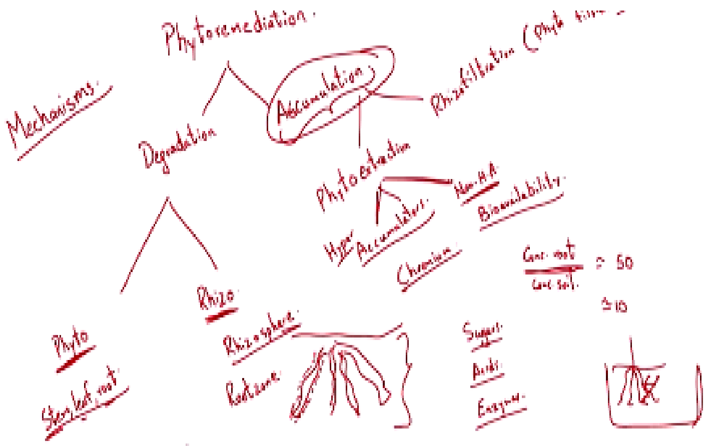
Environmental Remediation of Contaminated Sites
Prof. Bhanu Prakash Vellanki
Department of Civil Engineering
Indian Institute of Technology – Roorkee

Lecture - 58
Phytoremediation

Hello everyone. So again welcome back to the latest lecture session. So today we are going to discuss or you know look at the aspects relevant to Phytoremediation right. So obviously as we discussed earlier we know bio remediation we look at aspects relevant to both the living organism right or you know the living organism. So when we talk about living organism we refer to both the microorganisms and plants let us say right.

(Refer Slide Time: 00:48)



So when we talk about Phytoremediation typically we are also you know talking about bio remediation too right Phytoremediation right. So in this context of Phytoremediation recently there was particular proposal that was put forth from our particular side as in from few departments (()) (01:08) to a particular national agency let us say for remediating a particular contaminated site.

So as part of or in conjunction with some of the other remediation techniques we also suggested Phytoremediation for a particular what do we say land let us say or set of contaminated land let us say right. So at that particular point in time you know the relevant person let us say from the agency was dismissively was mentioning that. Phytoremediation you know just change phase from of the contaminant from one to the other but you are not actually degrading that, but you know that is a myth and even though a part of that is true.

Event that is better than having the contaminant in the soil or the groundwater than being available for transport let us say to the relevant human population. As in the relevant criticism was that so rather than having the contaminant only the soil now you are having it in the plant or such let us say right. So that is what the relevant issue was, but again rather than having it in the land or contaminating the groundwater you can have it in another phase let us say where it is relatively mobile that is obviously within the plan.

But it is not as if just change in phase you are also going to have a degradation let us say or transformation of the relevant compounds. So obviously we are going to look at some of those aspects in a bit more detail let us say. So when we talk about Phytoremediation we obviously need to look at the mechanism let us say what are the different mechanism right and so typically we have.

What do we have one based on degradation and one based on may be accumulation if I may say so right. So let us look at degradation first. Again there are self exclamatory obviously one you are actually in one case you are actually degrading the relevant contaminant. The other may be you can think of either remobilizing it or just accumulating it in one particular zone or let us seeing to it that relevant compound is not available for transport.

So within the context of degradation you have phyto and Rhizo let us say right. So when I talk about phyto I am referring to relevant uptake of the contaminant right through the root zone and such let us say into the relevant stem, leaves and the root let us say right and within this particular plant let us say degradation or transformation of the relevant product takes place let us say right.

So that is with respect to Phytoremediation let us say right so that is what we have, but what is this Rhizo degradation let us say that we have out here. So this obviously as the name indicates is occurs in the Rhizosphere let us say right or in the root zone of the plant let us say as in if you have your root zone let us say if this is the subsurface and you have all your roots and such out here right.

So there is a particular what do we say zone around the roots let us say where the conditions are relatively more favorable for the microbes to thrive let us say right. So may be around 1 mm now right away from these particular roots let us say right. So that particular zone let us say is remarkably conductive typically let us say for microbes to thrive why is that. You have what do we say the exudates from the relevant roots or the plant let us say.

They can be sugars let us say right different acids let us say right or such aspects or enzymes let us say from the relevant plants right that can aid in or promote the growth of these relevant microbes let us say or create conditions that let the microbes thrive let us say right. So here it is not that the plant is directly involved in degrading the relevant contaminant but that it creates conditions for bio remediation to take place are the degradation to take place by the microbes let us say right.

So that is the one Rhizo degradation if I may say so right. So in phyto the plant itself is actually degrading the relevant contaminant after taking it in and that is present as in the contaminant can represent either in the stem, leaves or the relevant root and the relevant transformation can be taking place let us say right. In the root zone obviously as we discussed that there are other aspects let us say.

So there are different aspects too as in sometimes you can choose the tree such that you know there is no uptake of the contaminant. As in the contaminant does not go into the root, stem or leaves, but only that the relevant Rhizo degradation is promoted let us say. There are some such trees that you can choose, but obviously there is no one tree that you can choose for all contaminants.

There are some particular trees that have shown some affinity in particular soils and climate conditions for some kinds of contaminants or such let us say right and another aspect is that here the limitation is that as you can see right if the degradation is occurring at great depths is this relatively feasible not really why is that. Obviously the bio degradation will only take place within the root depth let us say or you know to the extent to which the roots can penetrate or such let us say.

So the time required for the roots to penetrate to the relevant locations or even the depth towards the roots can penetrate to right that is a major limiting factor or aspect out here let say right so that is something to keep in mind. So let us move on to accumulation let us say right. So one again is phyto is phyto extraction right and the other is Rhizo filtration or phyto filtration let us say right.

