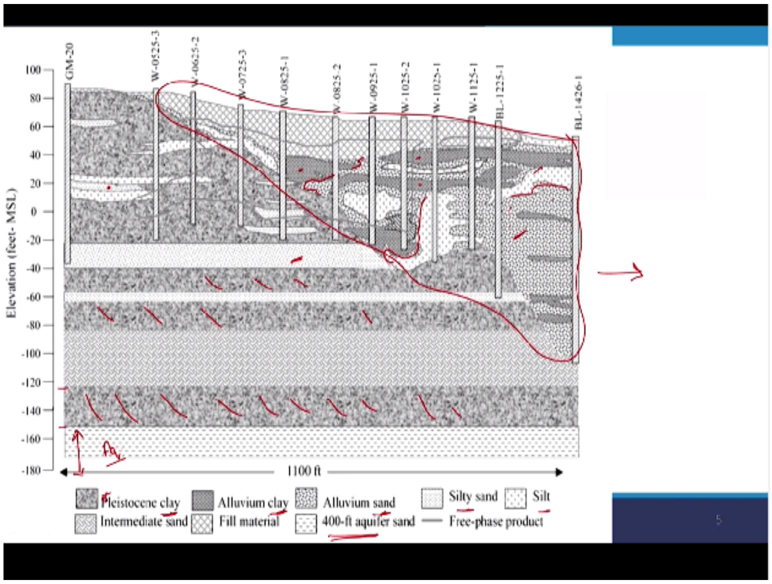

And so now as we can see along this particular set of wells that were dug earlier, right, I believe we are going to see that. So you can see the profile here, right. So let us understand the different, what do we say, layers here. So you have this ancient clay layer, right and typically that is what you see out here, right. And also different ancient clay layers here from this particular legend, yes.

And obviously beneath that you have this 400 feet aquifer. And obviously as we discussed or mentioned earlier, right, we do not want the relevant, what do we say, contaminant to reach this particular huge aquifer now, right. That is something to keep in mind. And then obviously you have some alluvium clay, right at some zones. Out here alluvium clay, some alluvium clay and considerable sections of alluvium sand for which we saw that the hydraulic conductivity was very high and we see that out here alluvium sand, right, into sandwiched between different clay layers, right.

Silty sand obviously again, silty sand out here, right. Different locations you can find that, silty sand, let us say, right, silty sand layers. Again silt, considerable silt, layers of silt, again sandwiched. So the key here is that because it is on the river bed, let us say, or near the river bed, you have a remarkably complex, what do we say, site here, right. That is something to keep in mind.

But one aspect is that, do you have, what do we say, deep lying aquifer, you have some level of comfort in that, you have layer of less hydraulic conductivity, the ancient clay layer above it. And the thickness seems to be around a few 10s of feet, right. Maybe 20 feet, yes or 40 feet. But that is something that you need to take or keep a note of. But obviously you need to contain the relevant NAPL, right.

So that is something to keep in mind. But the other take home message is as you move towards the river, as in the river is in this direction, you see that the amount of, what do we say, the amount of layers, let us say, or the number of layers, let us say, or the fraction of the soil that is relatively more conductive or has greater hydraulic conductivity or greater permeability increases.

So that is what you see out here, right. Example, mostly here you have clay and so on and so forth. But as you move towards the river, let us say, as you see because of the relevant deposits and such, you have different layers of, what do we say, sand or silt that were deposited by the relevant river. That is something to keep in mind. Why is that? Because now, let us say, the plume shape and distribution is going to be remarkably complex, right. So let us move on.

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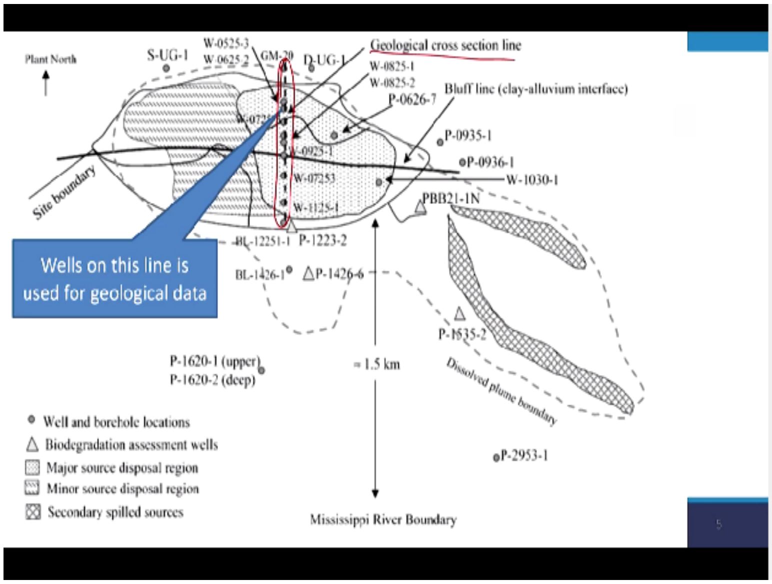
Wells on this line is used for geological data

And now as we see these were the set of wells we looked at.

