PHYTOREMEDIATION OF SOILS AND GROUNDWATERS POLLUTED WITH CHLORINATED SOLVENTS

Dra. Amparo Cortés

SEMINARIS DE RECERCA 2010-11

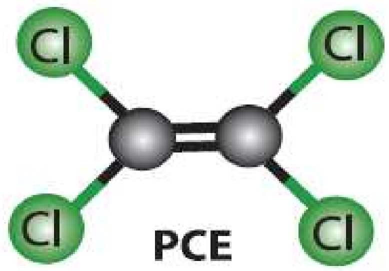
FACULTAT DE FARMÀCIA. UB.

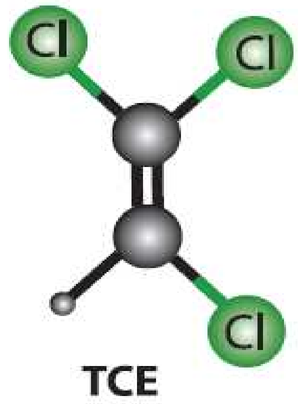
CHLORINATED SOLVENTS USES

Industry	Industrial process
Electronics manufacturing	Metal cleaning
Solvent production	Metal machining
Pesticide / herbicide manuf.	Tool and die operations
Dry cleaning	Vapour and liquid degreasers
Instrument manufacturing	Paint stripping
Solvent recycling	Storage and transfer of solvents
Engine manufacturing	
Steel product manufacturing	
Chemical production	
Rocket engine / fuel manufacturing	
Aircraft cleaning / engine degreasing	

CHLORINATED SOLVENTS

Chlorinated Ethenes
Tetrachloroethene (PCE)
Trichloroethene (TCE)
cis-1,2-Dichloroethene (cDCE)
trans-1,2-Dichloroethene (tDCE)
Vinyl Chloride (VC or Chloroethene)
Chlorinated Ethanes
1,1,1-Trichloroethane (1,1,1-TCA)
1,1,2-Trichloroethane (1,1,2-TCA)
1,2-Dichloroethane (1,2-DCA or EDC)
Chlorothane (Ethyl Chloride)
Chlorinated Methanes
Carbon Tetrachloride (CT)
Chloroform (CF or Trichlormethane)
Dichloromethane (DCM or Methylene Chloride) [1]
Chloromethane (Methyl Chloride)





1. pharmaceuticals, chemical processing, aerosols, food extraction, urethane foam blowing and surface treatment

Compound	CAS Number	Liquid Density	Vapor Density	Flash Point, ºF	ppm Odor Threshold
Perchloroethylene	127-18-4	1.6	5.8	NA	47
1,1,2,2-Tetrachloroethane	79-34-5	1.6	5.8	NA	72
1,1,2-Trichloroethane	79-00-5	1.4	4.6	NA	
Carbon tetrachloride	56-23-5	1.6	5.3	NA	250
Chloroform	67-66-3	1.5	4.1	NA	192
Methylene chloride	75-09-2	1.3	2.9	NA	160
Trichloroethylene	79-01-6	1.5	4.5	NA	82
Methyl chloroform *(1,1,1-Trichloroethane)*	71-55-6	1.3	4.6	NA	390
1,2,3-Trichloropropane	96-18-4	1.4	5.1	164	
Ethylene dichloride	107-06-2	1.2	3.4	56	26
1,2-Dichloropropane (*Propylene dichloride)*	78-87-5	1.2	3.9	60	0.5
1,2-Dichloroethylene	540-59-0	1.3	3.4	37	
1,1-Dichloroethane	75-34-3	1.2	3.4	17	445

Dense Non-Aqueous Phase Liquids
DNAPL

Chlorinated solvent DNAPL

→ **Chloromethanes**,

→ **Tetra and trichloroethane**,

→ **Tetra and trichloroethene**,

Chlorobenzenes,

PCBs (electrical transformer oils),

Creosote (wood treaters),

Coal tar (manufactured gas plants [MGPs]).

Dense Non-Aqueous Phase Liquids
DNAPL

Chlorinated solvent DNAPL

Immiscibility with water - they form separate 'phases'.

Low absolute solubilities - DNAPL can't dissolve quickly in groundwater: it may persist for decades before dissolving.

Relatively high densities - DNAPLs are denser than water, and can therefore sink beneath the water table, polluting the full thickness of an aquifer.

Low viscosities – that allows rapid subsurface migration.

Toxicity - Many DNAPLs are suspected or proven human carcinogens.

Compound Name	Chemical Formula	MW (g/mol)	Density (g/mL-20°C)	Solubility (g/100mL-20°C)	Log K_{ow}
Carbon Tetrachloride	CCl_4	153.823	1.594	0.08048	2.64
Chloroform	$CHCl_3$	119.3779	1.498	0.795	1.97
3,3-Dichlorobenzidine	$C_{12}H_{10}Cl_2N_2$	253.1304		0.00123	3.21, 3.5
1,1-Dichloroethene	$C_2H_2Cl_2$	96.9438	1.213	0.225	1.32
cis-1,2-Dichloroethene	$C_2H_2Cl_2$	96.9438	1.284	0.08	1.86
trans-1,2-Dichloroethene	$C_2H_2Cl_2$	96.9438	1.257	0.63	2.09 [a]
1,1-Dichloroethane	$C_2H_4Cl_2$	98.9596	1.176	0.506	1.79
1,2-Dichloroethane	$C_2H_4Cl_2$	98.9596	1.253	0.8608	1.48
Methylene Chloride	CH_2Cl_2	84.9328	1.325	1.32	1.3
Perchloroethylene	C_2Cl_4	165.834	1.623	0.015	3.4
Polychlorinated Biphenyls	*	*	*	*	*
1,1,1-Trichloroethane	$C_2H_3Cl_3$	133.404	1.3376	0.1495	2.49
1,1,2-Trichloroethane	$C_2H_3Cl_3$	133.404	0.442	1.4411	2.42
Trichloroethylene	C_2HCl_3	131.388	1.462	0.11	2.42
Vinyl Chloride	C_2H_3Cl	62.4987	0.9106	0.11	1.36

Data for this table extracted from the NIST Chemistry Webbook, Cambridge Chemfinder, the Agency for Toxic Substances and Disease Registry (ATSDR) ToxFaqs™ and Pankow and Cherry (1996)

* 209 possible PCBs. See the ATSDR internet resources at http://www.atsdr.cdc.gov/toxfaq.html for data.

[a] recommended.

CHLORINATED SOLVENTS TOXICITY

CHLORINATED METHANES

Carbon tetrachloride is listed as a suspect carcinogen, an animal carcinogen at relatively high doses, not a likely human carcinogen; however, liver cancer has been reported. It can be absorbed through intact skin. It causes CNS depression, can damage the kidneys, liver, or lungs, and can cause anemia, rapid and irregular heartbeats. Health effects appear to be greatly increased by alcohol consumption.

Chloroform is a suspect carcinogen. It causes CNS depression, rapid and irregular heartbeat, and liver and kidney damage.

Methylene chloride is listed as a potential carcinogen. It causes CNS depression, liver and kidney damage, and can cause elevated blood carboxyhemoglobin (also caused by exposure to carbon monoxide). Contact of the liquid with skin or eyes causes painful irritation and possible burns.

CHLORINATED ETHANES

1,1-Dichloroethane is highly flammable. It is a CNS depressant, but seems to be less likely than other chlorinated solvents to cause liver or kidney damage.

1,1,1-Trichloroethane: Effects reported in humans due to acute inhalation exposure to methyl chloroform include hypotension, mild hepatic effects, and CNS depression.

1,1,2-Trichloroethane: Studies on dermal exposure in humans have reported stinging and burning sensations and transient whitening of the skin.

CHLORINATED SOLVENTS TOXICITY

CHLORINATED ETHENES

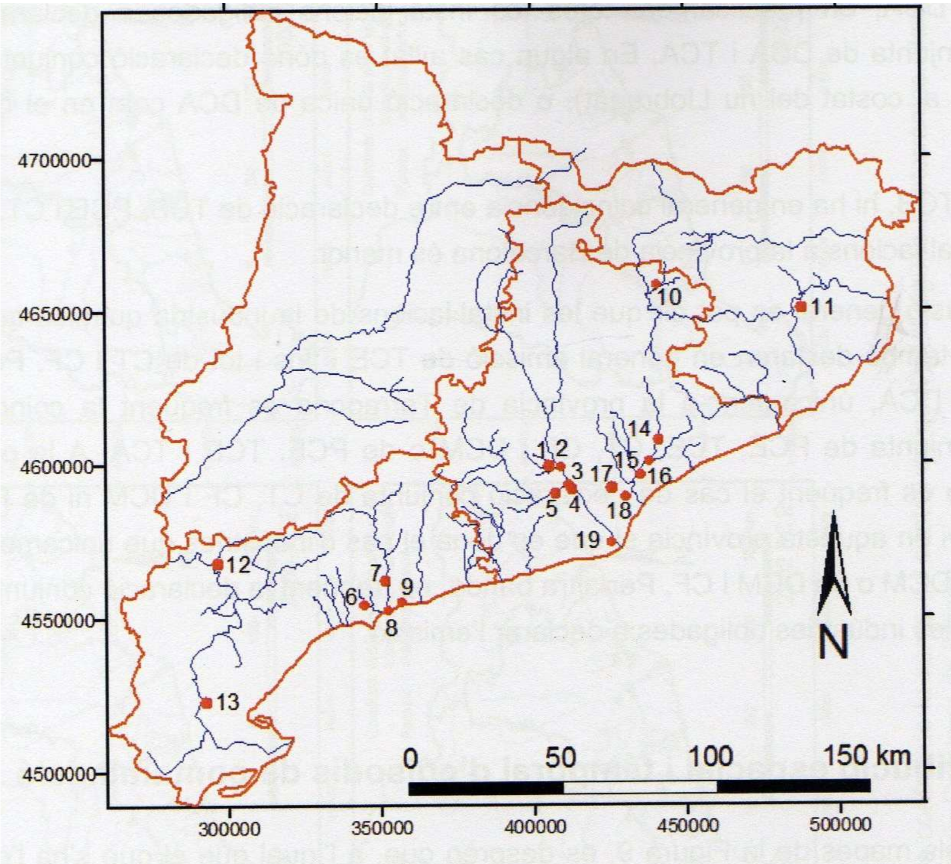
PCE **Tetrachloroethylene** causes irritation of the upper respiratory tract and eyes, kidney dysfunction, and at lower concentrations, neurological effects, such as reversible mood and behavioral changes, impairment of coordination, dizziness, headache, sleepiness, and unconciousness.

TCE **Trichloroethylene**: Short-term exposure causes irritation of the nose and throat and central nervous system (CNS) depression, with symptoms such as drowsiness, dizziness, giddiness, headache, loss of coordination. High concentrations have caused numbness and facial pain, reduced eyesight, unconsciousness, irregular heartbeat and ***death***.

VC **Vinyl Chloride:** Aside from being a known ***carcinogen***, it has been found to cause a number of other conditions, including Raynaud's syndrome, angiosarcoma, and acroosteolysis.

CHLORINATED SOLVENTS EFFECTS

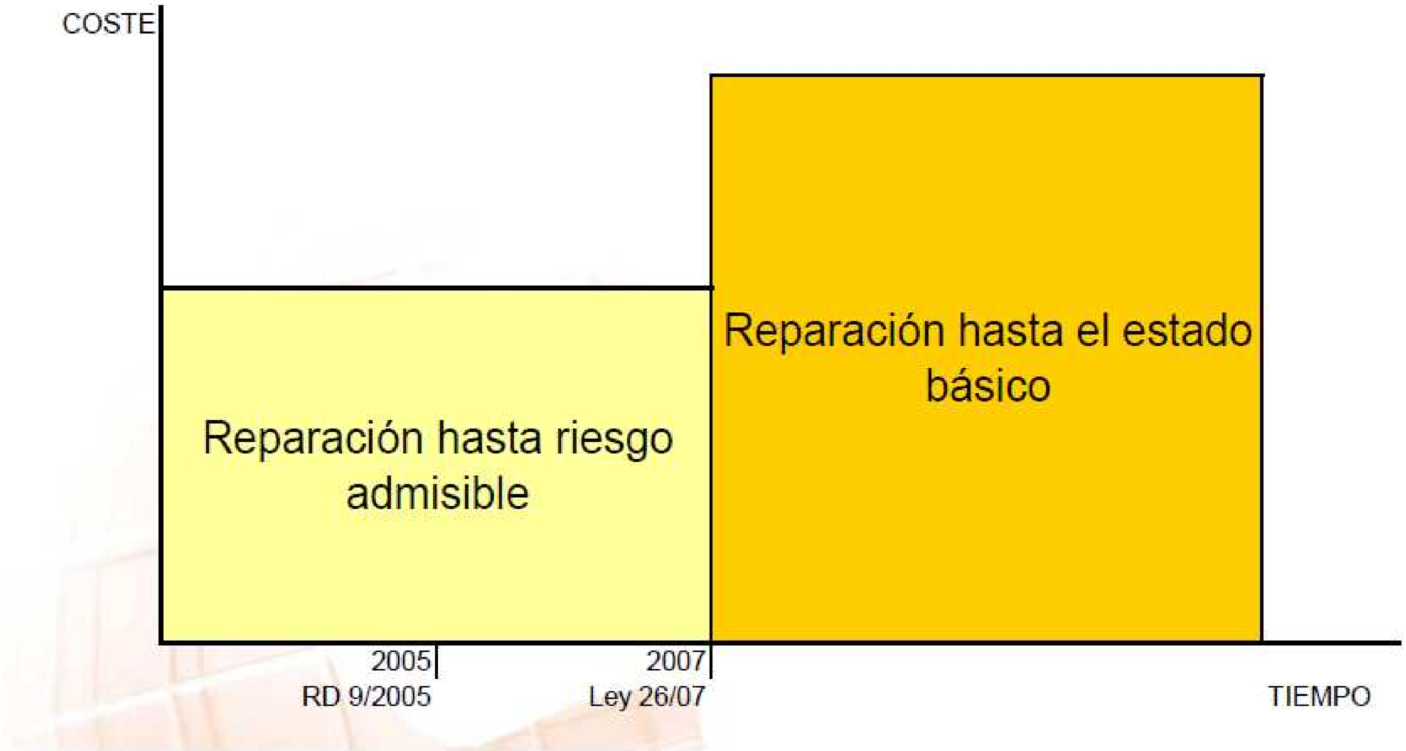
CHLORINATED SOLVENTS PRODUCTION IN CATALONIA



(A) Indústria per la producció i transformació de metalls
(B) Indústria química
[#] Nombre d'instal·lacions industrials