So again here keep in mind that the relevant aspect is that the compound is not being degraded, but that it is being accumulated let us say right. So typically what is the issue now if I have pollutant all around in this room let us say that is an issue because of the relevant people that might occupy this room will be exposed to the contaminant, but it has some way that I can accumulate all this particular contaminant that dispersed throughout this room let us say.

But the dispersion is such that the concentration is still toxic enough. So if I can accumulate all this in one particular location let us say I can limit the relevant affect of the toxicity let us say right. So in that case we have accumulation and we are going to look at phyto extraction. So in this context obviously as I mentioned you have accumulator or hypo or hyper accumulators let us say right.

Some of these trees let us say have a great affinity for some particular compounds typically let us say few metals let us say right as in you know some plants let us say taken heavy metals a few heavy metals let us say at concentrations that are almost 100 times or 1000 times more than other plants that you would typically observe for those same contaminants now right.

Again the reason is not clear, but I think related to reduced effects of toxicity or such let us say in the relevant zone So that is one particular aspect but again you know there is no such one plants that will you know thrive in all conditions, but there are some plants with respect to these hyper accumulators let us say that have been you know known to accumulate as many as 8 heavy metals at very high concentrations.

But sadly you know Chromium looks like is not one of those heavy metals that is taken up by these hyper accumulators let us say and the reason we mentioned Chromium is you know we have considerable issues with Chromium contamination at various sites let us say, but again you have some of these hyper accumulators. So other than that you still have you know these non hyper accumulators if I may say so non hyper accumulators let us say as in typical plants to well taken some of these relevant contaminants and such and so on.

And accumulate them either in the root or plant or such let us say right. So again here it is not degradation that is occurring that is something to keep in mind now right, but one aspect is that you will also need to look at is the bio availability of the relevant contaminant as in let us say sometimes you conduct tests as in let us say you conduct you know I think these are called hydroponic let us say right.

You have the plants let us say in the trees or you know plants pardon me in floating around in water let us say. You conduct the relevant tests and you see that most of the contaminant out here in the relevant water was accumulated in the relevant plant let us say right, but when you try to replicate that on actual site that is not going through why is that because here we know the tests were hydroponic let us say.

The contaminant was in water, but out there the contaminants let us say might be absorbed on to the soil or might be very much you know deeply or reached the interior of the relevant soil let us say So it is not available for uptake by the relevant plant or the relevant root let us say right. So sometimes you can (()) (10:32) agents let us say to make the relevant compound more mobile or such so that it can be taken in by the relevant root system or such let us say right.

And again keep I mind that there are different factors let us say at play but one factor that gives an idea about you know this particular uptake or accumulation is one where you look at the concentration in the relevant root to the concentration in the relevant soil let us say of the relevant compound obviously, concentration of the relevant compound in the root or the plant to the concentration of the relevant compound in the soil.

And typically it is around 50 for some (()) (11:06) for some heavy metals and so on and so forth though. So you get some idea about you know the relevant aspects here. So again that is with respect to phyto extraction and then obviously we are talking about Rhizo filtration I will write that out here.

(Refer Slide Time: 11:21)

Rhizofiltration (phytofiltration)

↓

Immobil.

Precip.

→ Dissipation (phytovol.)

TCE

Hg

→ Immobil.

So Rhizo filtration or phyto filtration let us say right. Right here we are concerned with you know the contaminant that is the groundwater or in the water let us say. Photo extraction we are concerned with the contaminant that is you know the soil or absorbed on to the soil and such and Rhizo filtration or such we are concerned with the contaminant that is in the water let us say. Again the contaminant can be transformed into such forms that it is immobilized or it precipitates out on to the relevant roots or such let us say.

Let us say or the conditions are transformed such that you know the contaminant is not available for transport or such let us say right that we are going to refer to as Rhizo filtration or Phyto filtration right. So another aspect is let us say is dissipation or may be even we can sometimes I think call this phyto volatilization let us say. So you have some forms of mercury let us say that are reduced to this particular form let us say right or you know there are other compounds let us say may be TCE let us say semi volatile.

So some of these compounds let us say are especially TCE let us say is semi volatile. So while it is transformed within the relevant plant let us say once it is taken in some of it is also dissipated through the relevant leaf now right. The leaf has some surface area again that is open to the relevant atmosphere or the gaseous phase. So the contaminant can change phase from the relevant what is this now leaf into the relevant gaseous phase let us say.

So rather than being in the soil and may be available for transport let us say right. And again as you know these hydrophobic contaminants right these contaminants such as TCE are remarkably difficult to remove. So here you are changing phase from one to the other, but again keep in mind that you know though the affects or the concentration in the gaseous phase or in the atmosphere would not be as high as you would and thus the toxic affects will not be as high as you would expect if the TCE were to stay in the soil or the groundwater.

You still are only changing the phase but not completely degrading that something to keep in mind let us say. So we have that particular aspect dissipation. So other aspect is also immobilization as in your particular plants or such let us say are going to change the characteristics of the soil let us say such that the relevant contaminants there and are being immobile.

So this can be brought about by you know stabilization let us say of the relevant soil again we are looking at physical, chemical or biological changes or typically physical or chemical changes that affect the soil properties let us say. And then during this particular process the relevant compounds can be adsorbed on to the relevant soil or even the roots let us say or precipitation can occur and so on and so forth right and these are the major aspects as in what are the major aspects one is degradation based let us say.

One is accumulation based and the other dissipation and the other immobilization. So 4 major aspects typically that we have looked at now right. So we are now going to look at one minor case study.