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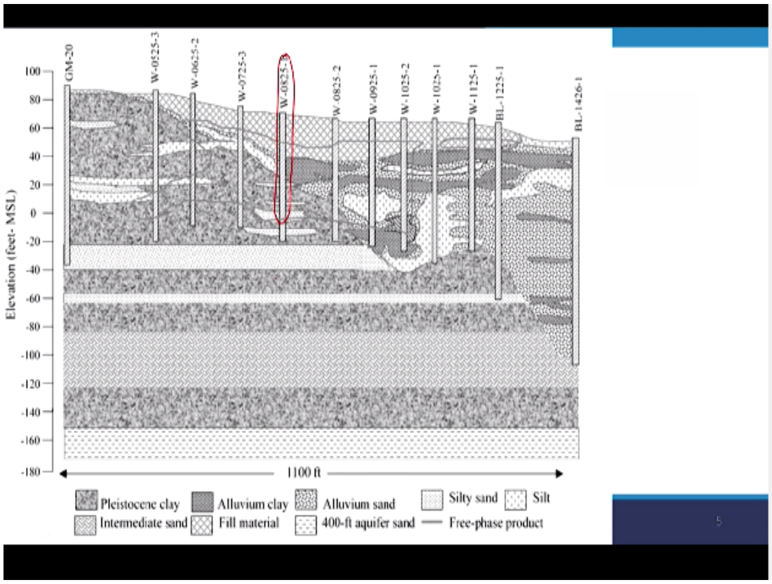

All these wells that we looked at. Let us say, this is the side view. This is the top view and we looked at the side view for these set of wells, right. So as you see this is the geological cross-section like. So we looked at this particular data right now.

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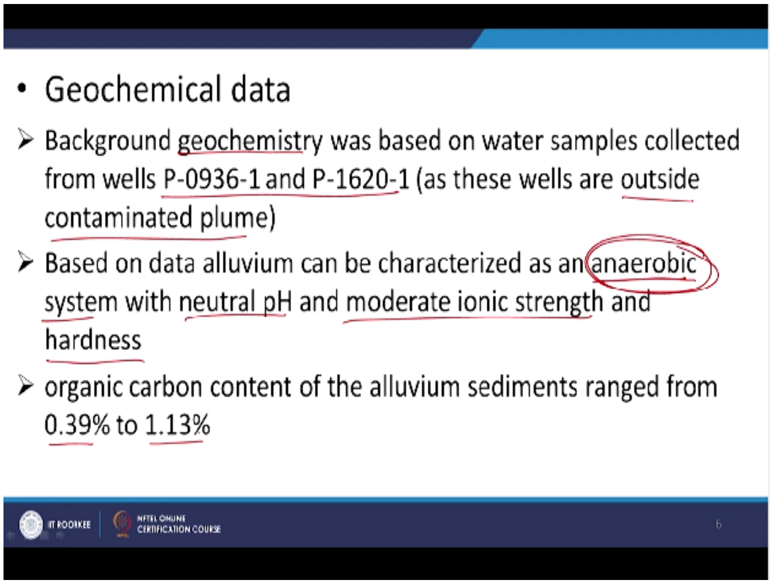

- Geochemical data
  - Background geochemistry was based on water samples collected from wells P-0936-1 and P-1620-1 (as these wells are outside contaminated plume)
  - Based on data alluvium can be characterized as an anaerobic system with neutral pH and moderate ionic strength and hardness
  - organic carbon content of the alluvium sediments ranged from 0.39% to 1.13%

So let us look at some of the geochemical data. Why is this important? Obviously you want to know, let us say, is the site relatively more, has more of reducing conditions, oxidizing conditions, or such, right. Because obviously only then can you understand, let us say, the system in terms of is it favourable for natural attenuation, yes or no and so on and so forth. So let us look at that data.

So background geochemistry, obviously needs to be based on samples that are not affected by this contamination. So they were based on samples collected from 2 particular wells which are outside the contaminated plume, right. That is the take home message. And then also data, based on the data, alluvium can be characterized as looks like the take home message is, it is anaerobic system and the pH is more or less neutral and the ionic strength is moderate and also hardness is moderate, right.

But the key aspect is that it is an anaerobic system, right. One of the aspects, I mean one of the reasons why that is, what do we say, key, what is that, I guess. If you think about it, what are the relevant contaminants we are looking at. They are chlorinated solvents or oxidized contaminants, let us say, or oxidized organic compounds now, right. So for monitored natural attenuation to go for, what you need?

You need both an electron donor and an electron acceptor, right. So let us say, we have some particular electron donor here. We are yet to look at the data but we look at the data. But once we look at the electron donor, let us say, we are obviously going to look for an electron acceptor. But if it is an aerobic system and you have oxygen, right, as we looked at the relevant preferences for the microbes, let us say, based on the delta g or the amount of energy that they can gain from the system.

If oxygen is present, obviously these chlorinated solvents will not play a role or the microbes would not want to degrade these chlorinated solvents, right. So that is something to keep in mind that anaerobic conditions are certainly requirement in this context. And obviously nitrate and nitrite and other relevant aspects, let us say, also need to be looked at. But at least from the preliminary data, we can understand that at least we can spend more resources and look at this slightly further detail, right.

So let us move on. And also organic carbon, it seems range from 0.39% to 1.1%, let us say. Again why is this important now? As we know, soil has organic carbon as we see here. And this organic carbon can adsorb your NAPL, right. So why is this the key aspect? As we looked at the relevant data or break down whenever, let us say, there is adsorption or even just the NAPL, let us say.

