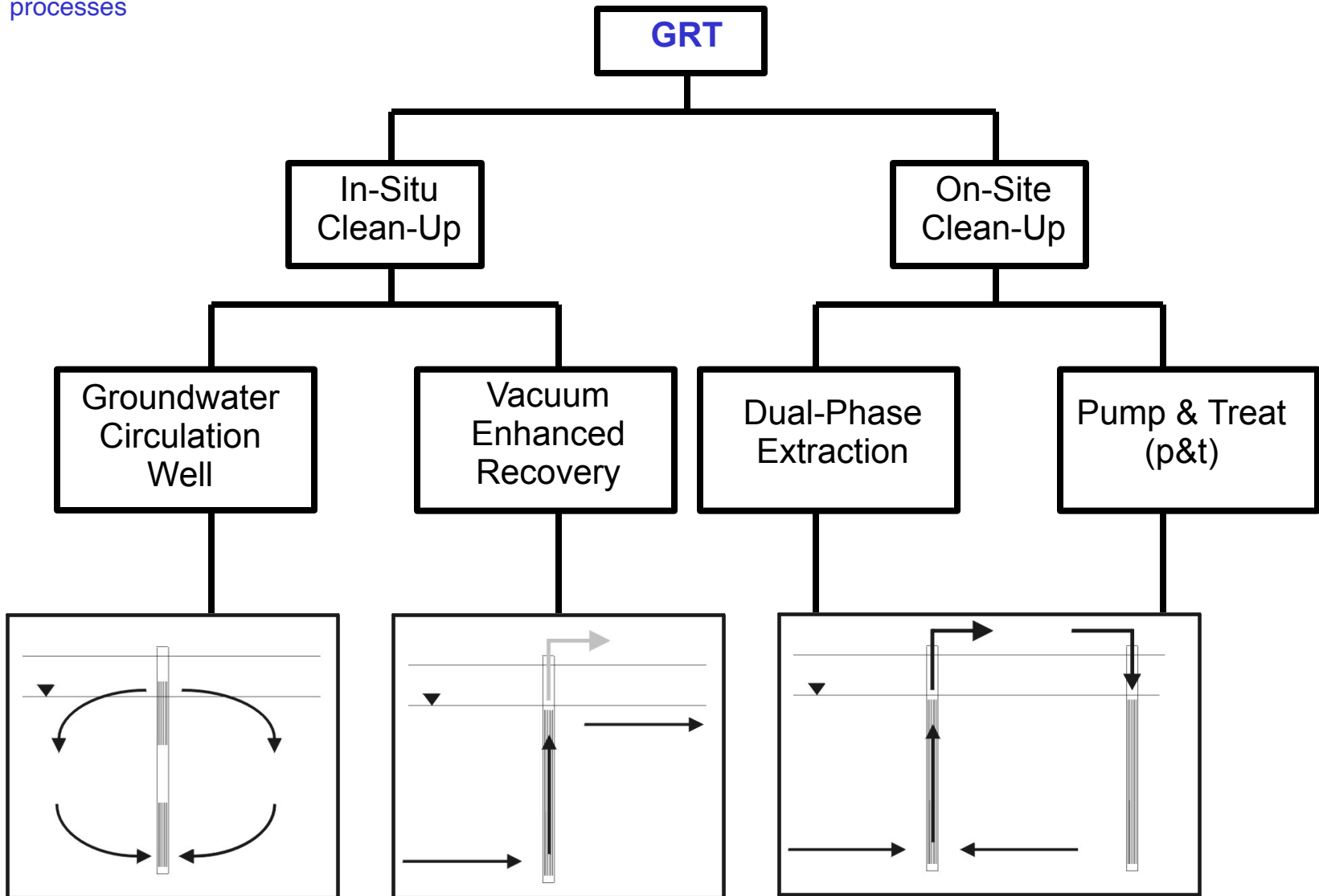




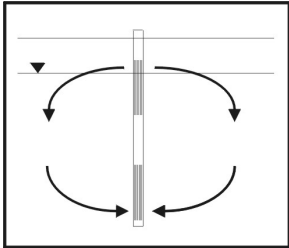
Groundwater Remediation Technologies:

Carbon Dioxide Vacuum Stripping (CVS)

Groundwater Remediation Technologies (GRT)

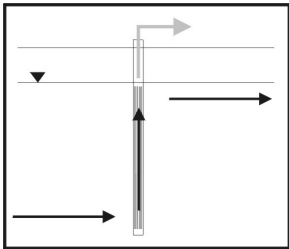


GRT: A Technology Evaluation



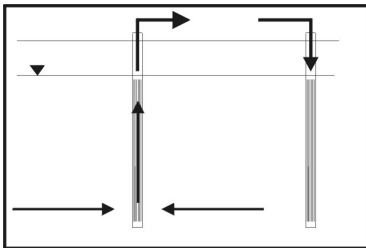
Groundwater Circulation Well:

- Due to poor extraction performance of injected air, a multiple passage of water through the well is required.
- Circulation requires high permeability ($kh \geq 10^{-2}$ cm/sec)
- Minimum thickness of the aquifer of 30 feet
- Remediation of volatile constituents only



Vacuum Enhanced Recovery:

- High extraction performance by Carbon Dioxide
- Effective also in low conductivity formations (silt, clay) and fractured rock
- Applicable also in depths > 100 feet
- By additional processes remediation of volatile and non-volatile constituents.
- Elimination of DNAPLs and LNAPLs



Pump&Treat:

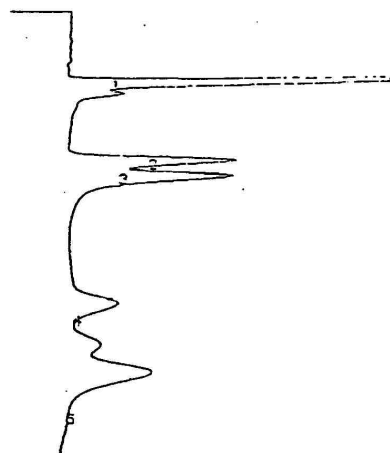
- Traditional method for securing a source area by intercepting a down-gradient flow-off of pollutants

Dual-Phase Extraction:

- Pumping achieved by a high vacuum

CVS In-Well Stripping

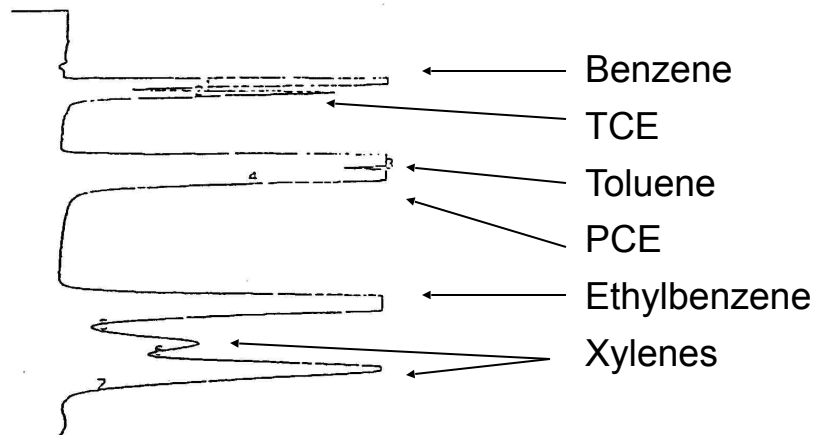
Stripping Agent: **Ambient Air**



DATE 04/02/90 TIME 19:21:54
NOISE = 16
BASELINE = 638

SEARCH MODE RESULTS			
PK#	HEIGHT	AREA	TIME
1	6119	45222	1:25
2	1748	19029	2:54
3	1675	15064	3:12
4	513	8943	5:36
5	301	22686	6:50

Stripping Agent: **Carbon Dioxide**



DATE 04/02/90 TIME 19:31:04
NOISE = 14
BASELINE = 610

SEARCH MODE RESULTS			
PK#	HEIGHT	AREA	TIME
1	13825	91955	1:26
2	2813	9129	1:39
3	12214	132343	2:55
4	7327	61785	3:13
5	7280	141312	5:35
6	1454	25288	6:20
7	3571	73956	6:50