(Refer Slide Time: 14:40)

REFERENCES

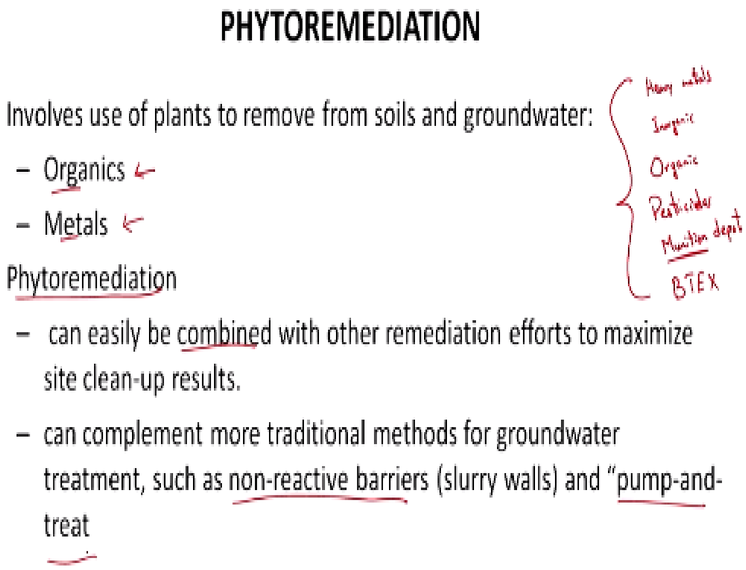
USEPA - *Cost and performance report, phytoremediation at Naval Air Station-Joint Reserve Base Fort Worth, TX* – November 2005

US-Geological Survey - *Demonstration-Site Development and Phytoremediation Processes Associated With Trichloroethene (TCE) in Ground Water*, Naval Air Station-Joint Reserve Base Carswell Field, Fort Worth, Texas- August 2004

So let us look at what I have here. So the references that we looked at let us say for getting the relevant data are from the USEPA the title being cost and performance report. So again this is available in the public domain you can access that the other is from the US GS let us say right or US geological survey and this is from demonstration or site development and phyto remediation process associated with TCE Trichloroethene this is something we have faced a lot in groundwater at Naval Air Station Joint Reserve Base in Texas let us say right.

Again these are the documents that we used to develop the relevant presentation right again they are available in the public domain.

(Refer Slide Time: 15:19)



So obviously Phytoremediation. So here they were trying to look at removing organics and metals and there is something may be I have discussed earlier, but what are some of the relevant compound that can be removed by your particular Phytoremediation or degraded or immobilize or such. Some of them are heavy metals obviously some inorganic, but considerable fraction of organics let us say or considerable organics pesticides.

And many times the Phytoremediation let us say has been widely what do we say employed or deployed at these army basis or ammunitions basis let us say or munition depot as in where they hold the munition or ammunition there you have contamination and that is where they looked at this particular Phytoremediation widely let us say and you know these are some of the kinds let us say BTEX let us say right.

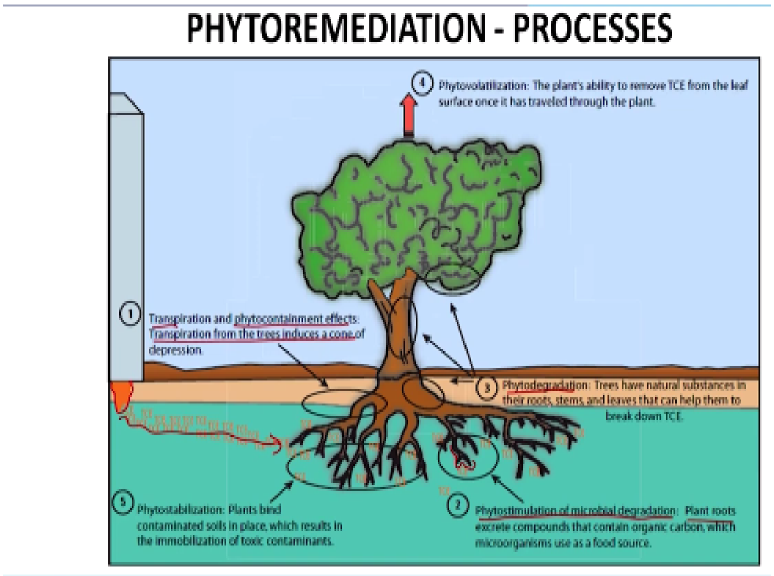
These are different compounds that are have been you know looked at or you know where Phytoremediation has been typically successful let us say. So in this context we are looking at organics and some metals. So again you know the major aspects with Phytoremediation is that it can be combined with other remediation efforts or in conjunction with the other efforts right.

So obviously you are just not just you are trying to plant certain kinds of tress or you know trees that are naturally occurring out there and then increase bio degradation or you know immobilization of the relevant contaminant let us say right. So typically let us say they are also looked at with respect to non-reactive barriers let us say or with pump and treat let us say right.

So if the relevant contaminant is way out there let us say if the depth is way too high let us say obviously the root cannot penetrate to that particular depth or it takes time. So typically pump and treat is used to you know pump out that water let us say that is relatively far off from the root zone and also you know Phytoremediation is looked at for the relevant contamination in the relevant soil or in the shallow regions let us say right.

So that is something to keep in mind and non-reactive barrier typically slurry walls we might have or we will discuss these aspects or we have discussed these aspects rather. So our (()) (17:30) such that the contaminant is not transported off side and is available for the plant for degradation and so on and so forth right.