We saw that pumping and treating this water is remarkably or almost impossible, right. Why is that? Because these NAPL or the adsorbed, NAPL adsorbed on to the soil, let us say, act as reservoirs as in you keep pumping out, again there is going to be a rebound, let us say, right. So that is an issue. Again something to keep in mind. So lets us look at that.

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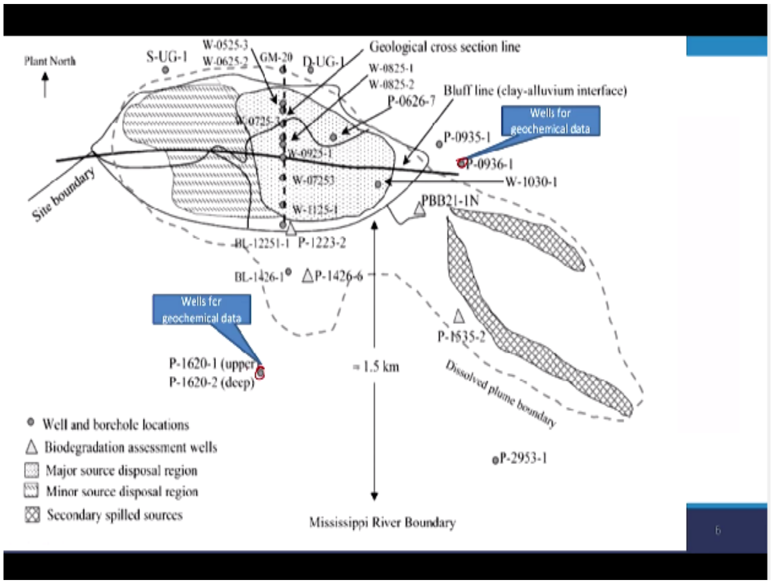

And so these are the wells that were used for geochemical data. As we mentioned, they are outside the relevant plume now, right. So let us look at what the data is.

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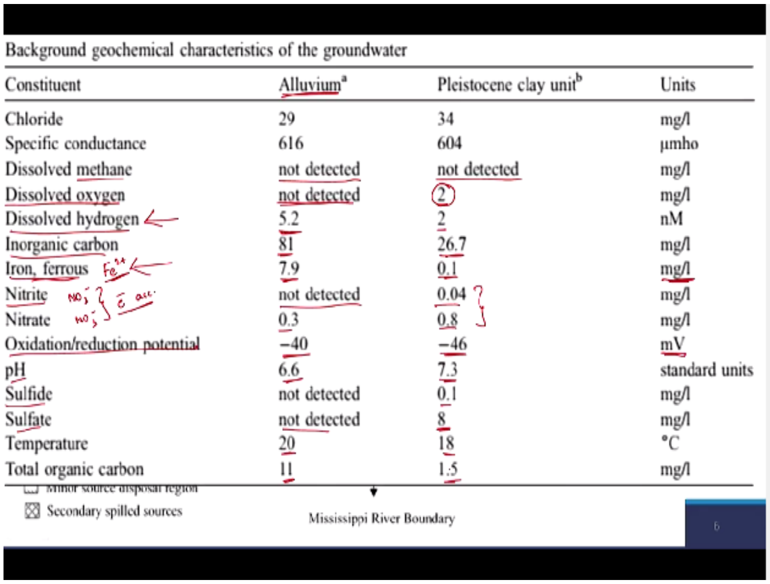

Background geochemical characteristics of the groundwater

Constituent	Alluvium[a]	Pleistocene clay unit[b]	Units
Chloride	29	34	mg/l
Specific conductance	616	604	µmho
Dissolved methane	not detected	not detected	mg/l
Dissolved oxygen	not detected	2	mg/l
Dissolved hydrogen	5.2	2	nM
Inorganic carbon	81	26.7	mg/l
Iron, ferrous Fe^{2+}	7.9	0.1	mg/l
Nitrite NO_2^- ē acc.	not detected	0.04	mg/l
Nitrate NO_3^-	0.3	0.8	mg/l
Oxidation/reduction potential	−40	−46	mV
pH	6.6	7.3	standard units
Sulfide	not detected	0.1	mg/l
Sulfate	not detected	8	mg/l
Temperature	20	18	°C
Total organic carbon	11	1.5	mg/l

So let us look at this data here. Geochemical characteristics, so constituent different parameters here. Alluvium in one case and Pleistocene clay in the other. Alluvium would be probably still present in the site that is closer to the river and the ancient clay in the well that is farther away from the river, let us say. So what they look at? Chloride, okay as expected levels. Specific conductance, not a major aspect out here, right.

And dissolved methane, again that is not detected. And obviously you would expect it to only affects in strongly reducing conditions and dissolved oxygen, this is the key that we were looking for. As you see, it was not detected again in the alluvium or the one that is closer to the relevant river anyway. Not detected. But the one relatively farther away from your particular or at least in the clay unit anyway, they had some dissolved oxygen, some but not a lot.

So again dissolved hydrogen indicative of the reducing conditions. Hydrogen is an electron donor, right, is a reducing agent. So you have considerable hydrogen in the alluvium and some in the clay layer, right. So inorganic carbon, again relatively higher in the alluvium as you would expect and relatively less in the clay layer. Iron, the ferrous form, Fe2+, again a reducing agent, right.