1 (A) [6]:		DCA	PCE		CT	CF	DCM
2 (B) [2]:		DCA					DCM
3 (A) [5]:	TCA	DCA	PCE	TCE	CT		DCM
4 (B) [5]:	TCA	DCA		TCE	CT		DCM
5 (B) [6]:		DCA	PCE		CT	CF	DCM
6 (B) [1]:		DCA					
7 (B) [10]:	TCA	DCA		TCE	CT	CF	DCM
8 (B) [9]:	TCA	DCA	PCE	TCE	CT	CF	DCM
9 (B) [11]:	TCA	DCA	PCE	TCE	CT	CF	DCM
10 (A) [1]:	DCA						
11 (B) [3]:			PCE	TCE	CT		
12 (B) [6]:	TCA	DCA	PCE	TCE	CT	CF	
13 (B) [8]:	TCA	DCA	PCE	TCE	CT	CF	DCM
14 (B) [7]:		DCA	PCE	TCE	CT	CF	DCM
15 (B) [1]:							DCM
16 (B) [4]:			PCE	TCE	CT		DCM
17 (B) [9]:			PCE	TCE	CT	CF	DCM
18 (B) [4]:			PCE	TCE	CT		DCM
19 (B) [6]:		DCA	PCE	TCE	CT	CF	DCM

SOIL POLLUTION CONTROL IN SPAIN



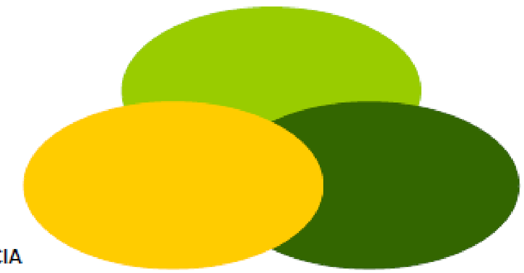
SOIL POLLUTION CONTROL IN SPAIN

NGR

- Objeto de protección
- Usos

Análisis de riesgos

FUENTE CONTAMINANTE



VECTORES DE TRANSFERENCIA

RECEPTORES A PROTEGER

RIESGO ACEPTABLE → SUELO NO CONTAMINADO

RIESGO NO ACEPTABLE → SUELO CONTAMINADO

CHLORINATED SOLVENTS NGRs

Protección de la salud humana

Sustancia	Número CAS	Uso industrial	Uso urbano	Otros usos
		(mg/kg peso seco)		
→ Diclorometano.	75-09-2	60***	6***	0,6
1,1-Dicloroetano.	75-34-3	100**	70***	7
1,2-Dicloroetano.	107-06-2	5***	0,5***	0,05
1,1,2-Tricloroetano.	79-00-5	10***	1***	0,1
1,1,2,2-Tetracloroetano.	79-34-5	3***	0,3***	0,03
1,1-Dicloroetileno.	75-35-4	1	0,1***	0,01
Tricloroetileno.	79-01-6	70***	7***	0,7
→ Tetracloroetileno.	127-18-4	10***	1***	0,1
1,2-Dicloropropano.	78-87-5	4	0,5***	0,05
1,3-Dicloropropeno.	42-75-6	7***	0,7***	0,07
Acenafteno.	83-32-9	100**	60***	6
Acetona.	67-64-1	100**	10***	1
Aldrin.	309-00-2	1***	0,1***	0,01
Antraceno.	120-12-7	100***(1)	100**	45
Benzo(a) antraceno.	56-55-3	20***	2***	0,2
Dibenzo(a,h) antraceno.	53-70-3	3***	0,3***	0,03
Benceno.	71-43-2	10***	1***	0,1
Clorobenceno.	108-90-7	35	10***	1
1,2-Diclorobenceno.	95-50-1	100**	70**	7
1,4-Diclorobenceno.	106-46-7	40***	4***	0,4
1,2,4-Triclorobenceno.	120-82-1	90***	9***	0,9
p-Cloroanilina.	106-47-8	30***	3***	0,3
Clordano.	57-74-9	1***	0,1***	0,01
→ Cloroformo.	67-66-3	5	3	0,7
→ Cloruro de vinilo.	75-01-4	1***	0,1***	0,01*
Cresol.	95-48-7	100**	40***	4

Protección de los ecosistemas

Sustancia	Número CAS	Organismos del suelo	Organismos acuáticos	Vertebrados terrestres
		(mg/kg peso seco)		
1,1-Dicloroetano.	75-34-3		0,06	4,18
1,2-Dicloroetano.	107-06-2		0,16	0,24
1,1,2-Tricloroetano.	79-00-5		0,16	0,3
1,1,2,2-Tetracloroetano.	79-34-5		0,02	0,04
Tricloroetileno.	79-01-6		0,21	0,45
Tetracloroetileno.	127-18-4	0,01*	0,06	0,15
1,2-Dicloropropano.	78-87-5	4,24	0,07	0,43
1,3-Dicloropropeno.	42-75-6		0,01*	0,58
Acenafteno.	83-32-9		0,02	4,85
Acetona.	67-64-1		0,54	6,71
Aldrin.	309-00-2	0,01*	0,01	0,01*
Antraceno.	120-12-7		0,01*	22
Benzo(a) antraceno.	56-55-3	3,8	0,01	
Benceno.	71-43-2	1	0,2	0,11
Clorobenceno.	108-90-7	1	0,03	7,66
1,2-Diclorobenceno.	95-50-1		0,11	3,15
1,4-Diclorobenceno.	106-46-7	0,1	0,16	0,53
1,2,4-Triclorobenceno.	120-82-1	0,05	0,79	0,94
p-Cloroanilina.	106-47-8	0,14	0,01*	0,09
Clordano.	57-74-9	0,04	0,01*	0,01*
Cloroformo.	67-66-3		0,01	0,01
p,p´–DDE.	72-55-9	0,14	0,01*	0,01*
p,p´–DDT.	50-29-3		0,01	0,01*
Dieldrin.	60-57-1	0,13	0,01*	0,01*
1,4-Dioxano.	123-91-1	1,45	13,9	
Endosulfan.	115-29-7	0,01	0,01*	0,04
Endrin.	72-20-8		0,01*	0,01*
Estireno.	100-42-5	0,68	0,25	100**
Etilbenceno.	100-41-4		0,08	4,6
Decabromofenil éter.	1163-19-5		2,66	59,7
Pentabromo difenil éter.	32534-81-9	0,32	5,18	0,01*
Octabromo difenil éter.	32536-52-0		0,51	0,24
Fenol.	108-95-2	0,27	0,03	23,7
2-Clorofenol.	95-57-8	0,04	0,01*	0,12
Benzo(a)pireno.	50-32-8	0,15	0,01*	
Tetracloruro de carbono.	56-23-5		0,12	
Tolueno.	108-88-3	0,3	0,24	13,5
Xileno.	1330-20-7		0,07	

GROUNDWATER POLLUTION CONTROL

LA DIRECTIVA DE AGUAS SUBTERRÁNEAS

Directiva 118/CE 2006

"Relativa a la protección de las aguas subterráneas contra la contaminación y el deterioro"

- **Objetivo:**
  - Establecer criterios y procedimientos para valorar el estado químico y sus tendencias
    - *NORMAS DE CALIDAD*:
      NO_3^- *(50 mg/l)*, Plaguicidas *(totales 0.5 ug/l, individuales 0.1 ug/l)*
    - *VALORES UMBRAL* (lista mínima a establecer por los Estados miembros):
      Hg, Cd, As, Pb, NH_4^+, Cl^-, SO_4^{2-}, TRI, PER, conductividad

- **Procedimiento de evaluación del buen estado químico**
  - Cumplir las condiciones básicas establecidas en la DMA
  - No superar las *Normas de calidad* y *Valores Umbral*
  - En caso de superar alguno:
    - No presentar riesgo significativo
    - El resto de condiciones se continúan cumpliendo
    - A pesar del incumplimiento es posible mantener los usos
    - Se están aplicando medidas para reducir la contaminación

Agència Catalana de l'Aigua

CHLORINATED SOLVENTS CATALONIAN VGs

Els nivells dels contaminants que s'estableixen com a criteri de gestió inclouen:

- **valor genèric de no risc (VGNR)**: concentració del contaminant que s'estableix com a valor objectiu de restauració.
- **valor genèric d'intervenció (VGI):** concentració del contaminant a partir del qual es considera necessària una actuació de restauració de la qualitat del medi.

Paral·lelament, es defineix també:

- **valor de fons:** concentració d'una substància a les aigües subterrànies que es considera com a propi o representatiu de la qualitat de les aigües en un emplaçament fora de l'àrea o volum afectat per la contaminació de l'episodi objecte de gestió.

	Valor Genèric de No Risc (VGNR) µg/l.	Valor Genèric d'Intervenció (VGI) µg/l.
Substàncies del GRUP 2		
Hexaclorobenzè	0,05	1
Tetracloroetà, 1,1,2,2	7	30
Tetraclorur de Carboni	8	30
Diclororetà, 1,2	10	50
Benzè	20	90
Tricloroetà, 1,1,2	20	90
Naftalè	10	500
Substàncies del GRUP 3		
Cloroform	70	210
Clorobenzè	80	240
Dicloroetilè, trans-1,2	80	240
ETBE	100	300
Etilbenzè	100	300
Bromoform	150	450
Xilens suma	200	600
Diclorometà	250	750
Substàncies del GRUP 4		
Tricloroetilè		50
Dicloroetilè, 1,1	* 10	60
Tetracloroetilè		75

ESBORRANY

SITE 1

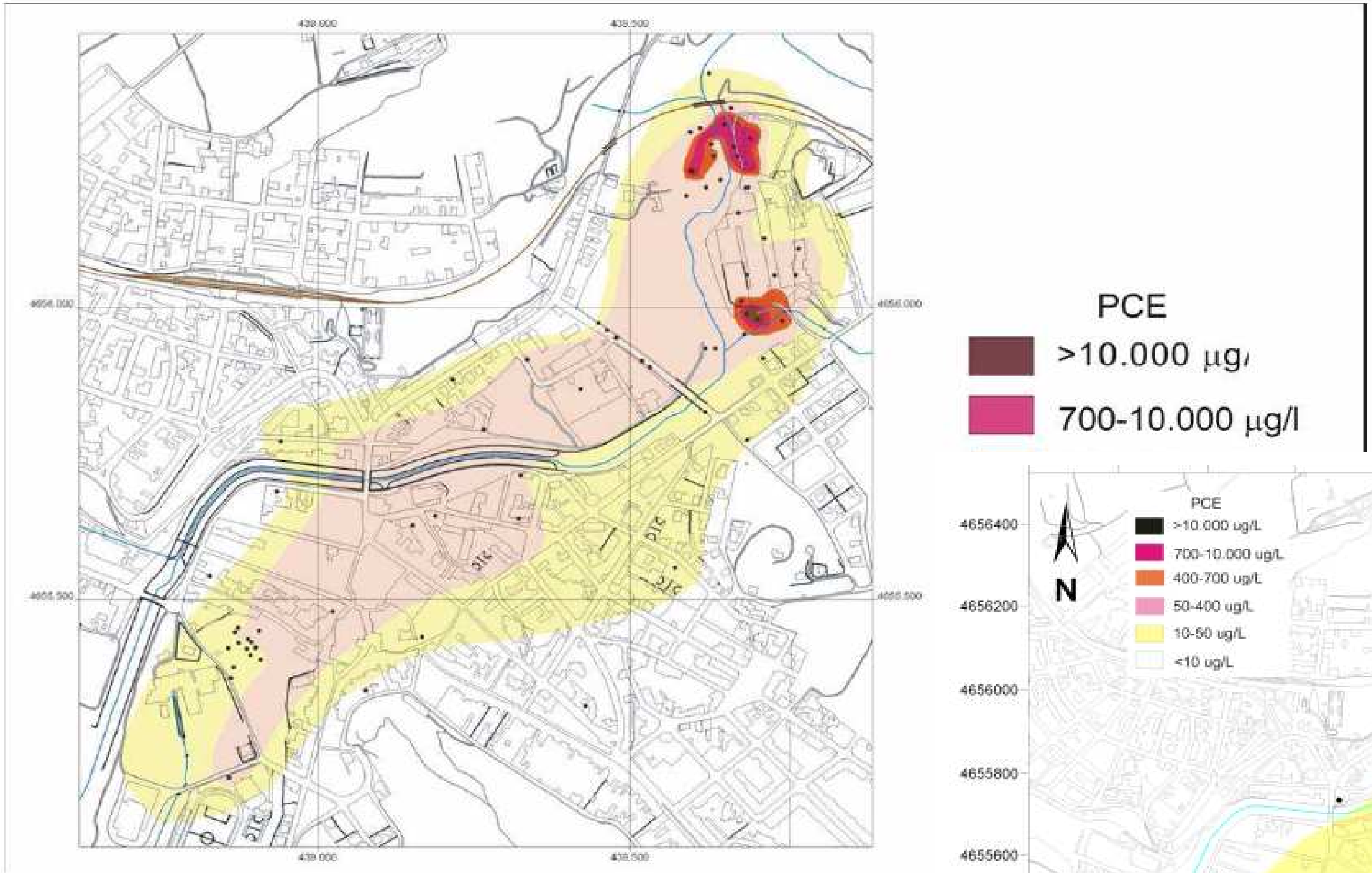


Figure PCE plumes in 2001 emerging from the source area old dug wells are included. Data from initial studies of ACA (July,