(Refer Slide Time: 17:38)



So in this case what are some of the aspects that they looked at. Again in this Naval Base considerable what do we say amount of TCE plume was present or contamination was present. And from that you had a plume. So here what are they looking at one is transpiration and Phytocontainment effects let us say right. So again transpiration from the trees induces a cone of depression that is something that looked at here let us say right.

And the second aspect is stimulation for microbial degradation this is something we looked at as in the zone around the relevant roots. What do you mention the plants roots excrete compounds that is something we discussed obviously different enzymes and so on that also contain organic carbon which is also used as a food source let us say. We looked at enzymes typically or obviously for a bio degradation to take place you need an electron acceptor and donor.

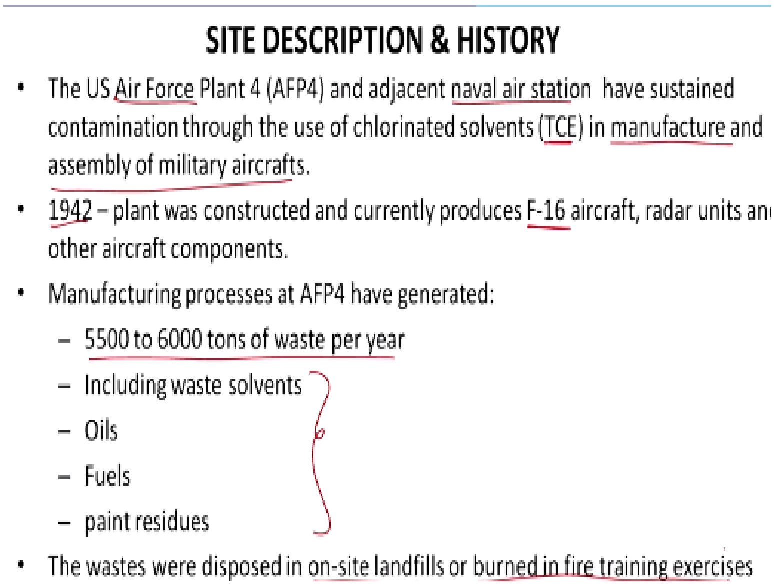
Even if you do not have one of them you know your relevant process is not going to take place. So obviously these roots can or the plants can provide one of these aspects let us say may be the electron donor in this particular case to allow for relevant bio remediation let us say right. So that is one aspect and then Phytodegradation right trees you know have their own systems metabolic process in during that time or during those process.

They can break down the TCE or stabilization plants binds contaminated soils in place which results in immobilization of toxic contaminants right. So that is something again we discussed or Phyto volatilization right. So in this context when they were looking at this particular fields or (()) (19:08) study on the field. These were the 5 aspects that they discussed as you see these are the 2 usual cases that we looked at earlier too right and this is what we have from the particular site.

(Refer Slide Time: 19:20)

So this is the relevant site here you have the contaminated plume and I believe the groundwater is flowing in this particular direction. There were some reasons for this particular lobe through right this is the central lobe, southern lobe and the northern lobe though this is a Naval or pardon an Air Force Base as they mentioned here right. So this is the contaminant plume and you have a contaminant or the contaminated plume you know over a wide area obviously right.

(Refer Slide Time: 19:47)



So let us look at that this particular plant was adjacent to also Naval Air Station let us say US Air Force based adjacent to naval air force or air station. Sustained contamination through use of chlorinated solvents TCE and where were they used in the manufacture and assembly of military air craft let us say right. So they were used widely during these manufacture and assembly.

So the plant was constructed in 1942 and they still produce there premium and F-16 aircrafts right radar units and so on. So they have generated almost 6000 tons of waste per year. Including these kinds of waste okay and these waste were disposed on-site landfills some may be with impermeable layer some may be not or burned during training exercise let us say right. Even when you burn you might have air pollution or even in the residual let us say might leach out let us say right. So that is one aspect to keep in mind.

(Refer Slide Time: 20:45)

SITE DESCRIPTION & HISTORY

- September 1982 – Potential contamination first noted.
- Dispersion and transport of TCE and its products created a plume of contaminated groundwater
- Pump & treat and steam-enhanced vacuum extraction previously used
  - Addressed only a portion of solvent-based source contamination at the site.
- 1996 – Phytoremediation demonstration project started
- The demonstration site is located over an approximately 70-meter-wide portion of the central lobe of the TCE groundwater plume, which originates approximately 1.5 kilometers upgradient of the demonstration area (near Plant 4).

So first aspects of contamination were noted in 1982 and then the transport of TCE obviously as we looked at earlier created a huge plume of contaminated groundwater right. So pump and treat was looked at for one particular lobe let us say which were the southern lobe and steam enhanced vacuum extraction was also tried for and addressed only a part right. Obviously pump and treat especially for TCE or those compounds we looked at these relevant calculation.

So you have what do we say the compound adsorbed on to the soil because it is a relatively hydrophobic let us say right. And also keep in mind that before I forget talking about this Phytoremediation will it be applicable to remarkably hydrophobic compounds or moderately hydrophobic compounds. So obviously only for moderately hydrophobic compounds or relatively not compounds that have very high Kow values.

Why is that because if it is very hydrophobic it will be strongly adsorbed on to soil and it will not be taken up by or it will not be easily taken up by the relevant plant let us say right. So that is something to keep in mind. So again coming back to what we were discussing when they are trying to address or we looked at the calculations too hydrophobic compound let us say considerable fraction of the contaminant will be adsorbed on to soil.

So pump and treat is not a great option but looks like they tried that right and also steam enhanced vacuum extraction let us say addressed only a part of that. So in 1996 a field scale or not field scale a pilot scale field demonstration was (()) (22:17) with respect to Phytoremediation over a 70 meter wide portion of the central lobe of the relevant plume and which approximately is 1.5 kilometer upgradient of the demonstration area let us say right.