It is considerable in the alluvium. Again the units are mg/l, so that is considerable concentration. Relatively less in the clay layers, right. Again we saw that we have reducing agent or couple of reducing agents. What are they? Hydrogen and ferrous iron, right. So at least you have the electron donor, right. At least that is one of key aspects that we are able to look at here. Nitrite and nitrate which can act as competing electron acceptors.

If you have way high concentrations of oxygen or nitrite or nitrate, let us say, what can happen now? Rather than the microbes taking the electron, let us say, or giving the electron, pardon me, or using this chlorinated solvent in the redox reaction are going to use nitrite and nitrate as the electron acceptor, let us say, right. Or that is going to play the role. Why is that? Because they give more energy or can provide more energy to the microbes now.

So obviously as you see either they are not detected or at relatively low concentrations. So that is something to keep in mind. And obviously we saw that we have electron donors, right at relatively high concentrations. So redox potential, let us say, is going to be reducing conditions, indicative of reducing conditions and that is why you say it is minus, let us say, may be worse typically that indicates that the reducing conditions are prevailing. pH as was mentioned earlier, is relatively neutral, right.

And sulfide is not detected. Sulfate, another probable, let us say, electron, what do we say, competing electron acceptor, let us say, is either not detected or at 8 mg but that is in the clay units or clay layers, pardon me. And again temperature as you would expect, let us say, and total organic carbon, right. But again what is the take home message here?

You have the electron donors which are ferrous iron and, what is it now, hydrogen. And you also have less to none of the electron or competing electron acceptors. What are the competing electron acceptors? Oxygen, nitrate, sulfates and so on. And they are at relatively low concentrations, right. So this is the background data though. So let us move further.

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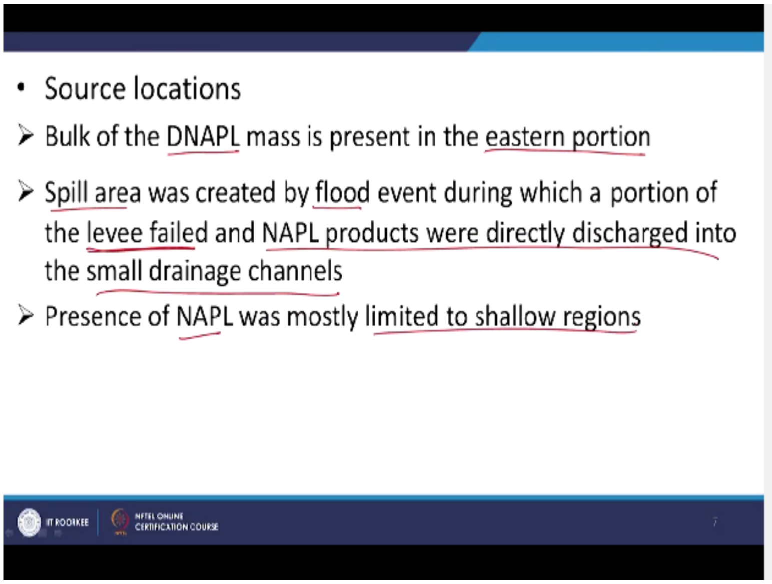

- Source locations

➢ Bulk of the DNAPL mass is present in the eastern portion

➢ Spill area was created by flood event during which a portion of the levee failed and NAPL products were directly discharged into the small drainage channels

➢ Presence of NAPL was mostly limited to shallow regions

So source locations obviously. So bulk of the DNAPL is present, it seems, in the eastern portion, that is something to keep in mind. Spill area as I mentioned earlier was caused due to a flood and the flood led to or during the flood, the levee failed and the NAPL products were directly discharged into the small drainage channels, right. So that is something to keep in mind, right. As in even though they are relevant, what do we say, protection against the flood, probably not a good way or not way, pardon me, site to store your DN, dense and light NAPL, right.

That is something to keep in mind. So presence of NAPL was mostly limited it seems to the shallow regions, okay.

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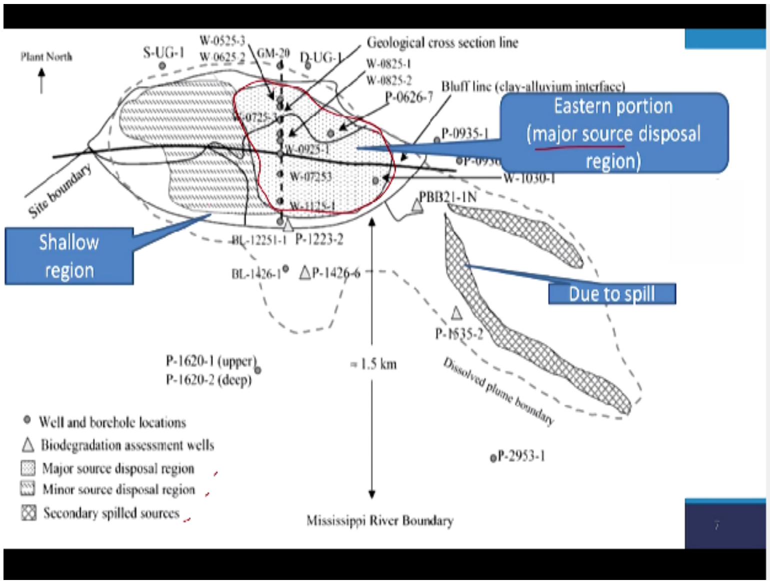

Eastern portion (major source disposal region)

Shallow region

Due to spill

- ● Well and borehole locations
- △ Biodegradation assessment wells
- ▨ Major source disposal region
- ▨ Minor source disposal region
- ☒ Secondary spilled sources

So let us look at the site again. So shallow regions, where do we have that secondary spill here, right. And minor source zones, yes. So eastern portion as it was mentioned is where we have the major source disposal, right. And due to the spill or due to the spill and transport, let us say, secondary spill anyway. And this is the shallow region, let us say, right. So that is something to keep in mind, right.