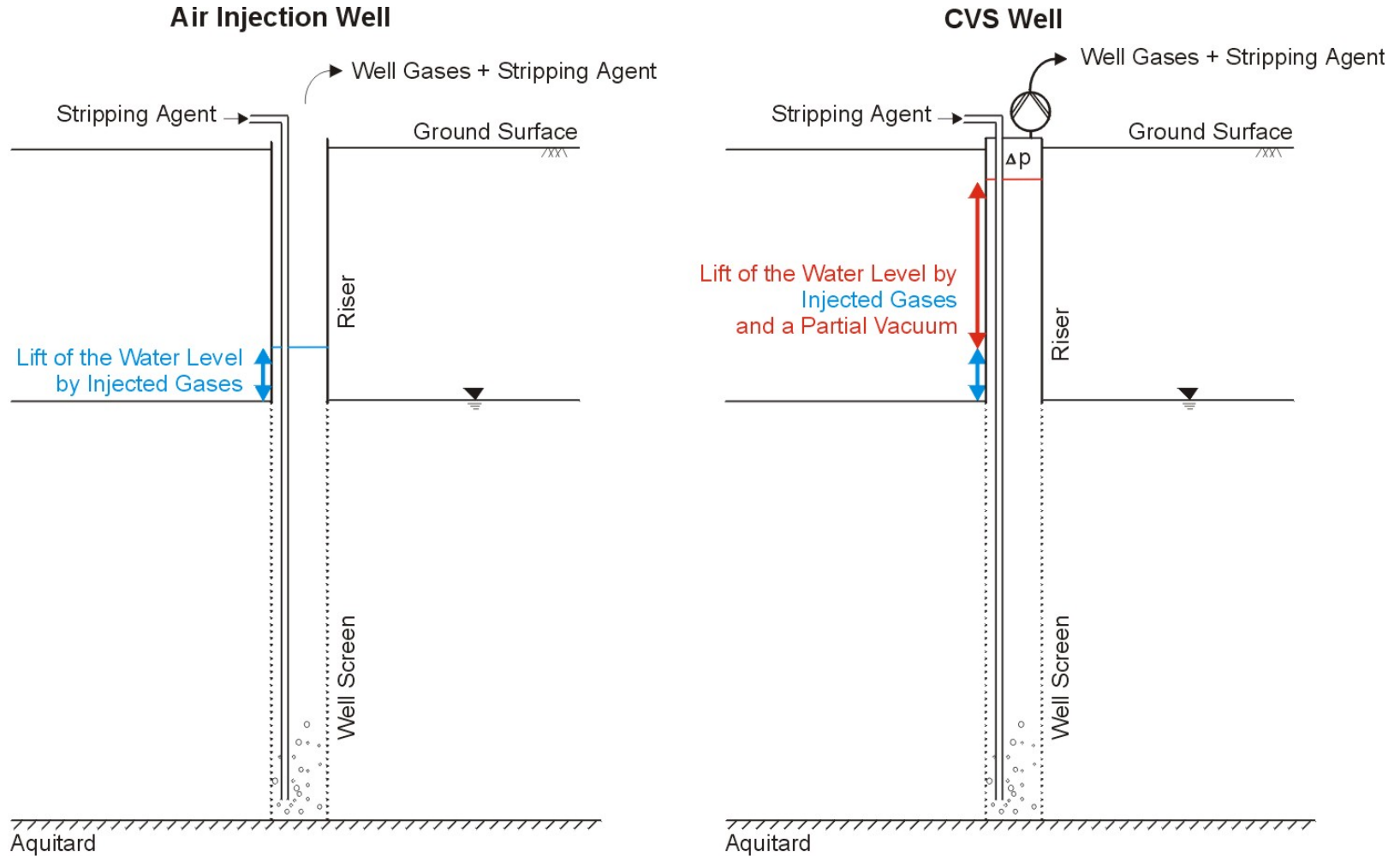
GC-PID, EPA Column 602, Lamp 10.2 eV all substances equal in weight

Solubility of Extraction Agents in Water

$$\frac{\text{Ncm}^3 \text{ (Gas)}}{\text{g (Water)}}$$

Gas	5	10	15	20 °C
Argon	0.045	0.040	0.036	0.033
Air	0.025	0.022	0.020	0.018
O ₂	0.041	0.037	0.033	0.030
N ₂	0.020	0.018	0.017	0.015
CO ₂	1.378	0.987	0.851	0.738