So let us look at that particular aspect so this is the central plume let us say or lobe and this is where they looked at the Phytoremediation let us say. So obviously as you see the concentration are more or less from 50 to 500 microgram per liter let us say right of TCE now. Once you have TCE obviously you will have other compounds too, but here they are primarily looking at TCE now right. So that is something to keep in mind.

(Refer Slide Time: 22:57)

MATRIX CHARACTERISTICS

$u = kI$

Matrix Characteristic	Value/Description
Soil classification	Clayey sands and gravels
Groundwater velocity	0.5 meters per day
Groundwater flow direction	Southeast
Depth to groundwater	2.5 – 4 meters below ground surface
Average gradient	Greater than 2%
Saturated aquifer thickness	0.5 – 1.5 meters
Hydraulic conductivity (average)	6 meters per day

So let us look at what we have here. So here they have clayey, sand and gravel so what does that mean that you know it is relatively the hydraulic conductivity or the permeability will be very or relatively high. As you can see hydraulic conductivity 6 meters per day that is relatively high and saturate aquifer thickness you know not too high average gradient again 2% depth to groundwater not a lot and again as I mentioned towards southeast that is where that is the direction of the groundwater flow.

And again let us say groundwater velocity as we mentioned earlier was based on the hydraulic conductibility obviously you know that u=kI and k is relatively high thus U is also relatively high let us say and the reason being that you have clayey sands and gravel let us say right.

(Refer Slide Time: 23:44)

PHYTOREMEDIATION - SYSTEM DESCRIPTION AND OPERATION

- Investigation of the ability of eastern cottonwood (*Populus deltoides*) trees to remediate shallow contaminated GW in a sub humid climate.
- Determination of the ability of the planted system:
  - to hydraulically control the migration of contaminated groundwater
  - biologically enhance the subsurface environment to optimize in situ reductive dechlorination of the chlorinated ethenes.
- April 1996 – USAF planted 660 eastern cottonwoods at two plantations in a 4000 m^2 area.

Again let us look at what they have so investigation of the ability of a particular kind of trees to remediate shallow contaminated groundwater in a particular kind of climate. So the determination of the ability of the planted system or the kind of plants that they looked at what were they trying to look at to hydraulically control the migration of contaminated groundwater. So more or less see mobilization or preventing transport of the contaminant from offsite or to offsite let us say.

And also to enhance the biological capacity of the relevant subsoil to remediate this particular contaminant right What we do we have biologically enhanced the subsurface environment to optimize in situ reductive dechlorination of the chlorinated ethenes let us say so you have TCE right and what we say 1, 2-DCE, VCE and so on let us say. So the particular answer seems to be upon let us see or at least their objectives were to see is by planting the relevant trees they can you know fasten this particular bioremediation let us say right.

So again 2 plantations let us say I believe at 2 plantations and total of a considerable area 4000 meter square area and they looked at 660 eastern cottonwoods let us say right. Let us look at what we have out here.

(Refer Slide Time: 24:58)

TYPES OF EASTERN COTTONWOOD STEMS USED

- **Whips** – Sections of 1-year old cottonwood stems, were planted in one plantation
- **Caliper trees** – More mature stems (2.5 to 3.8 cm trunk diameter) were planted in another plantation. They have higher evapotranspiration rates than the whips because of their larger leaf mass.

So types of cottonwood they looked at 2 types if I am not wrong. One is whips as in one year old were transported obviously you cannot start planting the seeds out there because it takes time obviously you are going to transport and replant the relevant trees out here or the sampling at least the trees. So one year cottonwood stems were planted in one plantation and in the other relatively more mature stems were planted in another plantation.

One is whips and one for caliper trees let us say and they are more or less eastern cottonwood trees and one of the reasons looks like why they choose caliper trees was that it looks like it will have or is supposed to have higher evapotranspiration why is that because of large leaf area let us say or large leaf mass let us say right. So let us look at one particular trial so this is one particular plantation.

Let us say the caliper trees plantation where they were looking at this particular pilot scale demonstration let us say right. So this is the actual picture from the relevant site right.

(Refer Slide Time: 26:00)

MONITORING SYSTEM

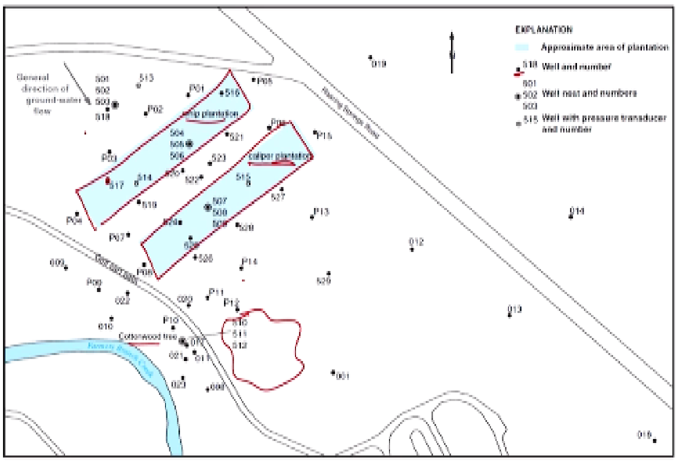
- 67 GW monitoring wells installed upgradient, within, downgradient, and surrounding the demonstration site
- Continuous water level recorders installed at three locations
  - one upgradient of the tree plantations
  - two within the plantations
- 9 tensiometers installed upgradient or within the tree plantations
- A weather station installed to collect site-specific weather data
- A stream gauge installed on a creek adjacent to the site to record stream stages
- Tree collars or tree probes installed periodically during the growing season to measure sap-flow in selected trees

And okay monitoring system. So considerable level of monitoring system is process are required right. Obviously why is that now you are looking at what do we say passive techniques. So obviously monitoring is in a very important aspect out here. So obviously upgradient within and downgradient. So continuous water level recorders obviously because they were also looking whether the to see let us say these particular plantation can look at hydrochloric control let us say.