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Levee is here

And we see the levee here. The levee across the, along the boundary of this particular site here and it seems that failed.

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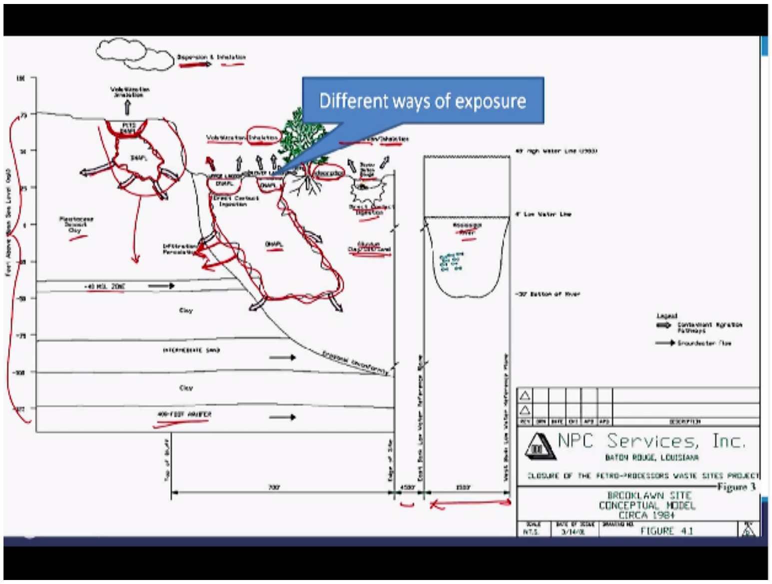

Different ways of exposure

And here we have the relevant picture, let us say, or schematic that will give us an idea about the different pathways while also understanding the transport or helping us understand how the NAPL is being transported, let us say, right. So let us look at what we have. First aspect is that we are looking at relatively low mean sea levels, that is something to keep in mind. As you can see here, this is that -40 mean sea level zone, sea level zone we talked about.

And a few feet maybe beneath that we have, let us say, or around 80 feet beneath that we have this huge 400 feet aquifer. And around, let us say, I think 1.5 km away, we have this huge Mississippi River here, right. The Mississippi River here, that is something to keep in mind, right. And here you have the spills where DNAPL is now present, DNAPL.

And as we know, DNAPL again being dense, that is going to permeate through and this is what we observe here, this has permeated through or the DNAPL has permeated through and more time obviously it is going to permeate further, let us say. So one of the aspects has to be to contain this particular transport of the DNAPL. But obviously we are not going to talk about all those aspects, other aspects were looked at.

We are only going to look at the monitored natural attenuation part of this particular remediation process, let us say, right. But we need to understand what is happening? So you have DNAPL, let us say, transport, right. And what else do we have? And then in this upper lagoons, let us say, and lower lagoons, we again have, due to the spill, other DNAPL and because this zone, let us say, has, what do we say, greater hydraulic conductivity because this is a mixture of alluvium, clay, silt, or sand, you can see that the DNAPL was spread over a larger extent, let us say.

And here because it is mostly clay, the DNAPL has only been able to percolate through to a smaller extent, let us say, right. Obviously we looked at the hydraulic conductivities, they were relatively less. And again tortuosity factors too can be looked at to understand how or why, let us say, you observe greater DNAPL transport in the relevant alluvium layer, let us say, right. Again we looked at some data here.

So what can happen again? From here again you can have this DNAPL reaching the lower portions of this particular clay layer. The key aspect is that even though the DNAPL here was not able to permeate or percolate or reach this particular deeper clay layers, what can happen is? You can have diffusion, let us say, or infiltration or percolation here as they mentioned, let us say, right.

From this particular DNAPL and the alluvium layer into the clay layer here, right. So that is something of concern here, right. Because that can lead to obviously reservoirs of the contaminant even at very deep layers or zones, right. That is something to keep in mind. Why is that? Obviously the deeper your contamination, again difficult to either address it or get it out or treat it, right.

That is one aspect to keep in mind. As in here, let us say, the people should not just be looking at this particular area but also be concerned with this particular, what do we say, transport from this DNAPL zone, right. So what else? Obviously you can have adsorption into the relevant, what do we say, life out here or the echo system. One of them being the trees here. And obviously LNAPL and such, they are going to be volatile, let us say, and also exposed to direct sunlight.

So you are going to have volatilization, change in phase into the gaseous phase. And thus have inhalation. Inhalation is one route of exposure for the different people in that or near that particular location, let us say. Obviously adsorption into the soil or on to the trees and such. And here, again direct contact through ingestion if it goes through to Baton Rouge, let us say, right. So that is something to keep in mind.