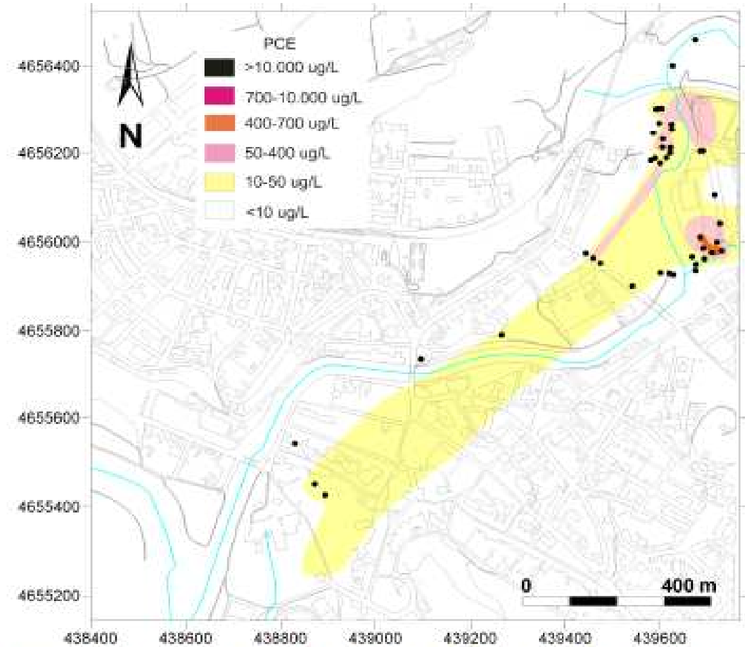
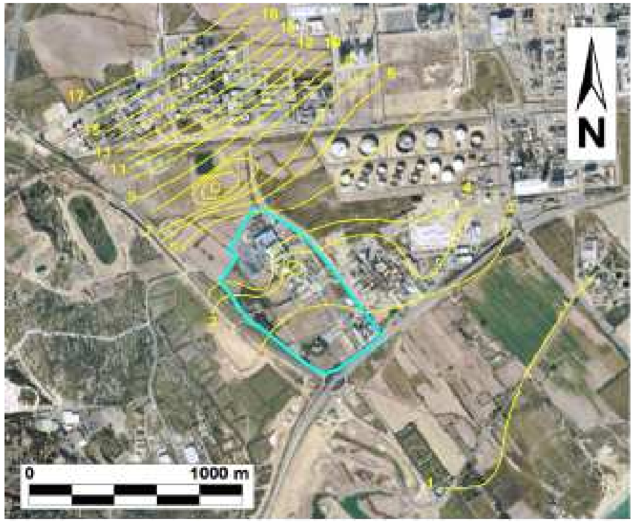
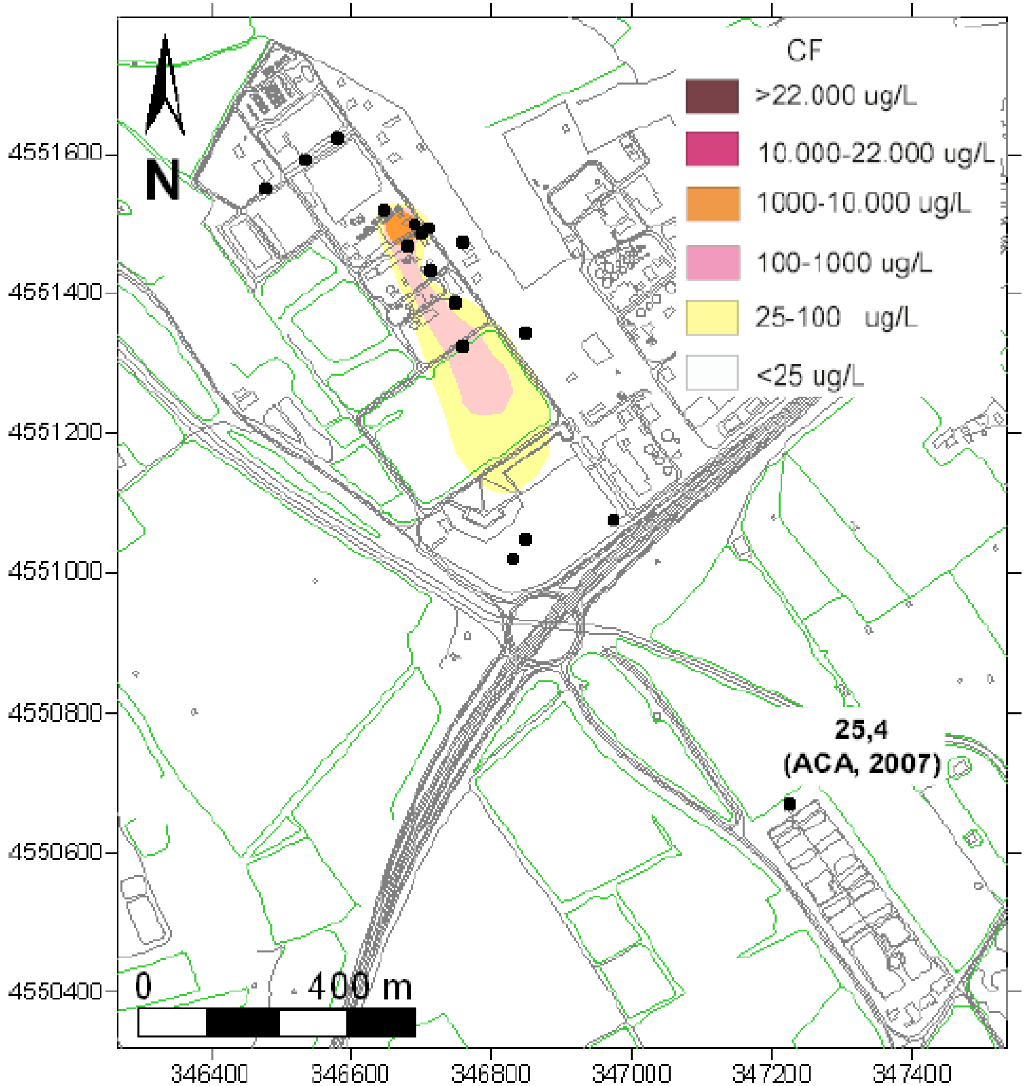


Figure . PCE plumes in 2006 emerging from the source areas. Monitoring piezometers and dug wells are included. Data from the GEAH 2005-2007 bimonthly monitoring (July, 2006).



SITE 2

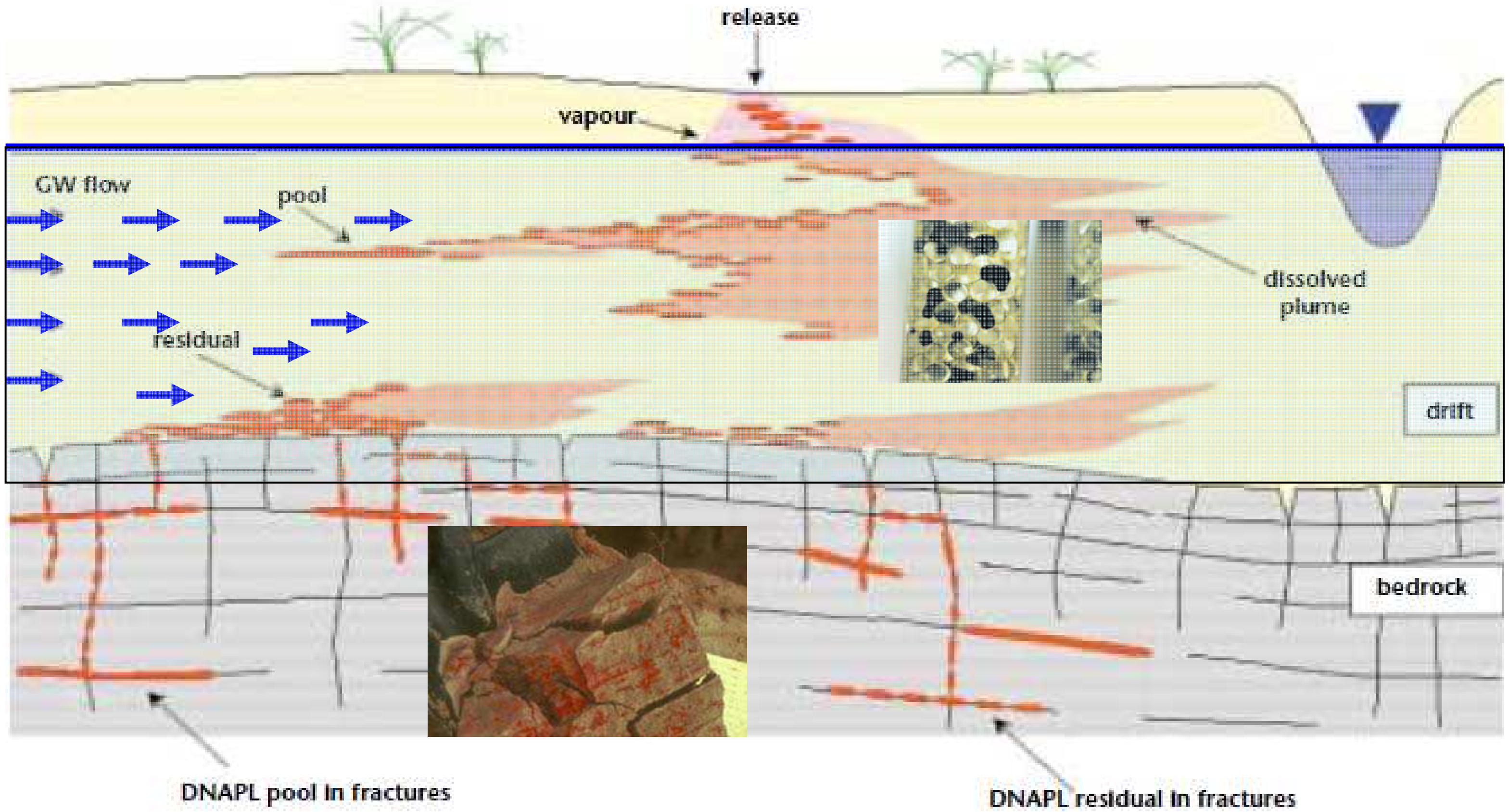


concentrations of CF and CT in groundwater.

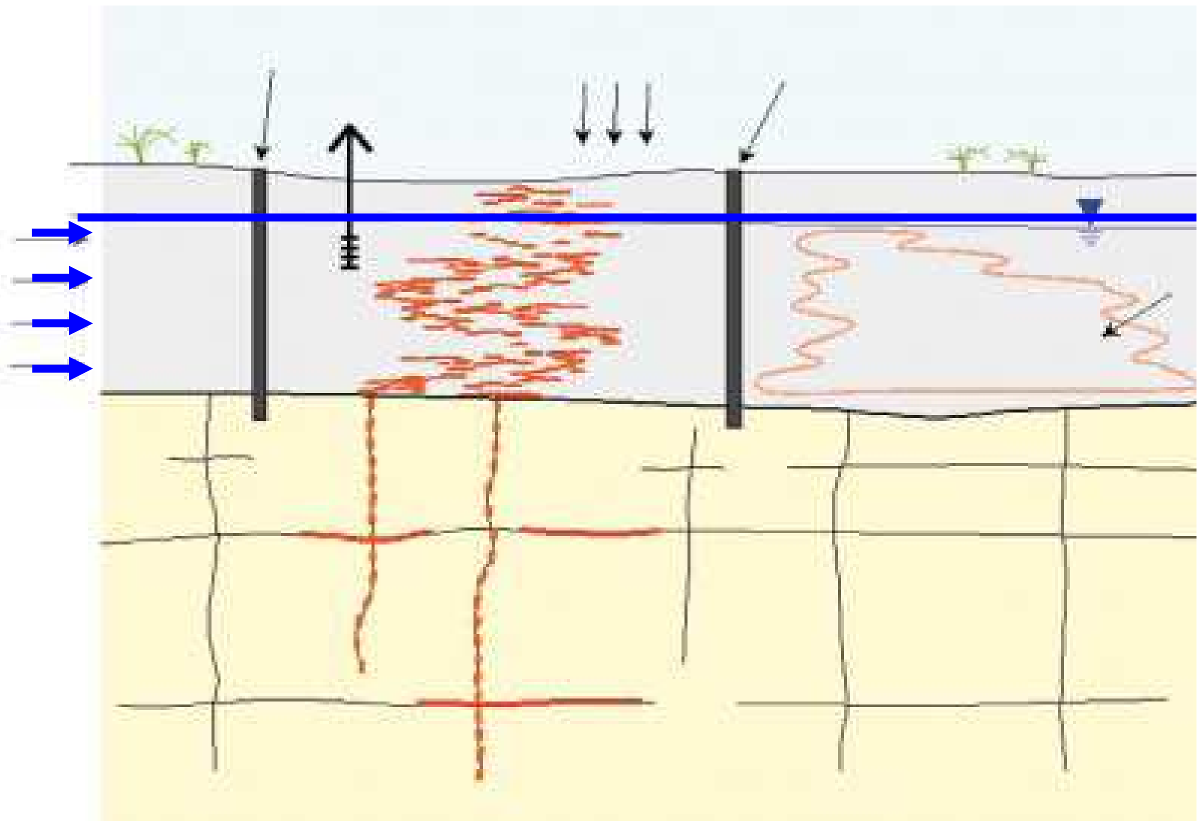
	1997	2006	1997	2006
	CT (µg/L)		CF(µg/L)	
Max	771	160	19,370	960
Min	7	ND	843	1
Average	196	26	11,700	79

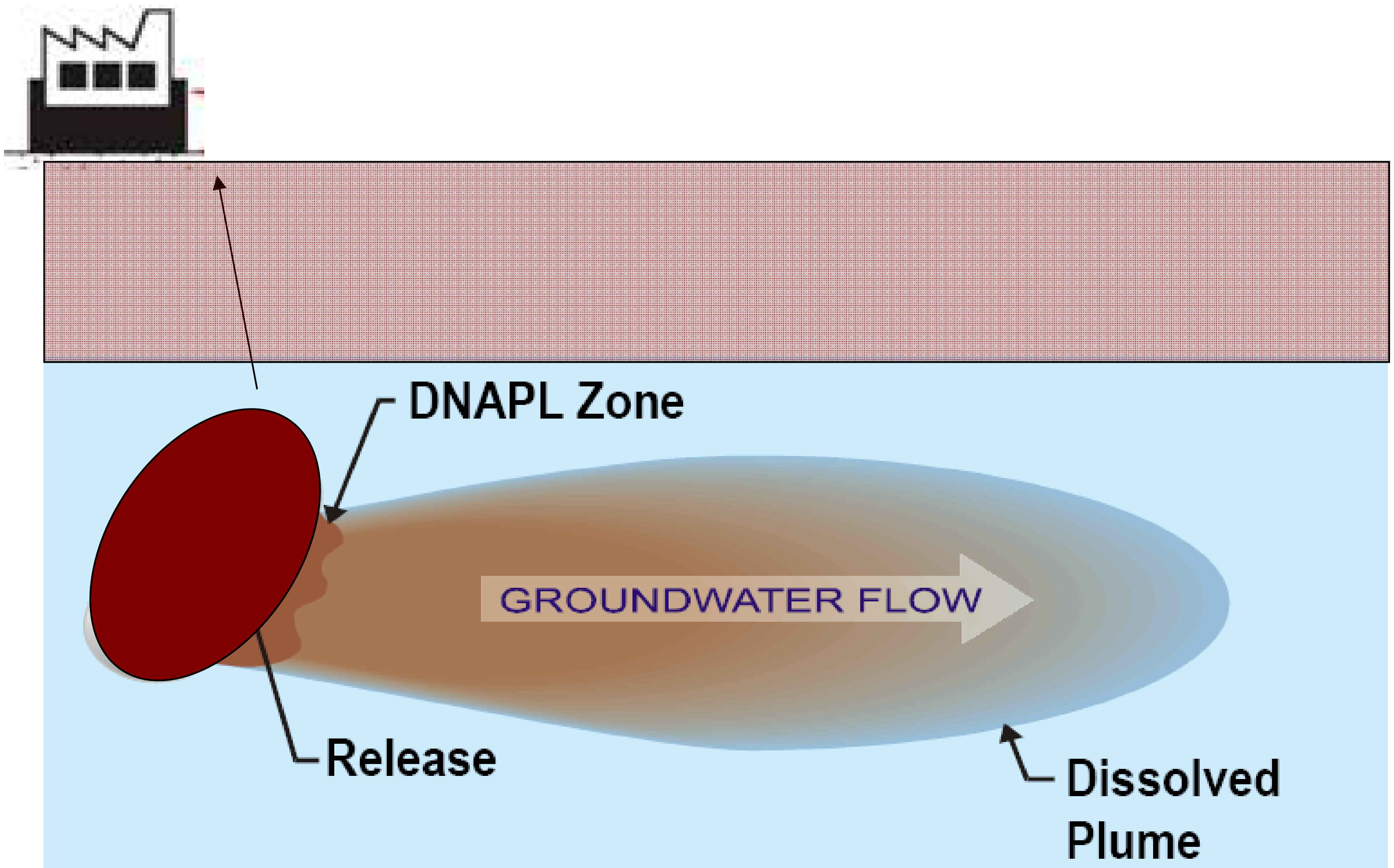
Figure 1: Location map of the network monitoring wells and the contaminant CF plume in October 2008.