So that is why they have these particular continues water level recorders right. 9 tensiometers installed upgradient or within the tree plantation let us say weather station too, stream gauge let us say and tree callers are tree probes to measures the sap-flow in the selected tress let us say because that is one of the ways let us say the relevant contaminant is going to be transported through the relevant trees let us say right. So that is one aspect.

(Refer Slide Time: 26:54)

LOCATION OF COTTONWOOD PLANTATIONS AND MONITOR WELLS AT PHYTOREMEDIATION DEMONSTRATION SITE



So location of cottonwood plantations and monitoring wells at the Phytoremediation site. So these were the 2 what do we say sites of plantation on the whip and one the caliper based plantation and they also had some cottonwood and pre existing cottonwoods out here. So as you can see the considerable number of what do we say monitoring wells upgradient downgradient and within the plantation out here right.

So upgradient downgradient and within the plantation so that is what you see out here and also some near the surface water body.

(Refer Slide Time: 27:30)

PERFORMANCE DATA ASSESSMENT – CHANGES IN TCE MASS FLUX

Event	Hydraulic Gradient Across Downgradient End of Planted Area[a]	Cross-Sectional Area Along Downgradient End of Planted Area[b] (m^2)	Volumetric Flux of Groundwater Across Downgradient End of Planted Area[c] (m^3/d)	Change in Volumetric Flux Across Downgradient End of Planted Area Attributed to Planted Trees (%)	Average TCE Concentration in Wells Along Downgradient End of Planted Area[d] (μg/L)	Mass Flux of TCE Across Downgradient End of Planted Area (g/d)	Change in Mass Flux of TCE Across Downgradient End of Planted Area Attributed to Planted Trees (%)
Baseline (1996)	0.0159	84	8.0	-	469	3.8	-
Peak[e] 2nd Season (1997)	0.0154	82	7.6	-5	535	4.1	8
Late[f] 2nd Season (1997)	0.0157	83	7.8	-2	-	-	-
Peak 3rd Season (1998)	0.0143	82	7.0	-12	483	3.4	-11
Late 3rd Season (1998)	0.0150	83	7.5	-6	473	3.5	-6
Peak 4th Season (1999)	0.0153	81	7.4	-8	-	-	-

So let us look at the data assessment here changes in the TCE mass flux. So the baseline right. So we have different columns out here as in hydraulic gradient right. So there is some decrease obviously as you see in the hydraulic gradient let us say some not allot again cross sectional area down this that is slight decrease we are not going to that in great detail let us say.

But the major aspect is volumetric flux of the groundwater across the downgradient and of the planted area right. So if you are looking for hydraulic control obviously it should decrease. So there is some or slight decrease let us say and that I think corresponds to the peak growing season let us say right. Obviously your trees are going to have based on the season of the year a peak growing season let us say right.

I think here it is June or July for these particular climates and in this particular peak let us say there as you can see the maximum what do we say hydraulic control let us say was achieved or the change in volumetric flux let us say was maximum let us say in that particular peak, but typically you see that there was a decrease in this particular volumetric flux of groundwater.

Why is this important that means that your transport of the relevant contaminant is being arrested or inhibited let us say right and also average concentration of TCE may be not a great deal to understand here, but mass flux of TCE let us say across this particular case again data is relatively limited, but they were trying to show that there was a decrease in the mass flux let us say, but again data is limited though, but obviously we have other data.

(Refer Slide Time: 29:05)

CONCENTRATIONS IN TREE SAMPLES (μg/kg) FOR FIRST 3 YEARS

Tree Type	Analyte	Plant Tissue	October 1996	July 1997	October 1997	June 1998	October 1998
Whips	TCE	Leaf	ND	ND	1.6 (2)	ND	ND
		Stem	26 (1)	ND	10.1 (3)	44 (1)	32.8 (5)
		Root	ND	NS	NS	140	NS
	cis-1,2-DCE	Leaf	ND	NS	ND	ND	ND
		Stem	ND	NS	1.9 (3)	14 (1)	13.5 (5)
		Root	ND	NS	NS	ND	NS
Calipers	TCE	Leaf	ND	ND	10.4 (3)	4.5 (2)	ND
		Stem	ND	ND	9.6 (3)	71 (1)	24.6 (5)
		Root	ND	NS	NS	13	NS
	cis-1,2-DCE	Leaf	ND	NS	ND	ND	ND
		Stem	ND	NS	1.6 (3)	15.7 (3)	8.9 (4)
		Root	ND	NS	NS	NS	NS
Mature cottonwood	TCE	Leaf	NS	ND	ND	ND	ND
		Stem	ND	ND	6.4	13	2.2
		Root	NS	NS	NS	NS	NS
	cis-1,2-DCE	Leaf	NS	NS	ND	ND	ND
		Stem	1.2	NS	10	ND	2.8
		Root	NS	NS	NS	NS	NS

Numbers in parentheses represent number of trees for which the analyte was detected.
Five whips and five caliper trees were sampled (except roots).