I think we more or less covered most of the aspects. So what are we concerned with? Adsorption, volatilization leading to inhalation, right. And obviously in the DNAPL pits, we are also looking at further transport by air, let us say, and dispersion and inhalation. And one major aspect of the site is that this particular alluvium or the contaminate in the alluvium layer can lead to contamination of the clay even at the deeper zones, right. That is something to keep in mind. Let us move on. So different ways of exposure.

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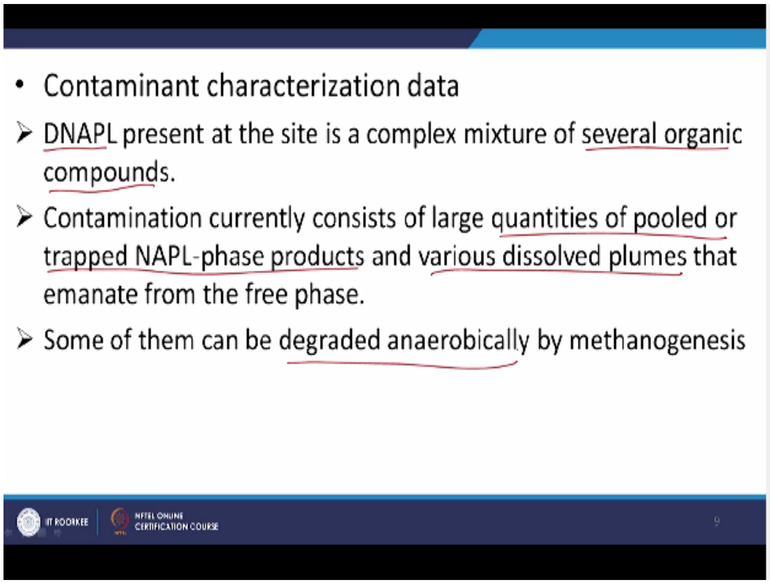

- Contaminant characterization data
- DNAPL present at the site is a complex mixture of several organic compounds.
- Contamination currently consists of large quantities of pooled or trapped NAPL-phase products and various dissolved plumes that emanate from the free phase.
- Some of them can be degraded anaerobically by methanogenesis

So let us look at characterizing the contaminant, let us say, or understanding what is present in this LNAPL and DNAPL, let us say. So DNAPL, it seems was a mixture or is a mixture of several organic compounds. It is not just 1 or 2 types of compounds but a lot of them. And contamination consists of large quantities of pooled or trapped NAPL phase and various dissolved plumes.

So this is the key here. We have either just NAPL pool or trapped NAPL phase products as in in the soil or such or even dissolved in the aqueous phase or in the ground water there, right. So it is the worst case scenario. You have the NAPL, you have NAPL adsorbed on to the soil and you also have NAPL dissolved into the relevant ground water, right. And some of them looks like can be degraded anaerobically. Let us look at them later, okay.

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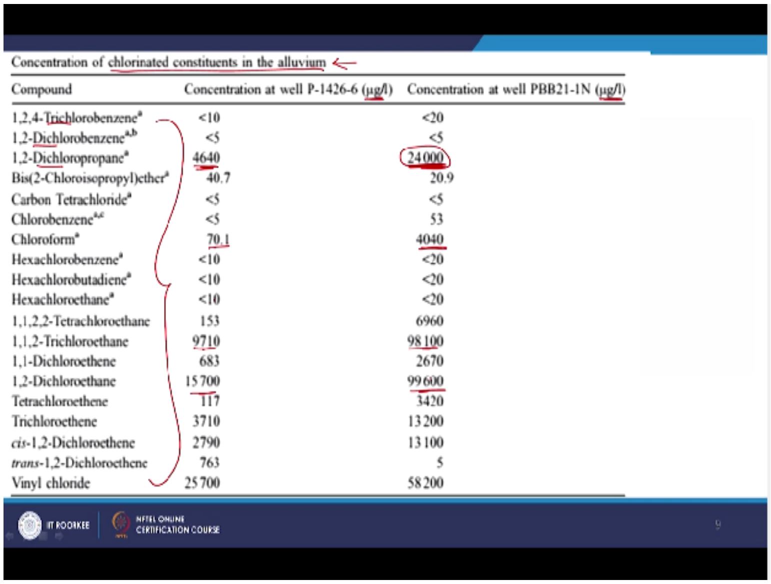

Concentration of chlorinated constituents in the alluvium

Compound	Concentration at well P-1426-6 (μg/l)	Concentration at well PBB21-1N (μg/l)
1,2,4-Trichlorobenzene^{a}	<10	<20
1,2-Dichlorobenzene^{a,b}	<5	<5
1,2-Dichloropropane^{a}	4640	24 000
Bis(2-Chloroisopropyl)ether^{a}	40.7	20.9
Carbon Tetrachloride^{a}	<5	<5
Chlorobenzene^{a,c}	<5	53
Chloroform^{a}	70.1	4040
Hexachlorobenzene^{a}	<10	<20
Hexachlorobutadiene^{a}	<10	<20
Hexachloroethane^{a}	<10	<20
1,1,2,2-Tetrachloroethane	153	6960
1,1,2-Trichloroethane	9710	98 100
1,1-Dichloroethene	683	2670
1,2-Dichloroethane	15 700	99 600
Tetrachloroethene	117	3420
Trichloroethene	3710	13 200
cis-1,2-Dichloroethene	2790	13 100
trans-1,2-Dichloroethene	763	5
Vinyl chloride	25 700	58 200

So here concentration of the various chlorinated constituents in the alluvium. We are looking at the alluvium, different wells out there, okay. Units are ppb micrograms per liter. So we have, as you can see, an exhaustive list of compounds, let us say. And again I believe this is not comprehensive but more or less a snapshot. Let us look at what is the common factor out here? As we can see, the common factor is that all of them are chlorinated organics, let us say, right.