CVS Hydraulic System



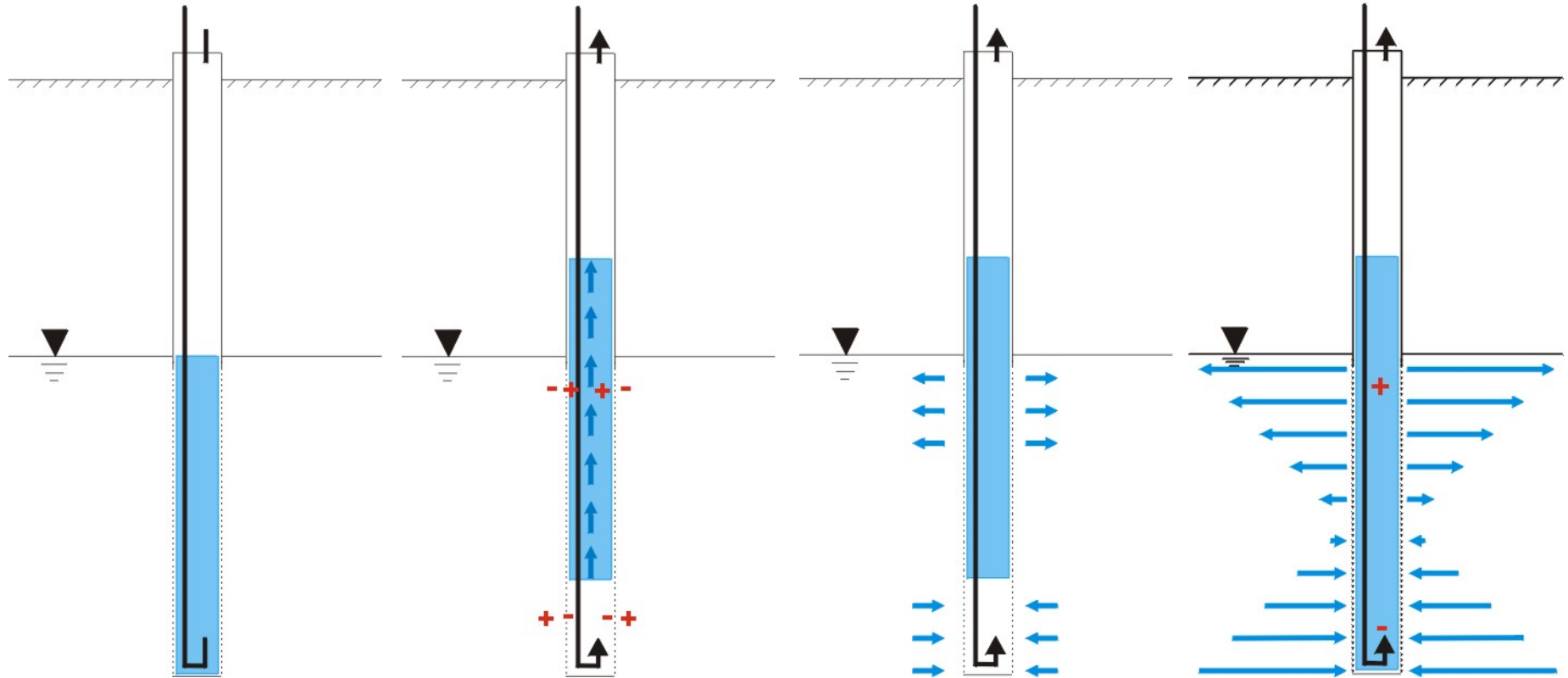
CVS Hydraulic System

$t(0)$

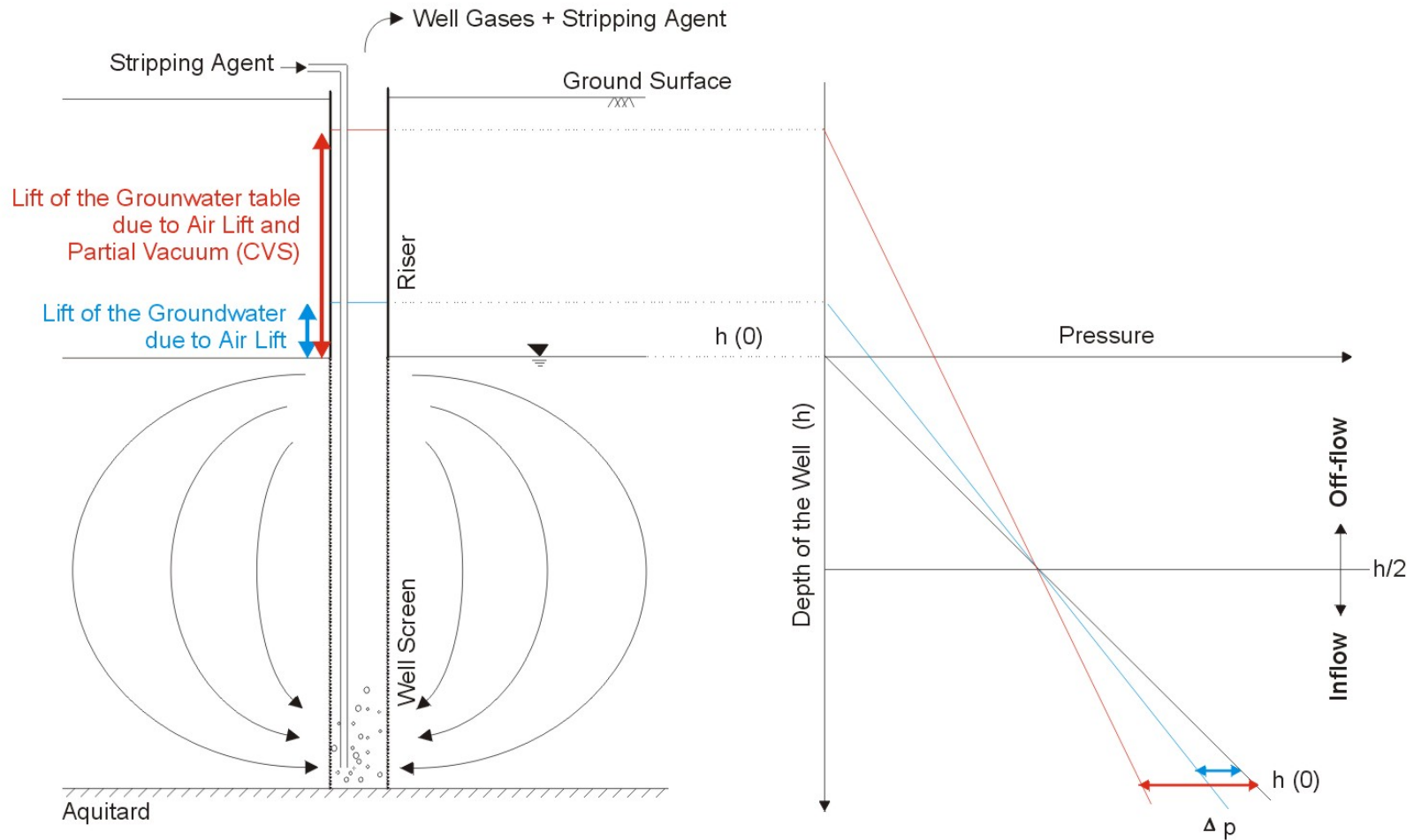
$t(+1 \text{ sec})$

$t(5 \text{ min})$

$t(1 \text{ hour})$