CHLORINATED SOLVENTS ENVIRONMENTAL DISTRIBUTION

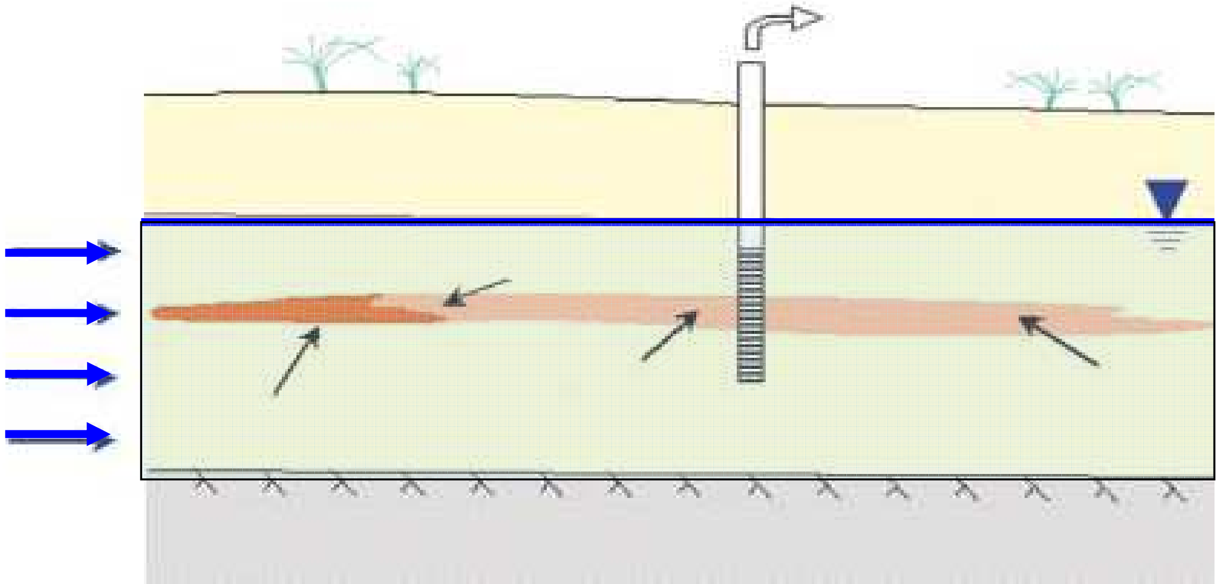


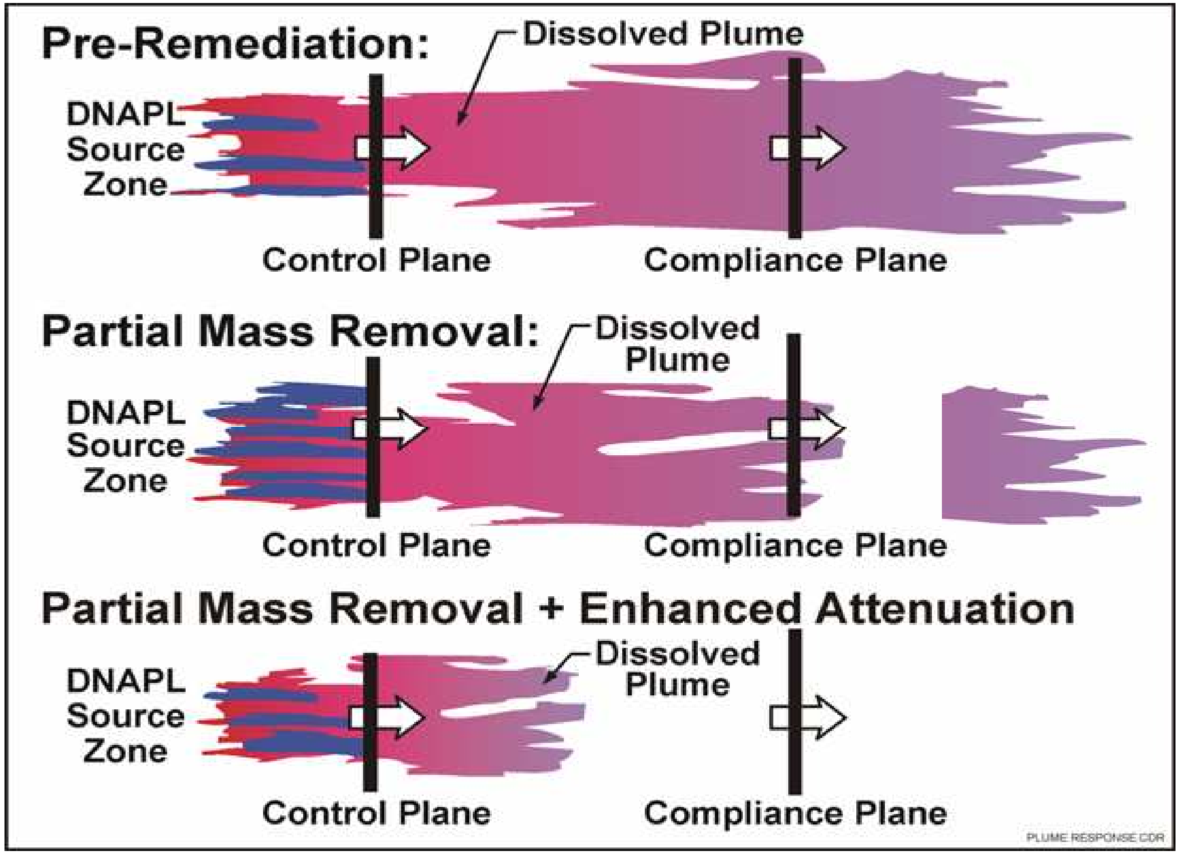
PHYSICAL ISOLATION OF DNAPL SOURCE ZONE




DNAPL Zone
GROUNDWATER FLOW
Release
Dissolved
Plume

DNAPL EXTRACTION: Pump and treat

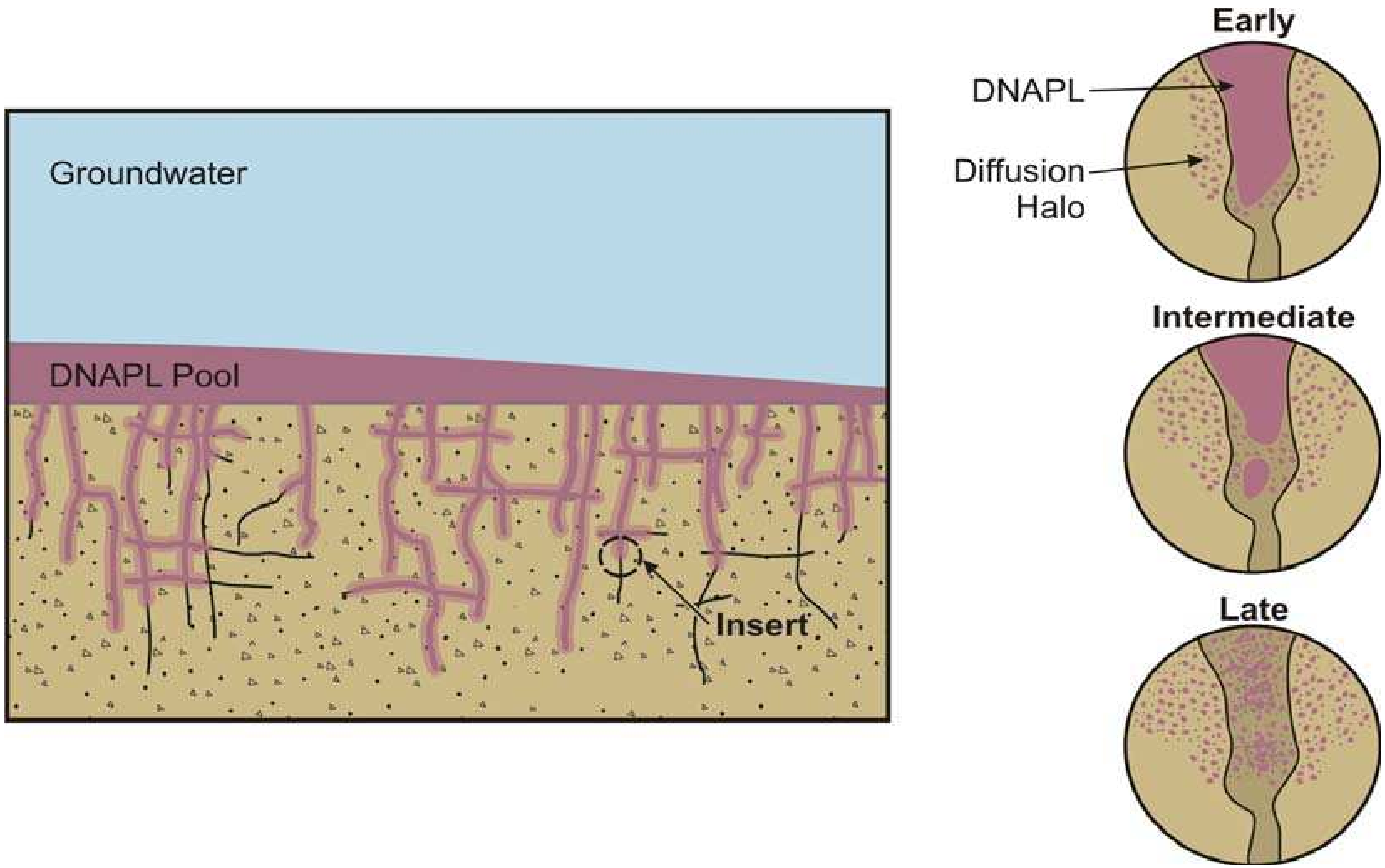




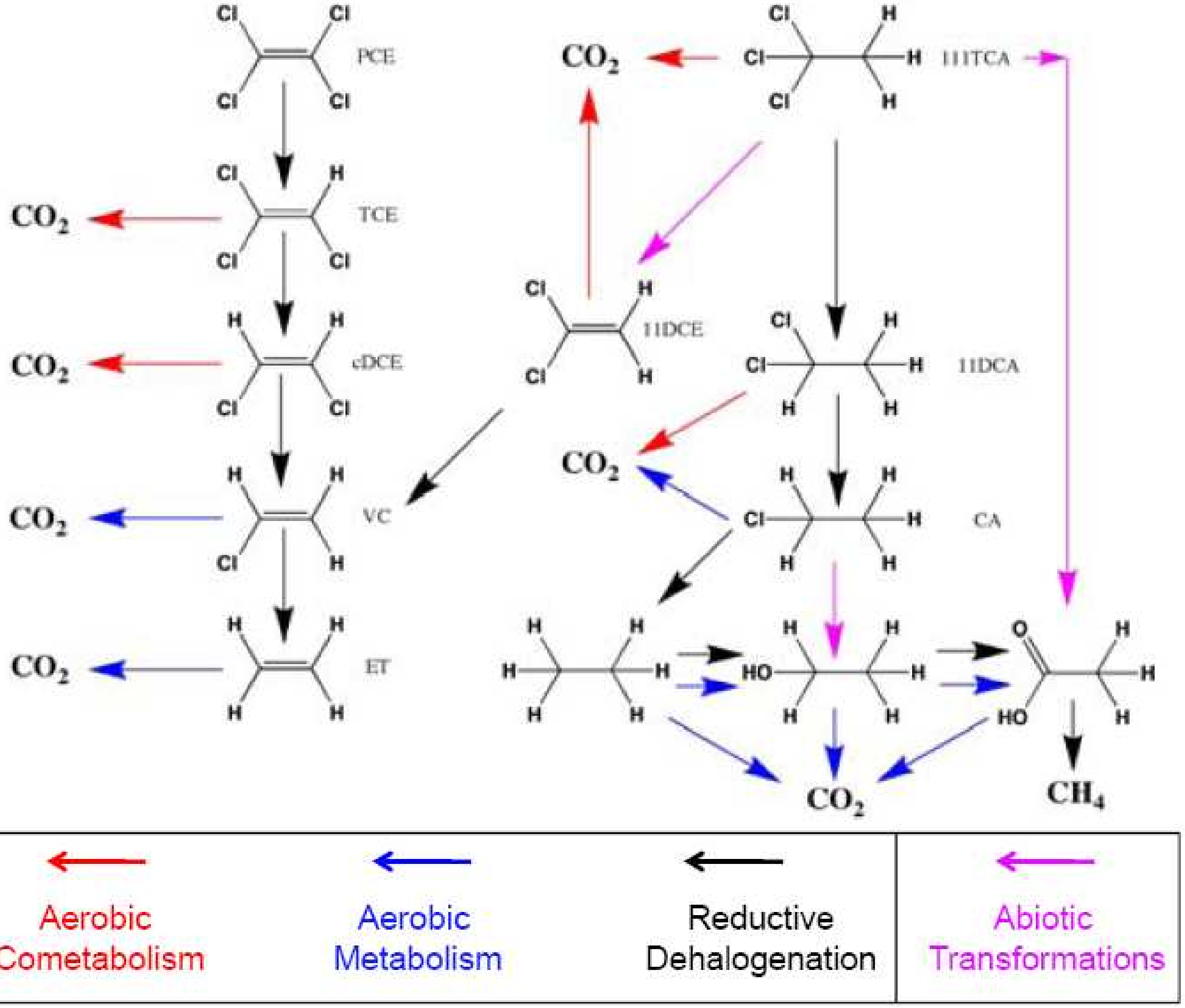
Pre-Remediation:
Dissolved Plume
DNAPL Source Zone
Control Plane
Compliance Plane
Partial Mass Removal:
Dissolved Plume
DNAPL Source Zone
Control Plane
Compliance Plane
Partial Mass Removal + Enhanced Attenuation
Dissolved Plume
DNAPL Source Zone
Control Plane
Compliance Plane
PLUME RESPONSE CDR