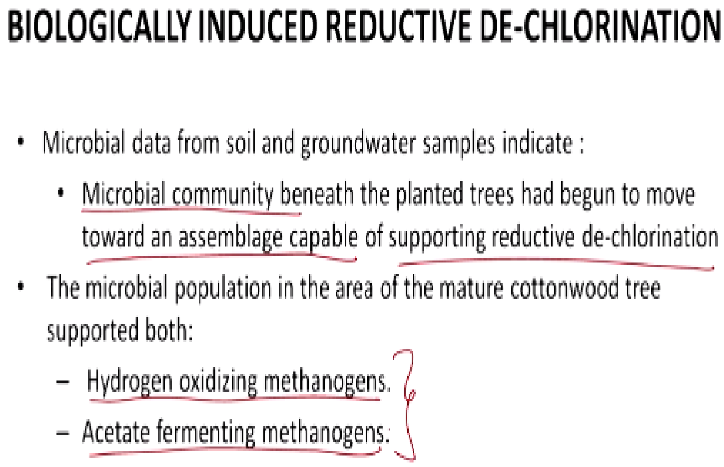
Concentration in tree samples microgram per kg for the first 3 years let us right. So let us look at 2 kinds whips and caliper that were planted and already mature cottonwood was already present there and we are looking at TCE and 1, 2-DCE for all these relevant compounds let us say yeah for all these 3 kinds of trees let us say right. And we are looking at leaf, stem and root for all these relevant aspects.

So let us look at one set of data so here for whips you see that in October 1997 a particular concentration of TCE was recorded in the particular tree in the stem let us say and relatively higher out there in the later year let us say right. So again keep in mind that you know this is one proof what do we say proof that you know the contaminant is at least being taken up by the relevant trees.

Bu to look at let us say is degradation taking place or just accumulation or such we need to look at other aspects, but we are not going to that in that detail because we do not have as much data. So same case with caliper and such may be a lot more actually right. Caliper seems to be doing a greater job, but I think the season is playing a considerable role or this decrease might be attributed to the relevant compound being transformed or degraded by the relevant plant itself.

But again we need more data though. Again here this is how you have more data out here.

(Refer Slide Time: 30:25)

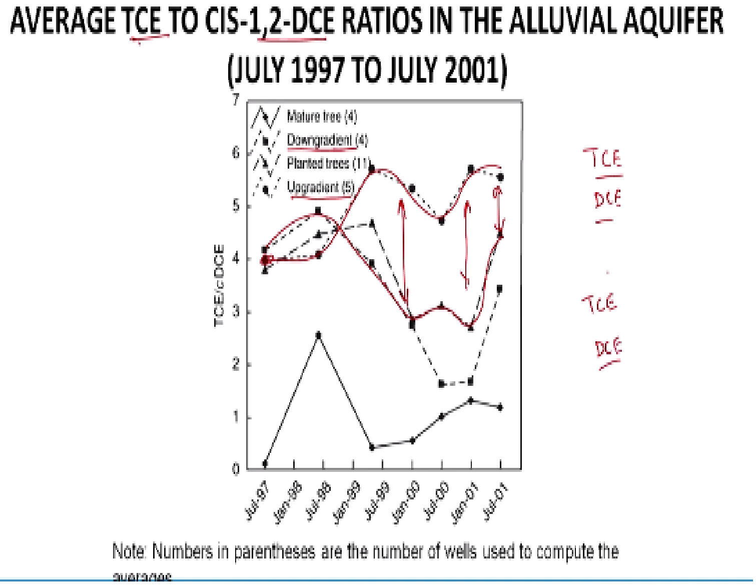


So biologically inducted dechlorination as in one of the aspects the people want to look at was let us say is the subsurface now more conductive for this reductive dechlorination. So let us look at what we have. So microbial data from soil and groundwater samples have indicated that the community between that is now more or less more diverse let us say or is moving towards a more diverse (()) (30:50) let us say or you know multi you have different kinds of microbes if I can say.

So that can support the reductive dechlorination let us say or you know to put it differently let us say planting these trees let us say has transformed the system such that you know more reducing conditions prevails that will allow for relevant microbes to prevail that can bring about reductive dechlorination now right. So that is what we have out here so again what do we have here now.

These microbes can support both hydrogen oxidizing methanogenes and also state fermenting methanogenes right. Typically let us say these are indicators of you know conditions let us say which will allow for reductive dechlorination of the relevant contaminants and I think that is something we looked at are real let us say.

(Refer Slide Time: 31:38)



So now we are now going to move on to average TCE to 1,2-DCE ratio in the aquifer let us say right. So TCE to 1,2-DCE right so again different trends out here based on the relevant what do we say season right, but let us look at upgradient right. This is the upgradient profile and then let us look at downgradient right. The downgradient is somewhere out here let us say the downgradient profile.

As you see with time let us say with time let us say there is some improvement let us say in the relevant aspect, but again keep in mind we are looking at TCE to DCE ratio let us say right TCE to DCE ratio right. So again it will be indicative of some level of what do we say degradation or such let us say. Again that is the same case with you know different aspects or such as in if this is lower what does that mean now.

TCE is being degraded to DCE let us say right that is what we see out here let us say right. Again it would have been better if we had actual concentration of TCE and DCE at this site, but we do not have that we have we have some proof is that the you know the transformation is taking place because 1, 2-DCE is a byproduct of TCE now.

(Refer Slide Time: 32:52)

GROUNDWATER CHEMISTRY PARAMETERS

O_2 NO_3^- Fe^{2+} Alk.