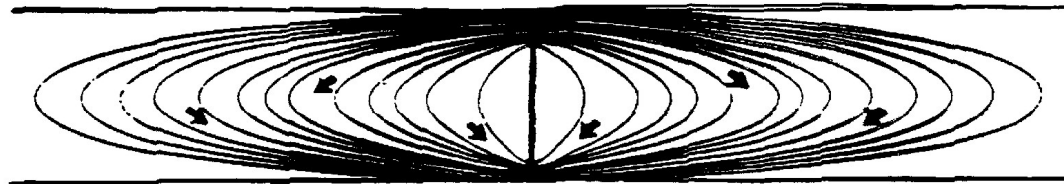
red: pressure gradient, blue: water flow



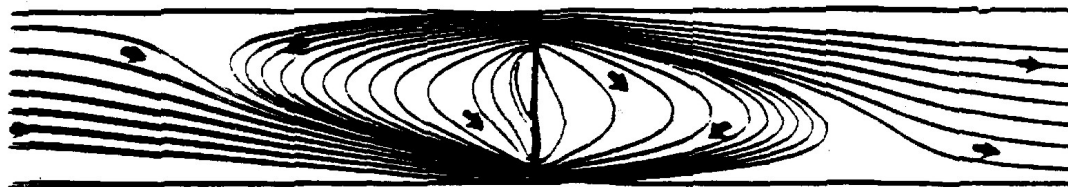
Hydraulic System Of the Circulation

45m 30m 15m 0m

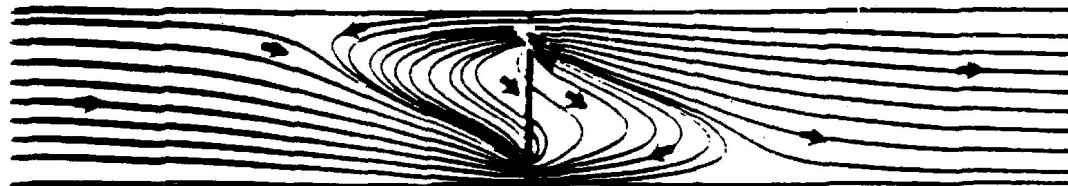
(a)



(b)