POTENTIAL NEGATIVE IMPACTS OF DNAPL MASS REDUCTION

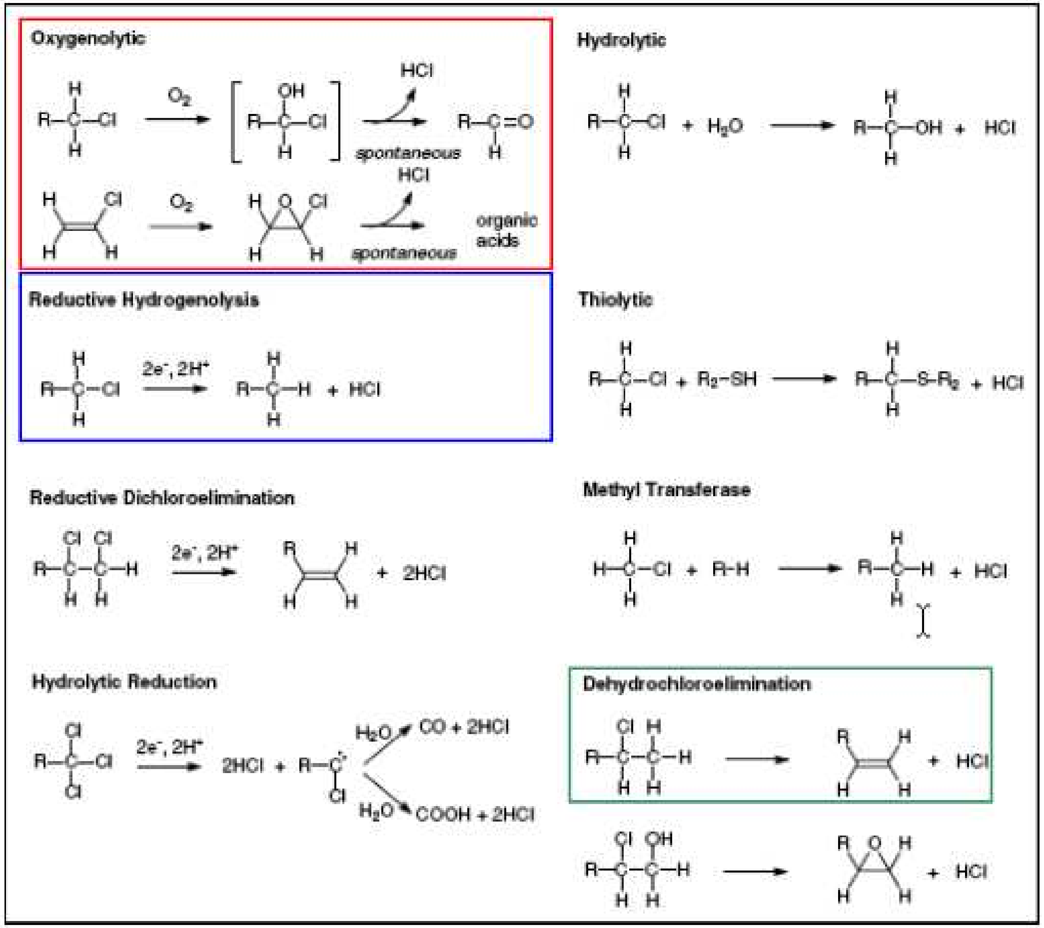
- Expansion of the source zone due to mobilization of residual DNAPL
- Undesirable changes in the DNAPL distribution
- Undesirable changes in physical, geochemical, and microbial conditions
- Adverse impact on subsequent remediation technologies
- Increased life-cycle costs of site cleanup


Groundwater
DNAPL Pool
Insert
Early
DNAPL
Diffusion Halo
Intermediate
Late

ABIOTIC AND BIOTIC TRANSFORMATIONS



DEHALOGENATION MECHANISMS

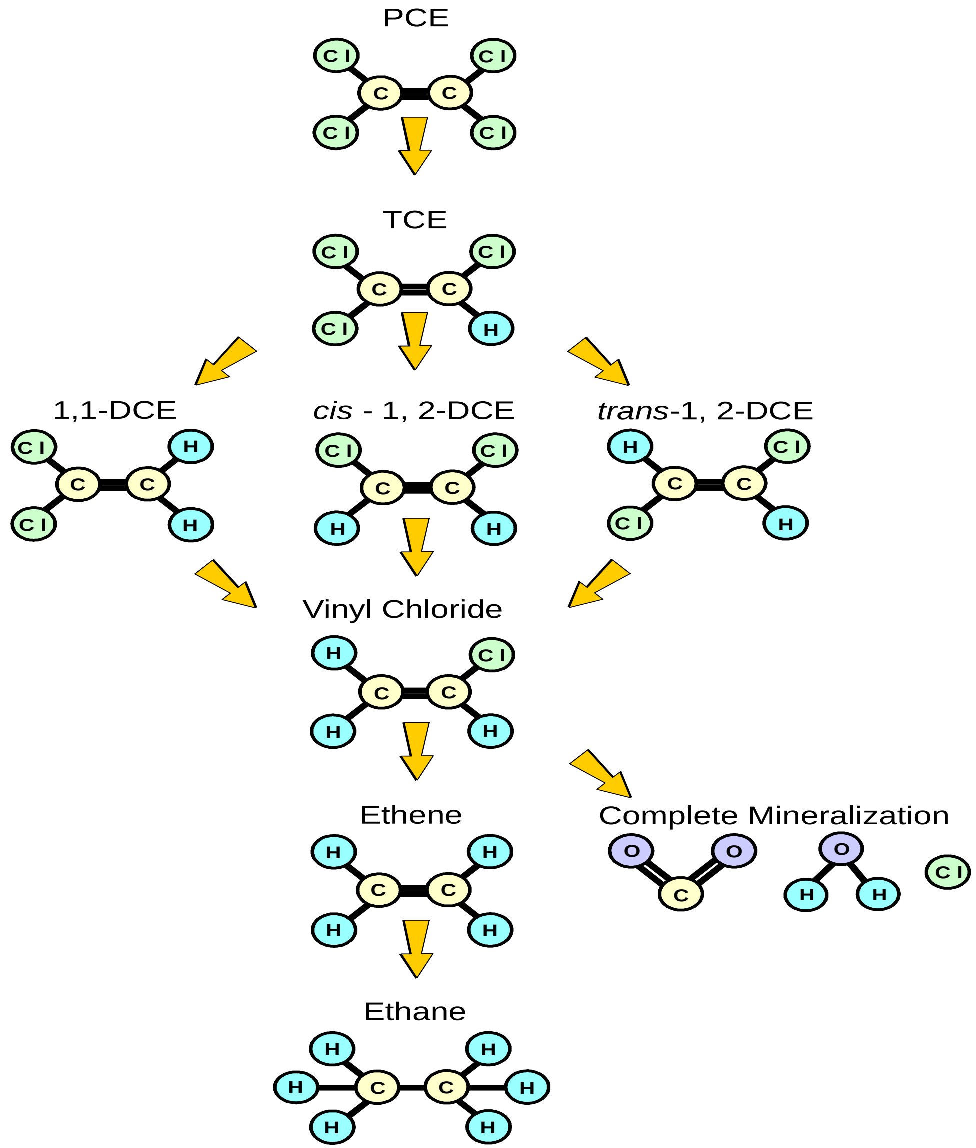


Oxygenolytic: Biodegradation process that requires O_2 for mono- or dioxygenases.

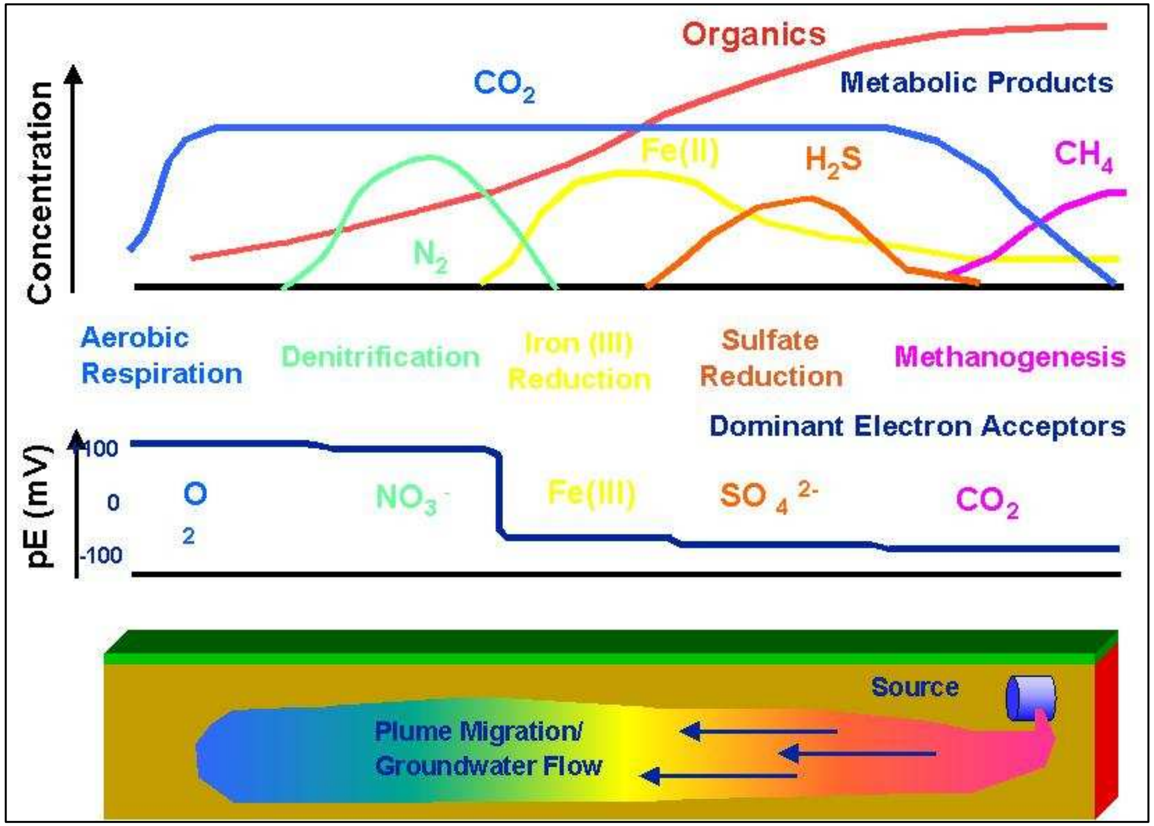
Reductive hydrogenolysis (*aka* reductive dehalogenation): Most common anaerobic biodegradation mechanism for PCE and TCE. Also occurs abiotically.

Dehydrochloroelimination: Common abiotic process that converts haloalkanes to haloalkenes

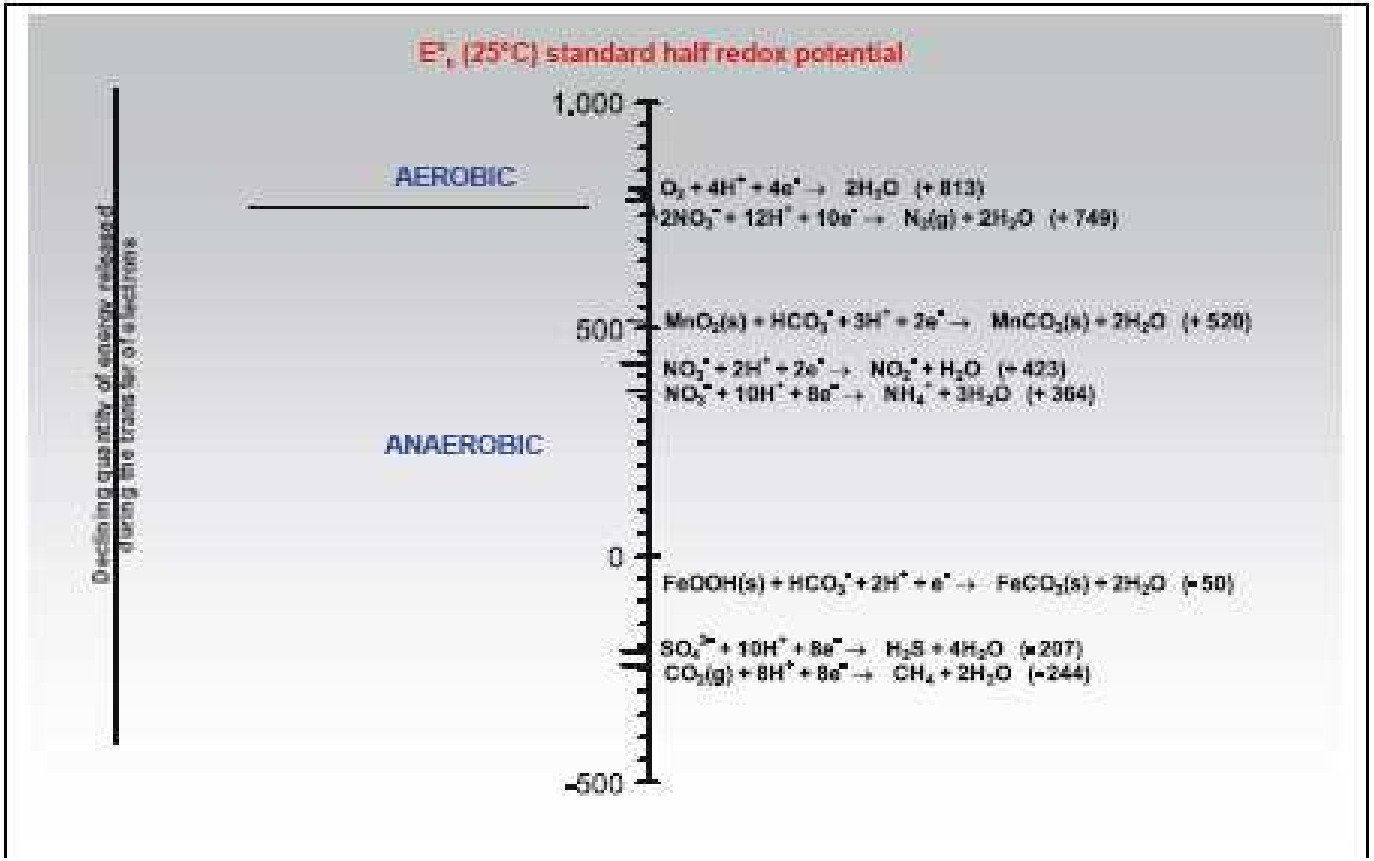
ANAEROBIC REDUCTIVE DEHALOGENATION



ELECTRON ACCEPTORS IN GROUNDWATERS



This schematic illustrates the relative performance range for the major biodegradation processes.