	Dissolved oxygen (mg/L)	Nitrate (mg/L)	Ferrous iron (mg/L)	Alkalinity (mg/L as bicarbonate)
Immediately upgradient of plantations	3.06	3.23	0.05	322
Beneath plantations	1.69	2.10	0.08	377
Downgradient of plantations	1.01	1.22	0.7	386
Beneath mature cottonwood tree	0.69	0.66	0.5	378

Reducing

So let us move on so some of the groundwater chemistry parameters. So we are looking at upgradient beneath the plantation and downgradient of the plantation and also beneath the mature cottonwood trees now right. So here we have dissolved oxygen nitrate so o2, No3 and ferrous and (()) (33:12) let us say right. So again these aspects though if you look at it they will give an idea about let us say or the condition more oxidizing or reducing.

So upgradient you have considerable level of (()) (33:22) nitrate and very less amount of ferrous iron let us say which is a reducing agent this is a reducing agent. These are oxidizing agents let us say right. So for your reductive dechlorination to take place your oxygen or no3- should be relatively low. As you can see beneath the plantation at least the transformation is taking place.

As in as you go further down the (()) (33:45) decreasing the nitrate is decreasing let us say and your ferrous iron concentrations are increasing out here. So that is what you see as in the conditions are slowly transforming into more reducing conditions let us say right and only in the reducing conditions where is no competing electron acceptor will you have what do we say reductive dechlorination of your relevant compound.

Why is that because if you have oxygen the microbes does not want to TCE 1, 2-DCE as an electron acceptor because it will get less energy let us say right.

(Refer Slide Time: 34:16)

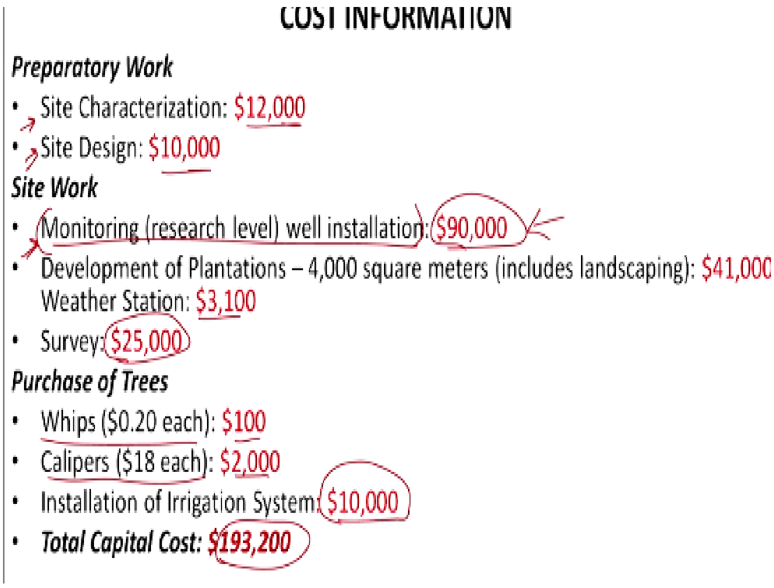
TREE HEIGHT AND TRUNK DIAMETER MEASUREMENTS

Parameter	Whips		Caliper Trees	
	December 1996	September 1998	December 1996	September 1998
Tree height (meters)	2.27	5.52	3.77	6.64
Trunk diameter (centimeters)	1.41	5.31	3.83	8.12

So let us move on. So tree height and trunk measurements obviously we need more data but obviously you can see that the height increases let us say and also the trunk diameter increases, but one aspect that this can be used to look at is that when we looked at the concentration of the contaminant in the relevant tree or stem let us say we saw that initially there was a considerable increase and there is slight decrease.

The slight decrease is all attributed to the fact that now your tree is relatively bigger let us say right. So the concentration will be slightly lower so that does not mean that you know the relevant contaminant is not been taken up, but just that the tree mass is more let us say, but again we need to careful when we draw such conclusions right.

(Refer Slide Time: 34:58)



So some basic cost information so site characterization some amount not a lot typically though site design, site work most of it is or goes in to the monitoring wells let us say this is the actual cost right 90000 dollars go into the monitoring aspects let us say and again the weather station and the survey I guess let us say are considerable amount, but primarily with respect to the monitoring let us say right.

And then purchase of the trees, but here obviously the cost are relatively high, but say in Indian context they will obviously not be very high let us say right. So here the cost are somewhat higher. So installation of the irrigation system again higher Indian cases it will not be very high. So total capital cost is 1,93,200 dollars now right. So again as you can see for considerable fraction of the relevant system and where they have keep in mind this is pilot scale so they will put in more monitoring networks and so on. The cost are relatively less here let us say.

(Refer Slide Time: 35:56)

COST INFORMATION

Annual O&M Cost

- Landscaping: $2,000
- Groundwater, soil, vegetation, transpiration, climate, soil moisture, and water-level monitoring (research level): $250,000
- ***Total Annual O&M: $252,000***

After Treatment Cost: None

So let us look at what we have. So we have operational maintenance as in just in minor landscaping. So here though we are going to look at again considerable cost with respect to monitoring the relevant variables here. What are the variables let us say groundwater, soil, vegetation, transpiration climate and so on right? So we need to monitor these aspects to understand their effects on the relevant Phytoremediation let us say.

So the total annual or operational maintenance comes to 2,52,000 right dollar and after treatment obviously none let us say right. So again one aspect to keep in mind here is that you cannot just remove the trees and expect this process to go through right the trees need to typically stay in place for this process to be sustainable now, but as you can see though let us say the cost are relatively less.

And once this can be or is implemented in full scale let us say. The effects are typically you know exponentially better let us say right because as you can see it gets better as you move downgradient and again larger the area typically the better the performance is, So I guess with that I will end today’s session and thank you.