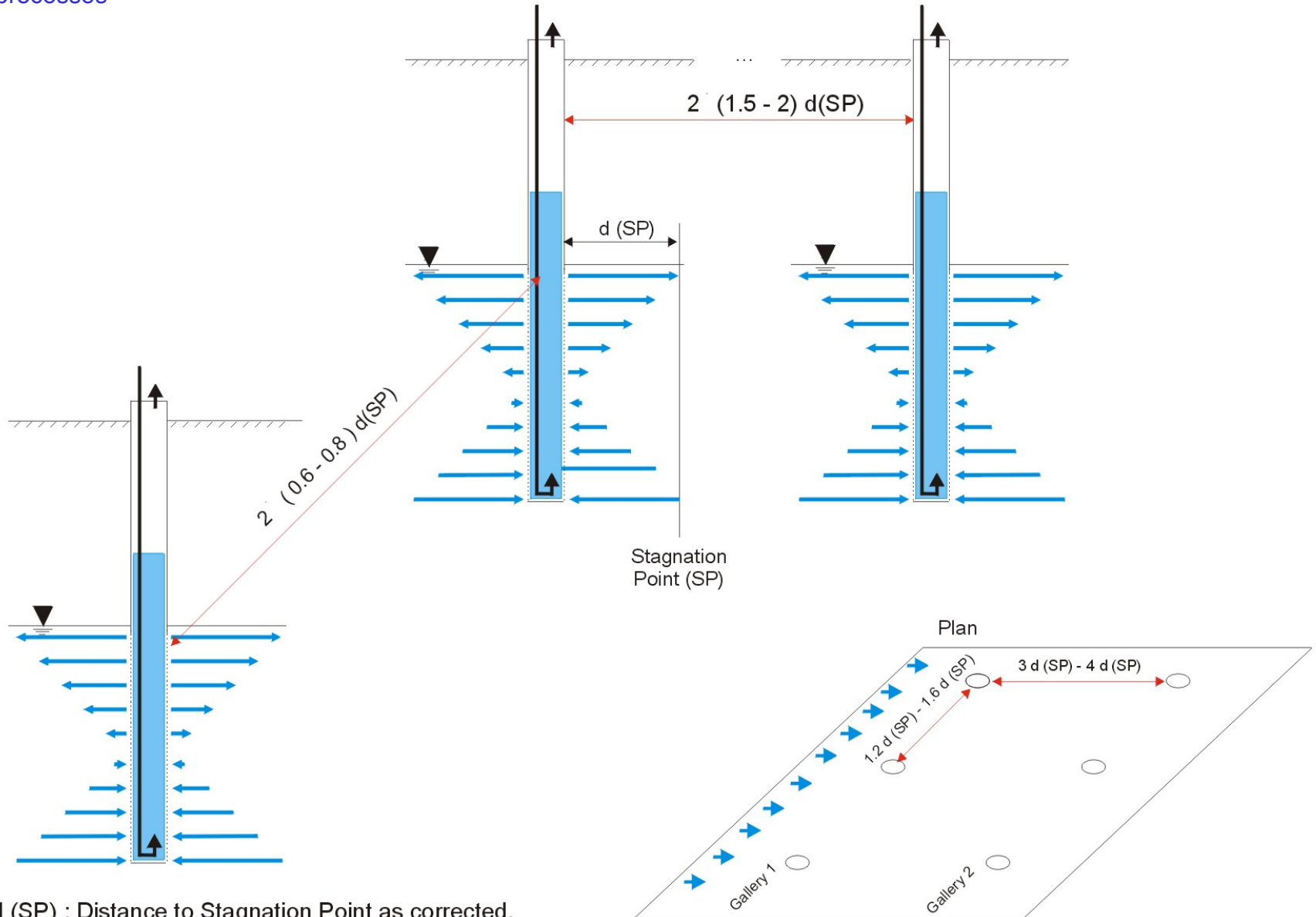


(c)



Streamlines clarified for a vertical longitudinal section with natural velocities:
(a) 0.0 m/day; (b) 0.3 m/day; (c) 1.0 m/day.

CVS: Multiple Well Arrangements

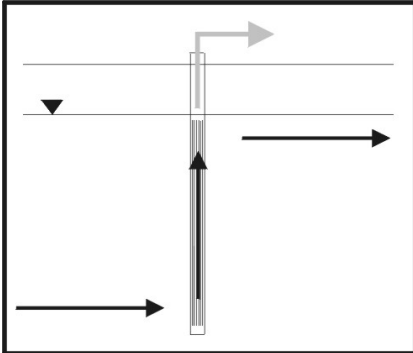


CVS Types

CVS I:

Treats: organic volatile constituents,
DNAPLs

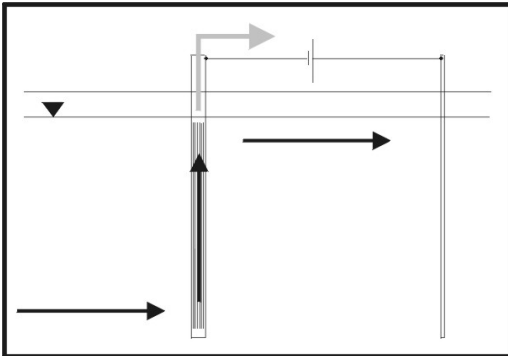
Method: in-well stripping



CVS II:

Treats: organic volatile and non-volatile constituents,
LNAPLs, DNAPLs

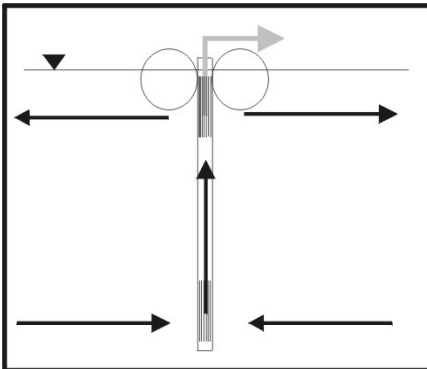
Method: in-well stripping, in-well floatation, in-well
electrochemical treatment (ECGO)