E°, (25°C) standard half redox potential
1,000
500
0
-500
AEROBIC
ANAEROBIC
Declining quantity of energy released during the transfer of electrons
$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$ (+813)
$2NO_3^- + 12H^+ + 10e^- \rightarrow N_2(g) + 2H_2O$ (+749)
$MnO_2(s) + HCO_3^- + 3H^+ + 2e^- \rightarrow MnCO_3(s) + 2H_2O$ (+520)
$NO_3^- + 2H^+ + 2e^- \rightarrow NO_2^- + H_2O$ (+423)
$NO_3^- + 10H^+ + 8e^- \rightarrow NH_4^+ + 3H_2O$ (+364)
$FeOOH(s) + HCO_3^- + 2H^+ + e^- \rightarrow FeCO_3(s) + 2H_2O$ (-50)
$SO_4^{2-} + 10H^+ + 8e^- \rightarrow H_2S + 4H_2O$ (-207)
$CO_2(g) + 8H^+ + 8e^- \rightarrow CH_4 + 2H_2O$ (-244)

BIOTIC REDUCTIVE DEHALOGENATION

Organism	Dechlorination reactions	Electron donors	Other electron acceptors	Morphology	Phylogenetic position	References
Dehalobacter restrictus	PCE, TCE → *cis*-DCE	H_2	None	Rod	Gram + *Desulfotomaculum* group	Holliger *et al.*, 1998; 1999
Dehalospirillum multivorans	PCE, TCE → *cis*-DCE	H_2, formate, pyruvate, etc.	Thiosulfate, nitrate, fumarate, etc.	Spirillum	*Proteobacteria*	Neumann *et al.*, 1994, 1998
Strain TT4B	PCE, TCE → *cis*-DCE	Acetate	None	Rod	?	Krumholz *et al.*, 1996
Enterobacter agglomerans	PCE, TCE → *cis*-DCE	Nonfermentable substrates	O_2, nitrate, etc.	Rod	γ *Proteobacteria*	Sharma and McCarty, 1996
***Desulfitobacterium* sp. strain PCE1**	PCE, TCE → (*cis*-DCE) *o*-chlorophenols	Lactate, pyruvate, butyrate, ethanol, etc.	Sulfite, thiosulfate, fumarate	Curved rod	Gram + *Desulfotomaculum* group	Gerritse *et al.*, 1996
***Desulfitobacterium frappieri* strain TCE1**	PCE, TCE → (*cis*-DCE)	H_2, formate, lactate, butyrate, crotonate ethanol, etc.	Sulfite, thiosulfate, nitrite fumarate	Curved rod	Gram + motile	Gerritse *et al.*, 1999
***Dehalococcoides ethenogenes* strain 195**	PCE, others → ethane	H_2	None	Irregular coccus	Novel eubacterium	Maymó-Gatell *et al.*, 1997
***Dehalococcoides* sp. strain BAV1**	VC, *cis*-DCE, *trans*-DCE, 1,1-DCE, others → ethene	H_2	None	Non-motile disc	?	He *et al.*, 2003
***Desulfuromonas michiganensis* sp. nov. (Strain BB1, BRS1)**	PCE → *cis*-DCE	Acetate, lactate, pyruvate, succinate, malate, fumarate	None	Short, ovoid rods (some club-shaped rods seen in early stationary phase when grown on fumarate)	*Desulfuromonas* cluster of δ *Proteobacteria*	Sung *et al.*, 2003

ANAEROBIC BIOREMEDIATION

If	Solution
Aerobic conditions	Add carbon (aerobic biodegradation of C will consume the dissolved O_2 present).
Limited carbon	Add carbon (propionate, lactate, butyrate, molasses, hydrogen releasing compound®.
Limited nutrients	Add nutrients (Ammonia and phosphate).
Low pH	Add buffer (bicarbonate)
Incomplete dechlorination	Add microbial consortium.

SUSTAINABILITY

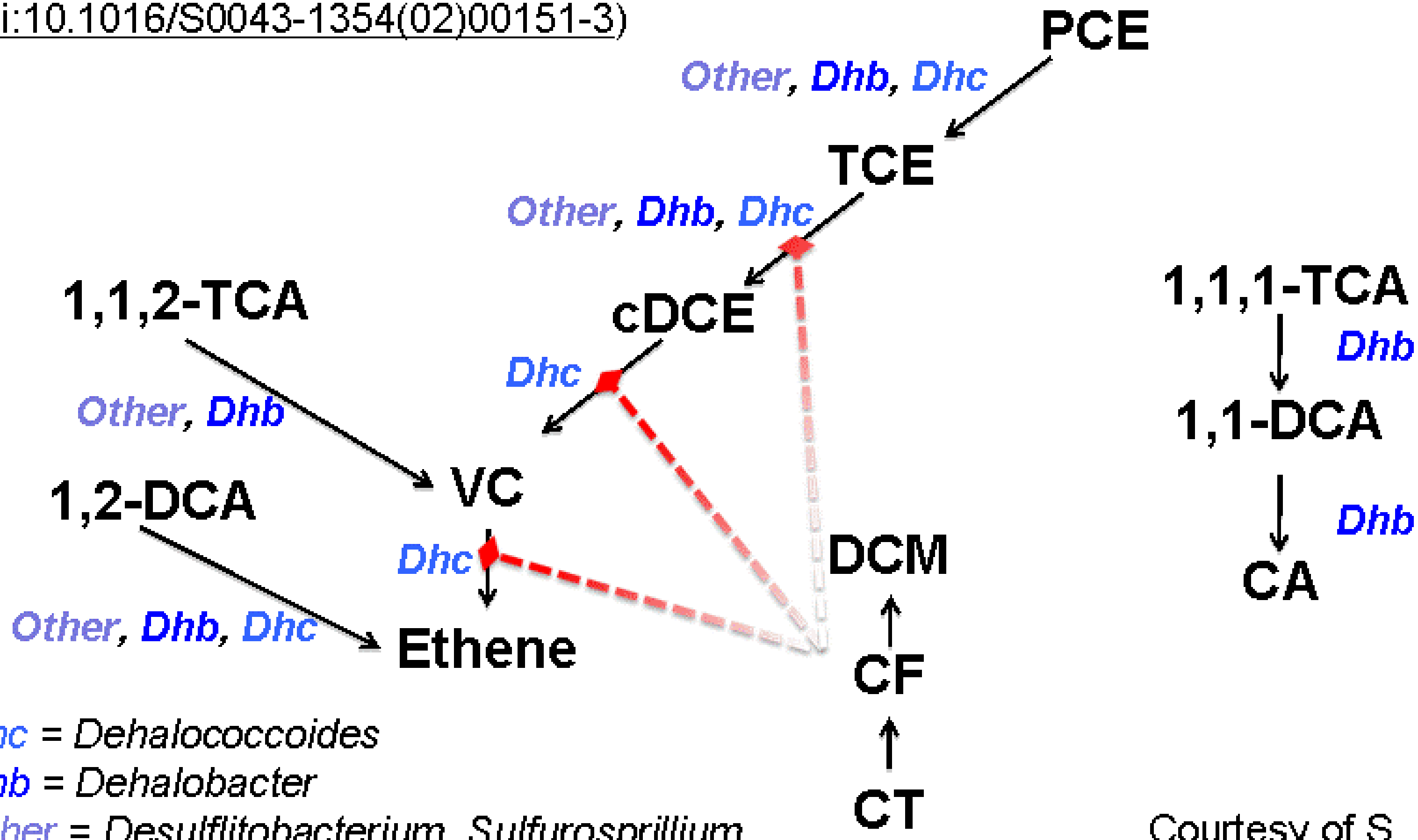
Ability of a system to maintain important attenuation mechanisms through time.

In the case of reductive dechlorination, sustainability might be limited by the amount of electron donor, which might be used up before remedial goals are achieved.

Sustainability is affected by the rate at which the contaminants are transferred from the source area and whether the protecting mechanisms are renewable.

CF DECHLORINATION INHIBITION

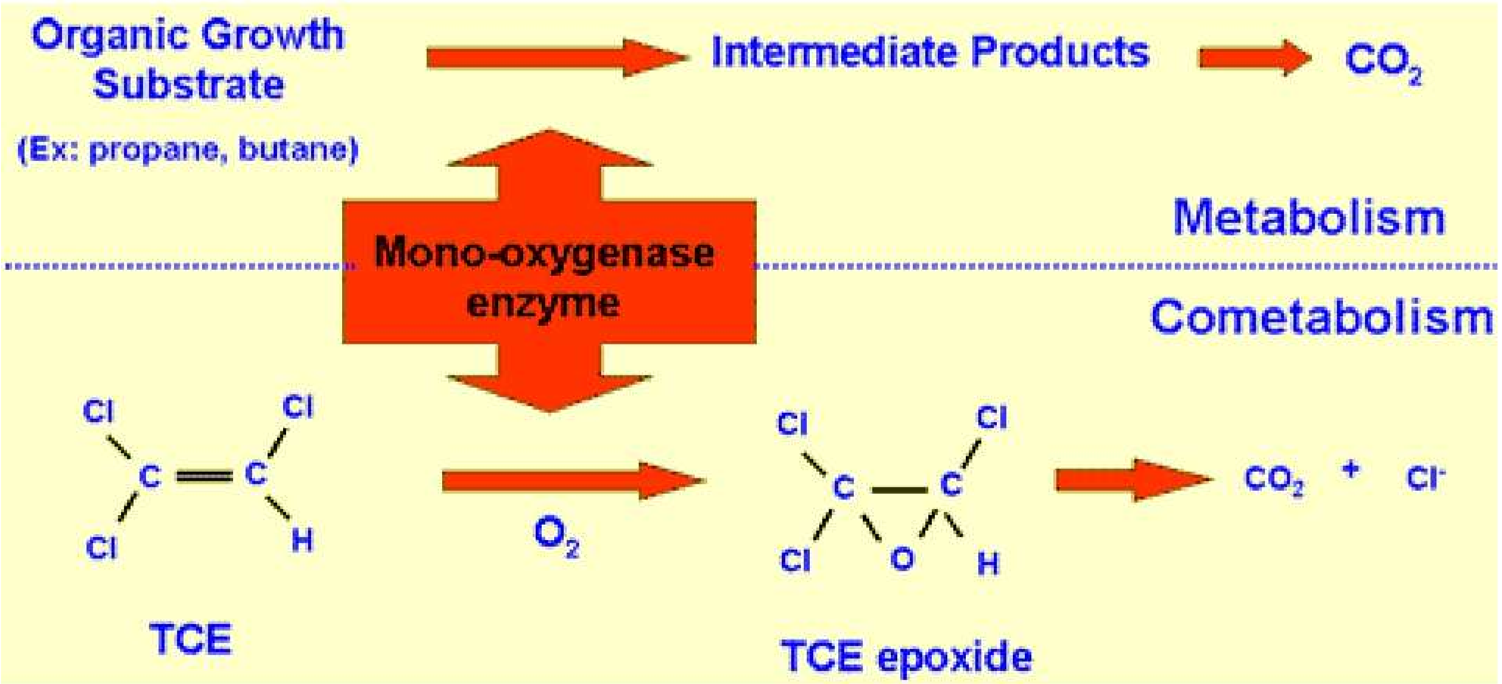
Inhibition starts ~ >0.07 mg/L (Duhamel et al, 2002
doi:10.1016/S0043-1354(02)00151-3)

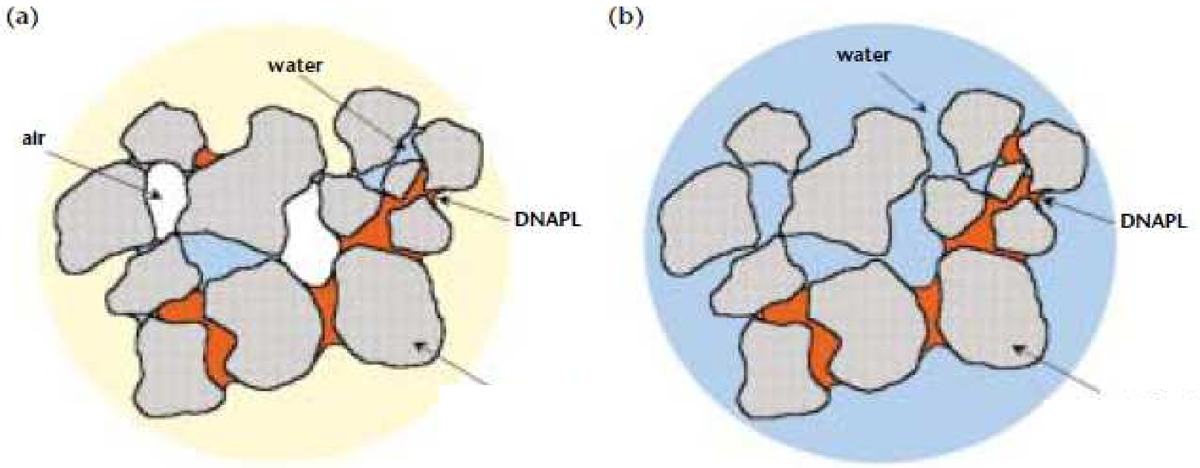


Dhc = *Dehalococcoides*
Dhb = *Dehalobacter*
Other = *Desulflitobacterium, Sulfurosprillium, Clostridium* Inhibition = ♦- - - - -

Courtesy of S. Dworatzek (SiREM)

AEROBIC COMETABOLISM



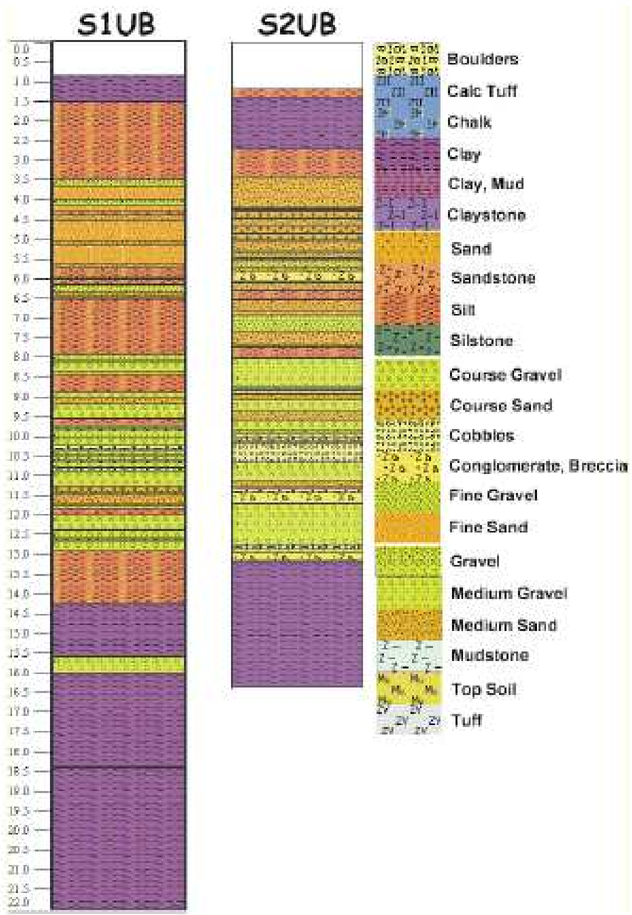


Residual DNAPL in (a) unsaturated and (b) saturated porous media

CONTAMINANT CHARACTERISTICS TO ESTABLISH

Parameter	Example use of Information
DNAPL density	DNAPL mobility and pool height calculations
DNAPL viscosity	Determine if DNAPL could still be moving Design of NAPL recovery system
DNAPL component composition	Effective solubility calculations Predict future composition of plume
DNAPL-water interfacial tension	Determine importance of capillary forces Pool height calculations
Organic carbon partition coefficient	Determine degree of aqueous phase sorption and rate of plume migration
Contaminant half-life	Determine degree of degradation and rate of plume migration
DNAPL vapour pressure	Determine if vapour migration is a potential issue; Estimate lifespan of DNAPL above water table
Date and volume of DNAPL release	Estimate of depth of DNAPL migration. Is DNAPL still moving?
Potential DNAPL release locations	Help guide monitoring well placement