So you have trichlorobenzene and dichlorobenzene and dichloropropane and ether, let us say. Again chloro here, carbon tetrachloride, chlorobenzene, chloroform, hexachlorobenzene and so on. Again as you see, all of these are chlorinated compounds, let us say, right, chlorinated organics. So concentrations, looks like for dichloropropane, considerable concentrations, right. At different, obviously the site, it is complex.

So you have different concentrations at different levels. Here it is almost, what do we say, 6 times greater here in this particular well, right. And again chloroform, remarkably toxic again. You have that at relatively high concentrations. And trichloroethane, dichloroethane and so on. As in if you remember, we looked at some of the examples in some of these compounds in a particular example.

I think we had PCE or TCE contaminating a site for a I believe PRB, right. And we looked at remediating that site by PRB, right. That is something to just refresh your memory. So let us look at what else we have.

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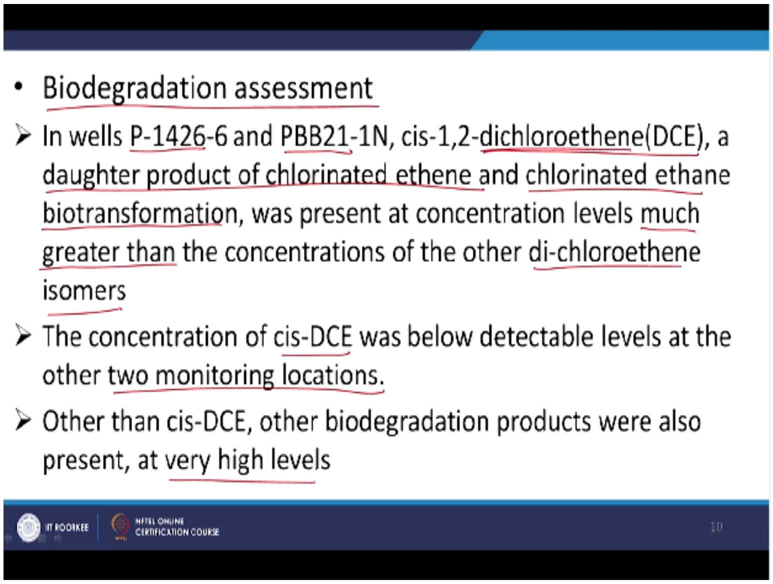

- Biodegradation assessment
  - In wells P-1426-6 and PBB21-1N, cis-1,2-dichloroethene(DCE), a daughter product of chlorinated ethene and chlorinated ethane biotransformation, was present at concentration levels much greater than the concentrations of the other di-chloroethene isomers
  - The concentration of cis-DCE was below detectable levels at the other two monitoring locations.
  - Other than cis-DCE, other biodegradation products were also present, at very high levels

So first obviously we want to understand, let us say, biodegradation feasible or not. We did look at some of the aspects, right. But obviously we also want to be able to have greater data out there or more data, pardon me. So in these 2 wells, looks like 1,2 DCE, let us say, which is a daughter product of chlorinated ethene and chlorinated ethane, let us say, or PCE and TCE, let us say, was present at concentration levels.

This is the key here which were much greater than the concentrations of the other dichloroethene isomers, right. So again this is the daughter product as in during, which you would expect during degradation, let us say, of this particular source compounds. And that was present at relatively high concentrations, right. So that is one particular aspect. And what else? The concentration of this DCE was below detectable levels at the other 2 monitoring locations, let us say, right.

And again we also going to look at the data for the source and we will see that in the source, this is 1,2 DCE is at relatively low concentrations. But as you look at the wells downstream, let us say, where you would expect, let us say, the microbial process to be relatively active, right, you see that the concentrations of this particular compound are relatively higher than then at the relative in the source, let us say, right. That is something to look at. Other biodegradation products were also present at very high levels. We look at what they are.

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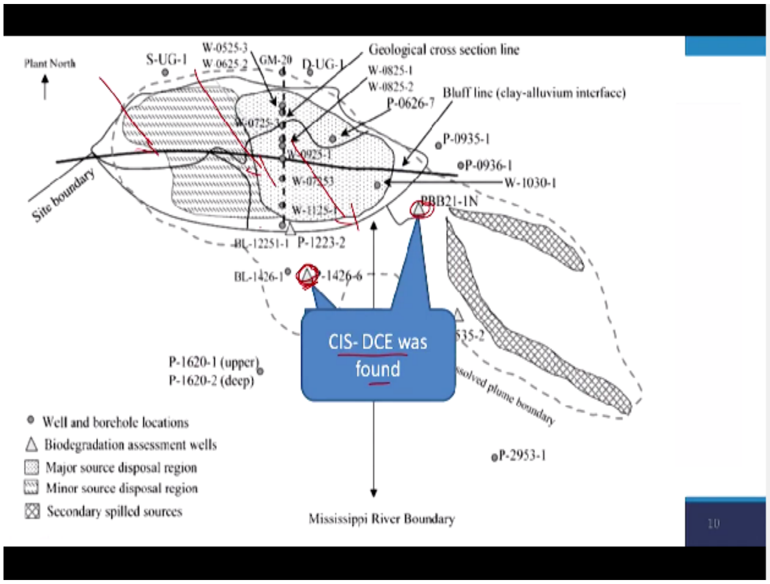