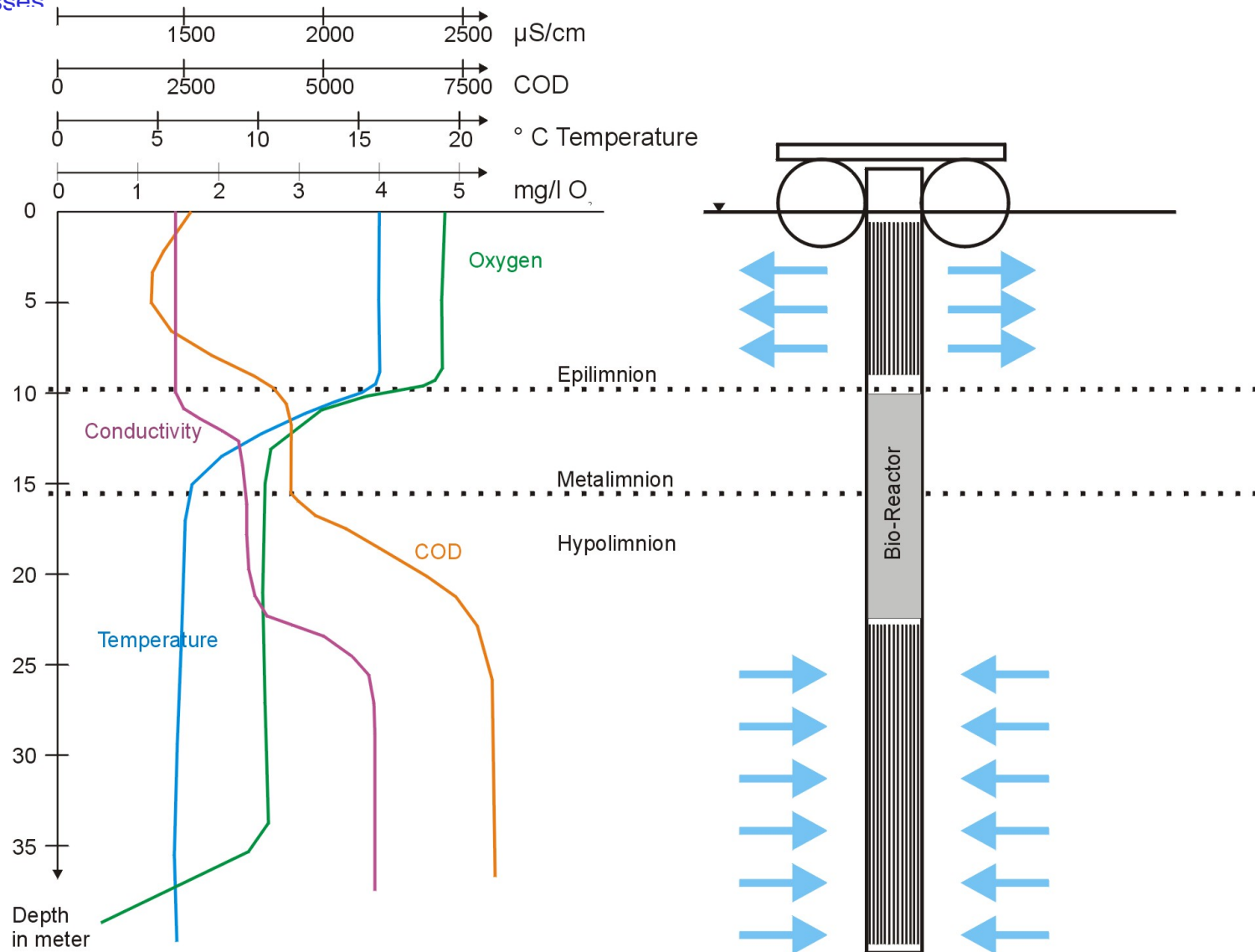
CVS III (floating on open waters):

Treats: organic volatile and non-volatile constituents
inorganic substances

Method: in-well stripping, bio-reactors, electrochemical
treatment (ECGO)



CVS Type III



References CVS I: Tank Farm Greater Stuttgart, FRG

Client: Manufacturer of Plastic Parts

Source Area: 11 UST containing
solvents (acetone, ethyl-acetate, MEK,
toluene, IPA, DMF, THF)

Geology: strongly fractured clay stone
(Jurassic Lias α)

THF tank was leaking below limits
of detection of leakage control.