SITE 2

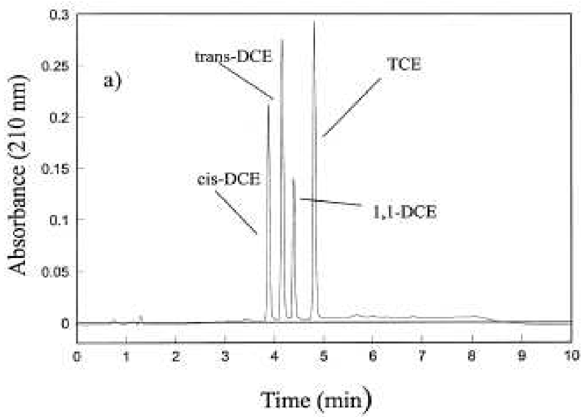


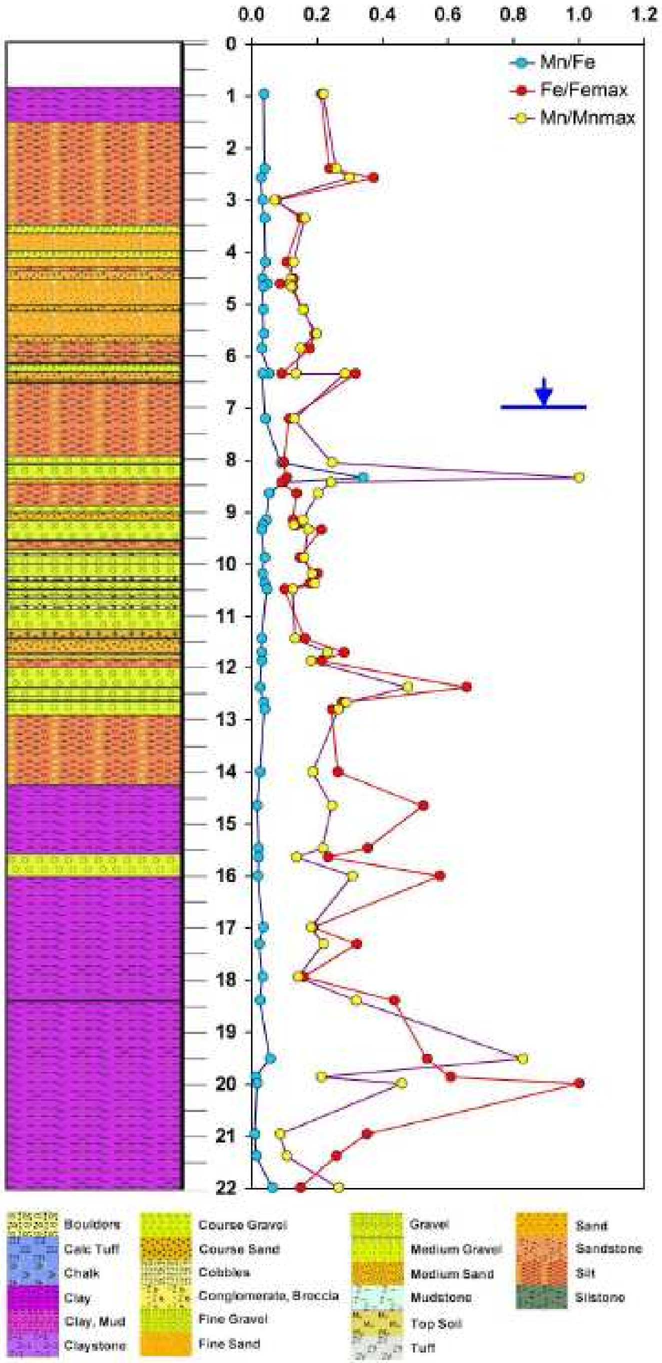
Geological testing of boreholes. A: S1UB. B: S2UB. April 2008.

Main statistical parameters of VOCs in porewater (µg/L) from sediment samples of S2UB S1UB boreholes. DL detection limit. (April-May,

	S1UB (µg/L)															
	Chloromethanes			Chloroethanes				Chloroethenes					BTEX				
% Samples >DL	33,3	81,0	41,3	25,4	15,9	17,5	33,3	42,9	17,5	6,3	22,2	20,6	20,6	87,3	42,9	71,4	71,4
VOCs	CT	CF	DCM	1,1,1,2 PCA	1,1,2,2 PCA	1,1,1 TCA	1,1,2 TCA	PCE	TCE	1,1 DCE	tDCE	cDCE	Benzene	Toluene	Ethylbenzene	M_xilene	P_xilene
Max	563,56	1468,48	5730,38	131,57	2258,95	78,83	98,47	139,37	78,63	15,28	152,49	24,92	50,41	593,28	98,08	180,76	354,54
Min	1,14	3,83	1,46	1,67	1,38	1,47	1,55	1,34	1,59	1,34	1,38	2,35	0,96	1,86	0,97	0,94	0,95
Geom. mean	11,32	87,75	31,55	8,59	5,36	5,12	7,93	11,31	5,57	4,16	5,64	4,79	3,65	60,03	6,21	12,39	12,95
Std. Dev.	113,27	250,64	1357,19	26,90	293,55	11,27	20,68	31,94	11,38	2,83	20,30	4,73	7,15	145,02	19,10	36,11	53,77
Geom. mean + 2 Std. Dev.	237,87	589,03	2745,92	62,39	592,46	27,65	49,30	75,19	28,34	9,82	46,24	14,24	17,94	350,07	44,41	84,61	120,48

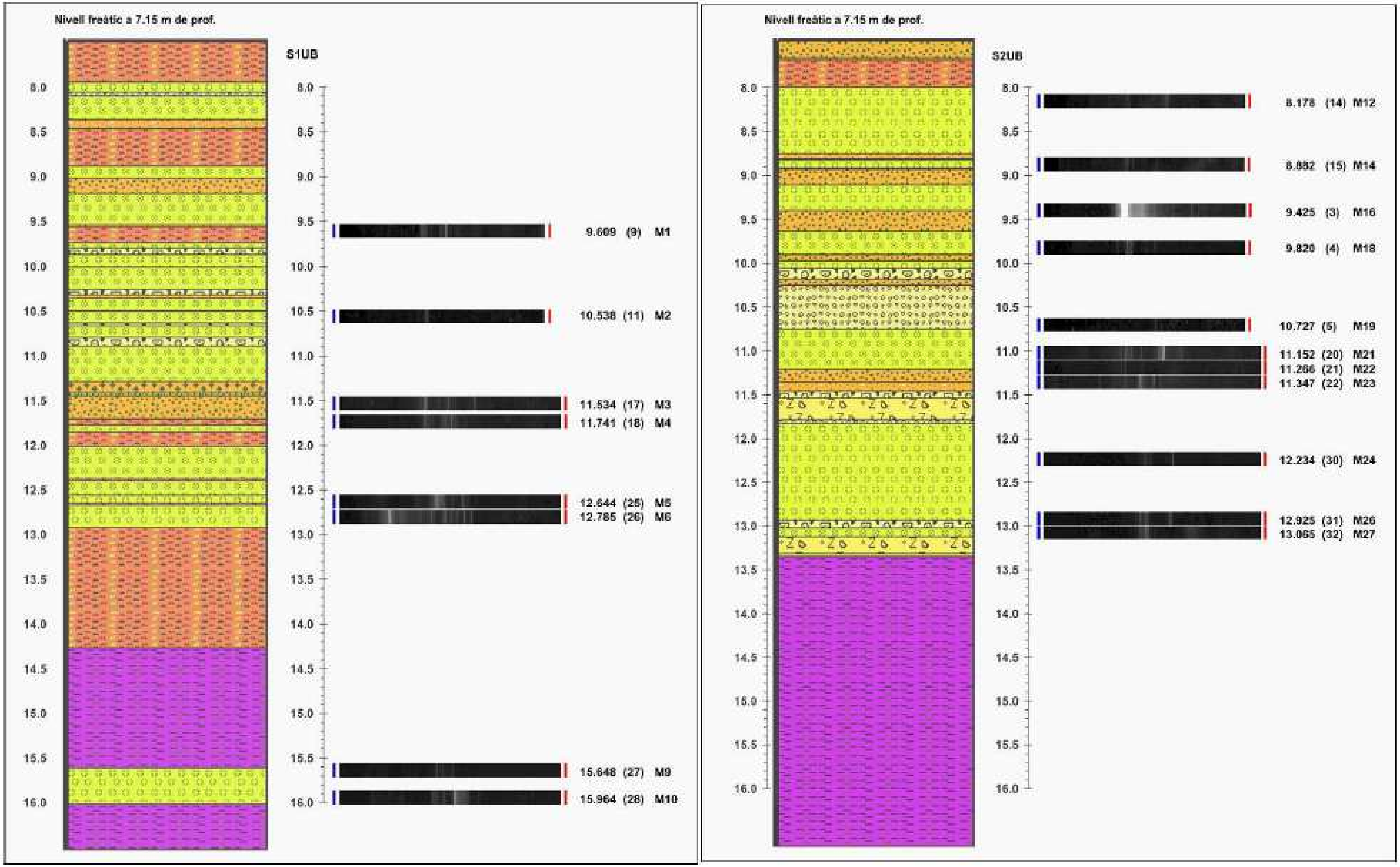
	S2UB (µg/L)															
	Chloromethanes			Chloroethanes				Chloroethenes					BTEX				
% Samples >DL	25,4	73,1	35,8	52,2	19,4	22,4	19,4	58,2	23,9	11,9	14,9	16,4	22,4	77,6	58,2	71,6	59,7
VOCs	CT	CF	DCM	1,1,1,2 PCA	1,1,2,2 PCA	1,1,1 TCA	1,1,2 TCA	PCE	TCE	1,1 DCE	tDCE	cDCE	Benzene	Toluene	Ethylbenzene	M_xilene	P_xilene
Max	406,37	1286,29	9053,49	848,62	1782,11	98,91	214,93	996,73	101,06	50,61	72,12	52,35	117,71	10056,28	215,33	263,04	713,28
Min	1,38	2,69	2,57	2,80	2,19	2,26	2,61	1,63	2,51	2,30	2,32	2,25	1,61	1,35	1,31	1,15	1,35
Geom. mean	7,32	122,69	23,51	19,96	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4,60	89,32	9,48	15,28	15,57
Std. Dev.	60,93	340,31	1606,59	164,58	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20,41	1279,53	40,35	59,06	141,54
Geom. mean + 2 Std. Dev.	129,18	803,30	3236,70	349,11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	45,42	2648,37	90,18	133,40	298,65





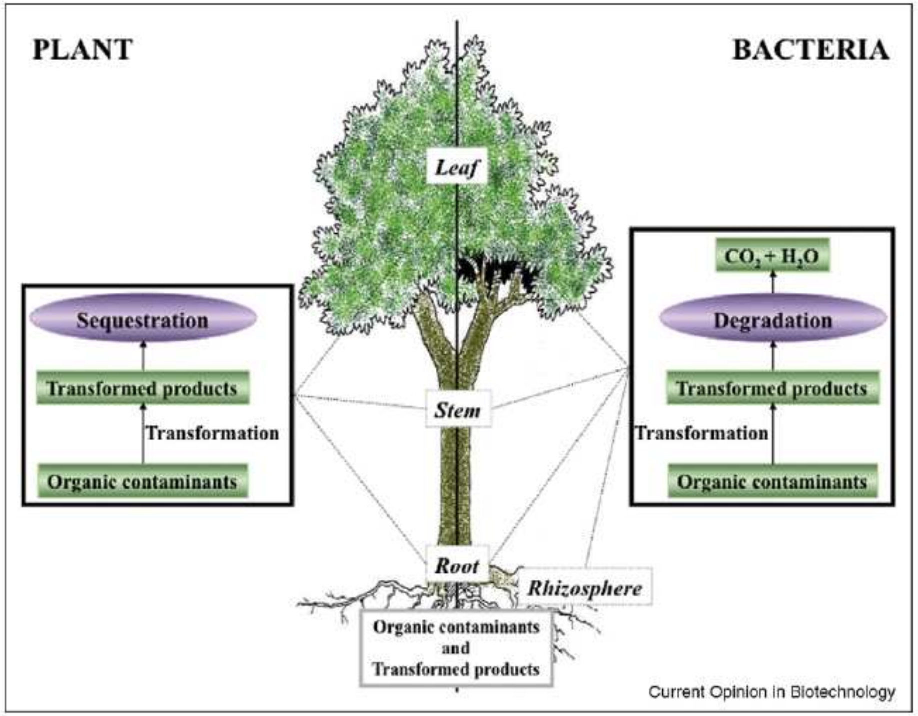
S1UB borehole.