CIS- DCE was found

So these are the locations where this daughter product was found as I mentioned earlier, the ground water I believe or is flowing in this particular direction. And as you would expect as the plume moves, let us say, right, or is transported, you would have microbial activity here depending on various process and here the daughter product was found.

Again the concentration of this by-product which you would typically, what do we say, assume would be present only when there is microbial degradation, let us say, or degradation of, what we say, the contaminant by the microbes is relatively higher than in the relative source though. We look at that data again.

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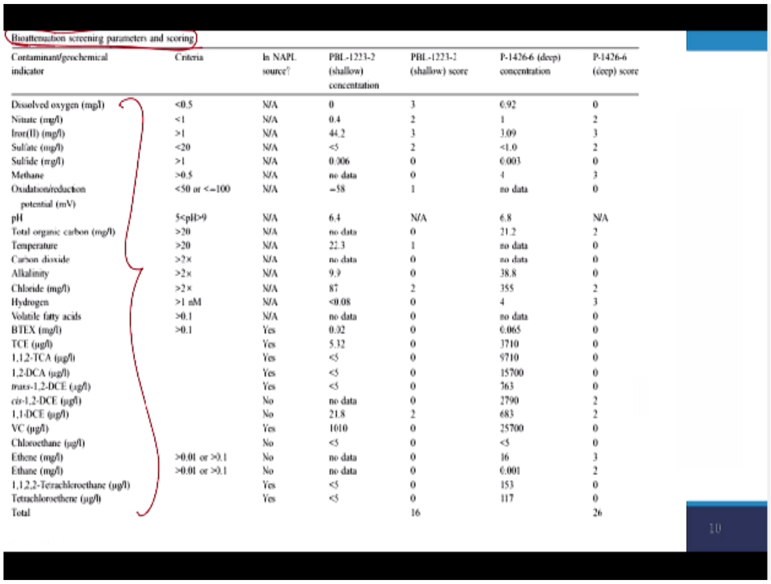

Bioattenuation screening parameters and scoring

Contaminant/geochemical indicator	Criteria	In NAPL source?	PBL-1223-2 (shallow) concentration	PBL-1223-2 (shallow) score	P-1426-6 (deep) concentration	P-1426-6 (deep) score
Dissolved oxygen (mg/l)	<0.5	N/A	0	3	0.92	0
Nitrate (mg/l)	<1	N/A	0.4	2	1	2
Iron(II) (mg/l)	>1	N/A	44.2	3	3.09	3
Sulfate (mg/l)	<20	N/A	<5	2	<1.0	2
Sulfide (mg/l)	>1	N/A	0.006	0	0.003	0
Methane	>0.5	N/A	no data	0	4	3
Oxidation/reduction potential (mV)	<50 or <−100	N/A	−58	1	no data	0
pH	5<pH>9	N/A	6.4	N/A	6.8	N/A
Total organic carbon (mg/l)	>20	N/A	no data	0	21.2	2
Temperature	>20	N/A	22.3	1	no data	0
Carbon dioxide	>2×	N/A	no data	0	no data	0
Alkalinity	>2×	N/A	9.9	0	38.8	0
Chloride (mg/l)	>2×	N/A	87	2	355	2
Hydrogen	>1 nM	N/A	<0.08	0	4	3
Volatile fatty acids	>0.1	N/A	no data	0	no data	0
BTEX (mg/l)	>0.1	Yes	0.02	0	0.065	0
TCE (μg/l)		Yes	5.32	0	3710	0
1,1,2-TCA (μg/l)		Yes	<5	0	9710	0
1,2-DCA (μg/l)		Yes	<5	0	15700	0
trans-1,2-DCE (μg/l)		Yes	<5	0	363	0
cis-1,2-DCE (μg/l)		No	no data	0	2790	2
1,1-DCE (μg/l)		No	21.8	2	683	2
VC (μg/l)		Yes	1010	0	25700	0
Chloroethane (μg/l)		No	<5	0	<5	0
Ethene (mg/l)	>0.01 or >0.1	No	no data	0	16	3
Ethane (mg/l)	>0.01 or >0.1	No	no data	0	0.001	2
1,1,2,2-Tetrachloroethane (μg/l)		Yes	<5	0	153	0
Tetrachloroethene (μg/l)		Yes	<5	0	117	0
Total				16		26

So let us look at what we have here. So by attenuation screening parameters, let us say, right and scoring. So again here we have different, what do we say, parameters and here we are trying to understand, let us say, is by attenuation occurring or not and how well it is occurring or not and for that, we have different screening parameters and so on and so forth. But I am slightly running out of time. So I will end this session for now and we will look at this particular aspect in the next session. And that is it for me from today, for today pardon me and thank you.