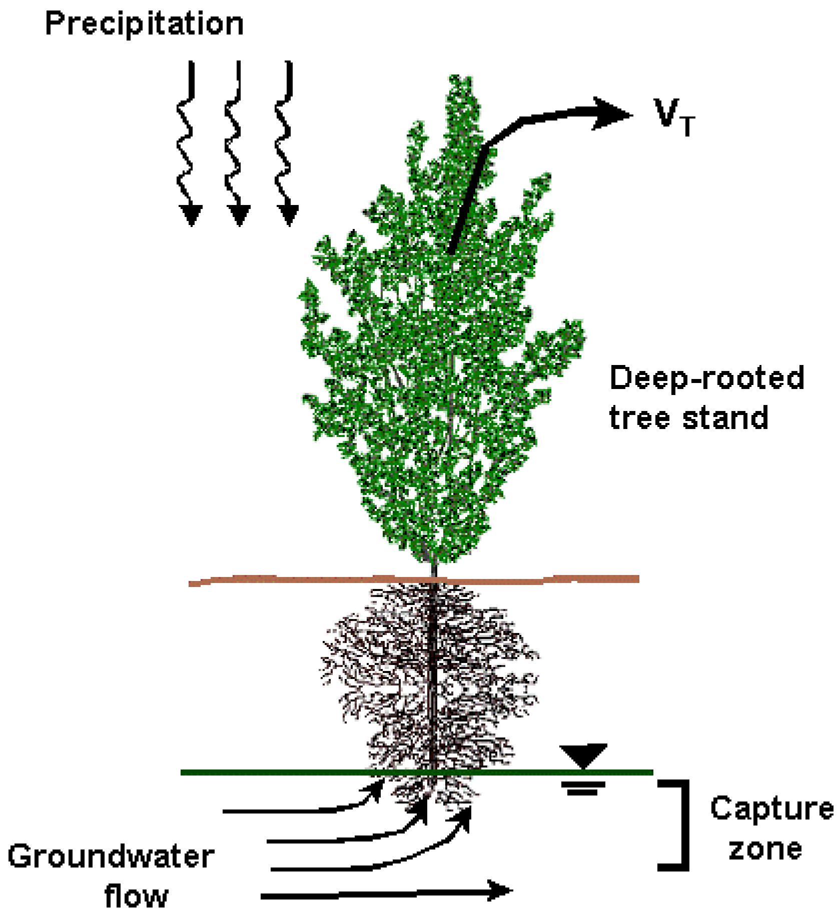
Denaturing Gradient Gel Electrophoresis (DGGE)



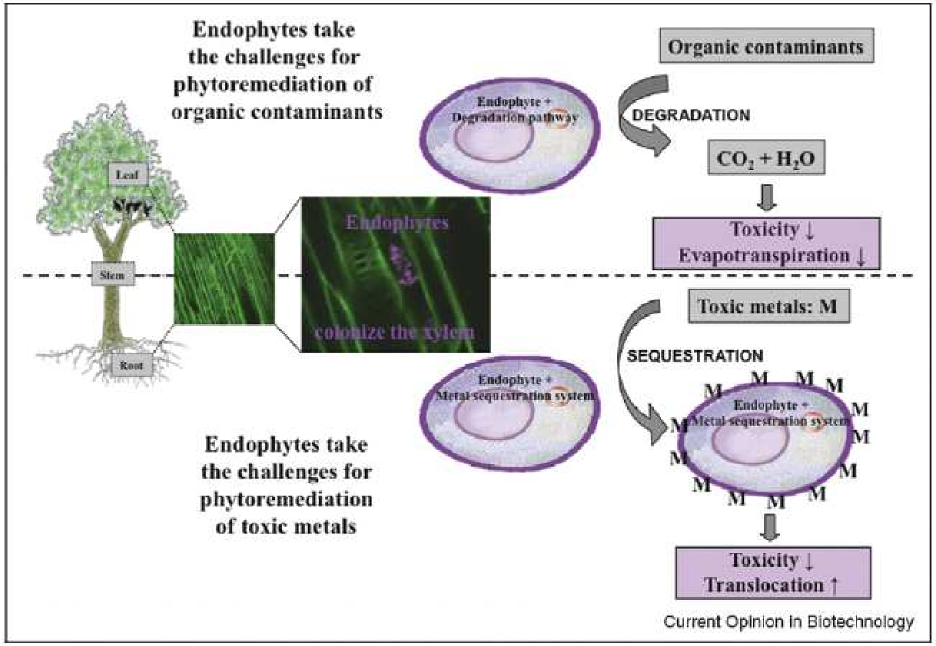
DGGE in the S1UB and S2UB core.

PHYTODEGRADATION




Precipitation
V_T
Deep-rooted
tree stand
Capture
zone
Groundwater
flow

PHYTODEGRADATION & BIOTECHNOLOGY



PHYTODEGRADATION & BIOTECHNOLOGY

Area A (contaminated):
Salix alba;
poplar hybrids DN-34 and NM-6

Area B (uncontaminated): Poplar hybrids DN-34 and NM-6

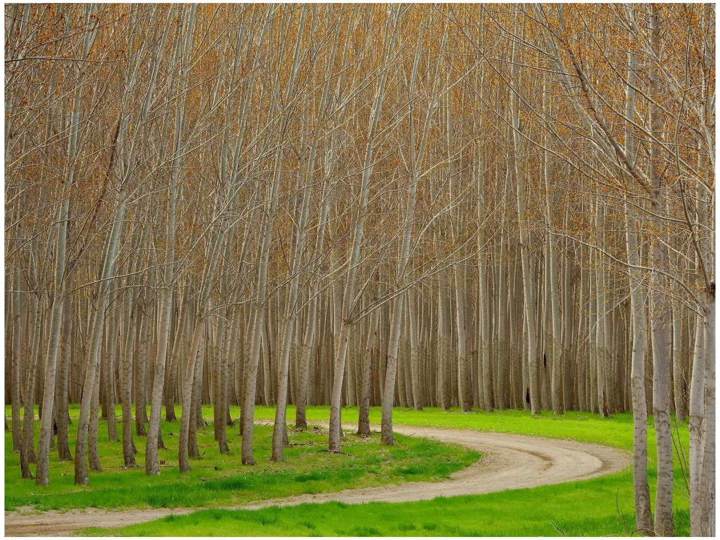
Clones

ADVANTAGES OF *Populus s*p. IN PHYTOREMEDIATION

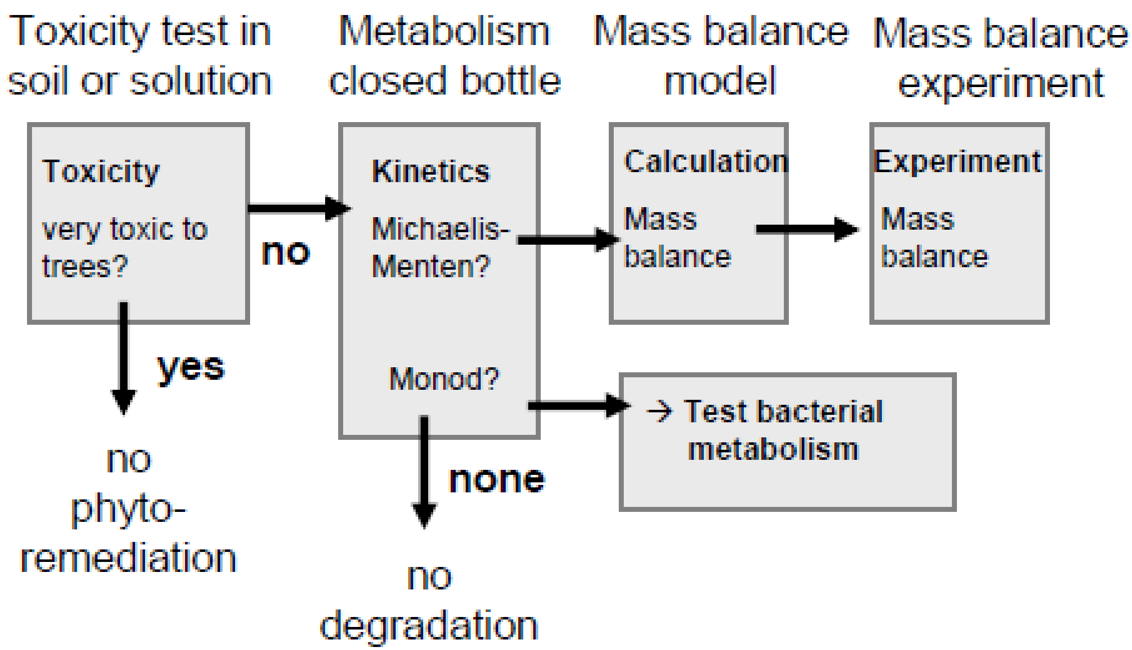
- Greater than 25 species worldwide
- Fast growing (3 to 5 meters/year)
- High transpiration rates (100 liters/day for 5 year old tree)
- Not part of food chain
- Trees can be used for paper production or as biomass for energy
- Long lived (25-30 years)
- Grow easily from cuttings
- Can be harvested and then regrown from the stump

Adapted from Gordon (1997) and Schnoor et al. (1995)



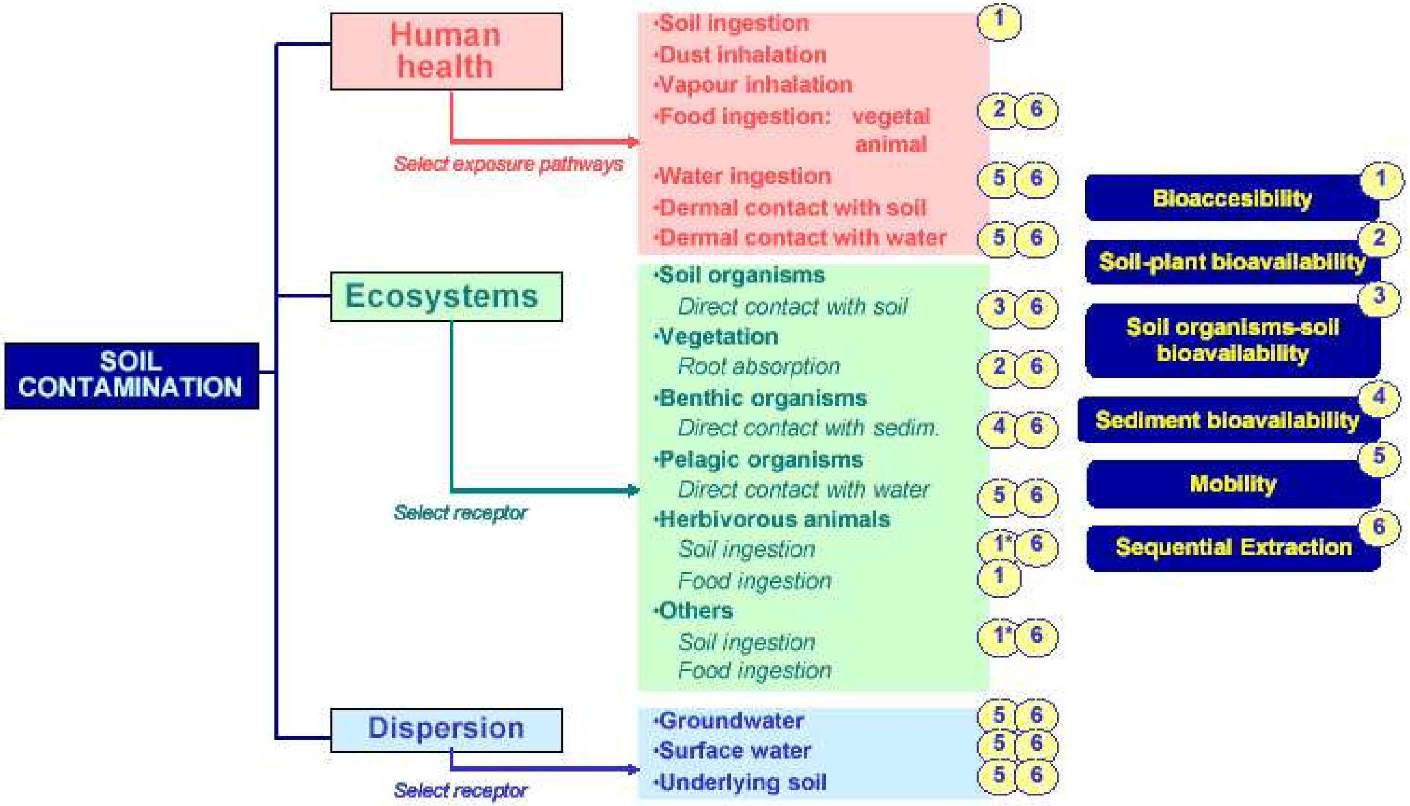
Test scheme phytoremediation



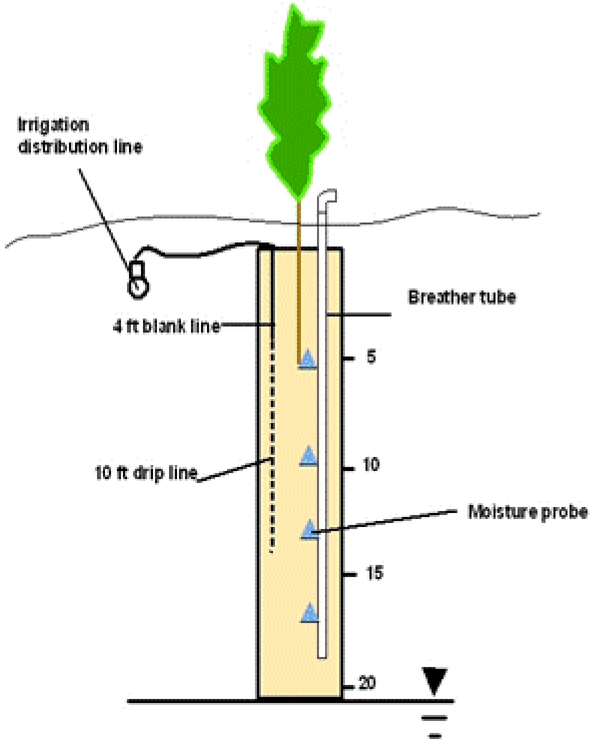
Poplars are able to survive when grown in water containing 50 ppm TCE (Gordon et al., 1997).

TCE is acutely toxic to a variety of crop plants at concentrations of about 2 mM in the gas phase (Ryu et al. 1996).

TOXICITY TESTS



Planting Methods and Cultural Practices



- Planting methods
  - boreholes, backfilled with sand/compost
  - vertical drip lines
  - breather tubes
  - moisture probes
  - poplar/willow poles deeply planted

- Subsurface irrigation
  - 2003 – 2006
  - no irrigation in 2007
  - using nutrient solutions in spring

RATE OF WATER USE

$$V_T = ET_O \bullet \theta \bullet LAI \bullet A$$

V_T = volumetric rate of water use by the stand

ET_O = reference evapotranspiration: rate of transpiration by a well-watered 15-cm tall fescue turf

θ = water use multiplier for the trees within the stand: rate of water use per unit leaf area as a percentage of ET_O

LAI = leaf area index: the leaf area per unit area of ground surface

A = area of the stand

SELECTION AND PRODUCTION OF INOCULS

GROUP PRESENTATION

Dra. Amparo Cortés (UB-Farmàcia)
Dr. José Mª Carmona (UB-Geologia)
Dra. Diana Puigserver (UB-Geologia)
Dra. Magdalena Grifoll (UB-Biologia)
Dr. Nieto (UB-Biologia)
Dra. Victòria Estaum (IRTA-GC)
Dra. Cinta Calvet (IRTA-GC)

GROUP OBJECTIVES

- **Improving knowledge on media, and on health and environmental risks;**
- **Reducing costs of sustainable soils and ground waters remediation, while increasing efficiency.**

Dra. Amparo Cortés Lucas

S.D. Edafologia
D. Productes Naturals, Biologia Vegetal i Edafologia
Universitat de Barcelona

Tel. 93 402 44 94
Fax 93 402 44 95

acortes@ub.edu