Phase I: Oct. 14 to Dec. 21, 1991 (65 days)
Recontamination;

Remedy: excavation and replacement of
tank,

Phase II: Jun. 04 to Aug. 07, 1992 (64 days)

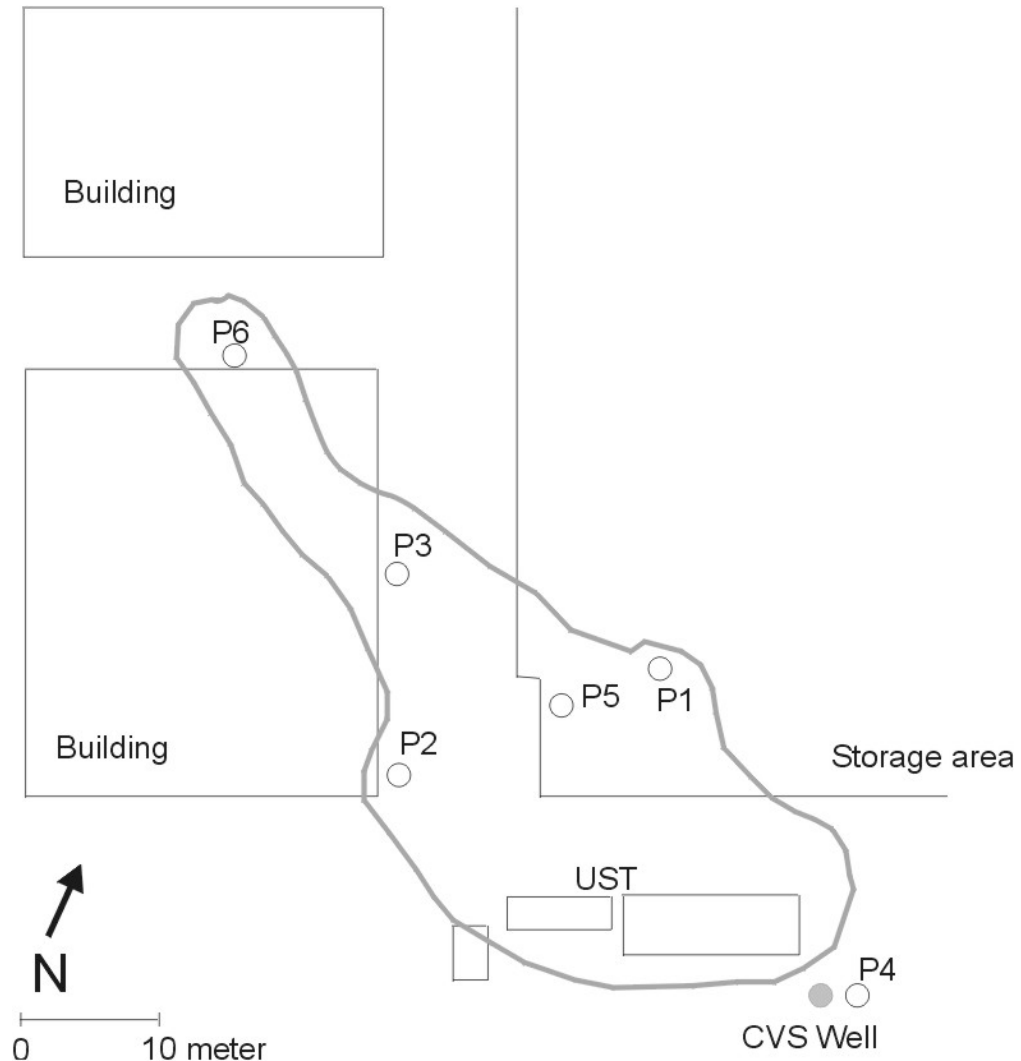
Dec. 12, 1992: Control Sampling

Dec. 12, 1993: Control Sampling by State EPA

Dec. 05, 1994: Control Sampling by State EPA

...

Annual inspections up to 2000 confirming
successful remediation.



References CVS I: Tank Farm Greater Stuttgart, FRG

THF [$\mu\text{g/l}$]

Phase I:

	Day 0	Day 65
P1	1107	n.d.
P2	866	n.d.
P3	1152	n.d.
P4	835	n.d.
P5	89	n.d.
P6	919	n.d.

Phase II:

	Day 0	Day 64
P1	n.d.	n.d.
P2	n.d.	n.d.
P3	6000	n.d.
P4	n.d.	n.d.
P5	n.d.	n.d.
P6	n.d.	n.d.

n.d. = non detect

all other pollutants: n.d.

Development of pH:

At start-up: pH 8.2

Injected Carbon Dioxide at P4: 150 NI/hour*

End of Project:	P1	P2	P3	P4	P5	P6
pH	7.2	7.1	7.3	6.1	7.0	7.2

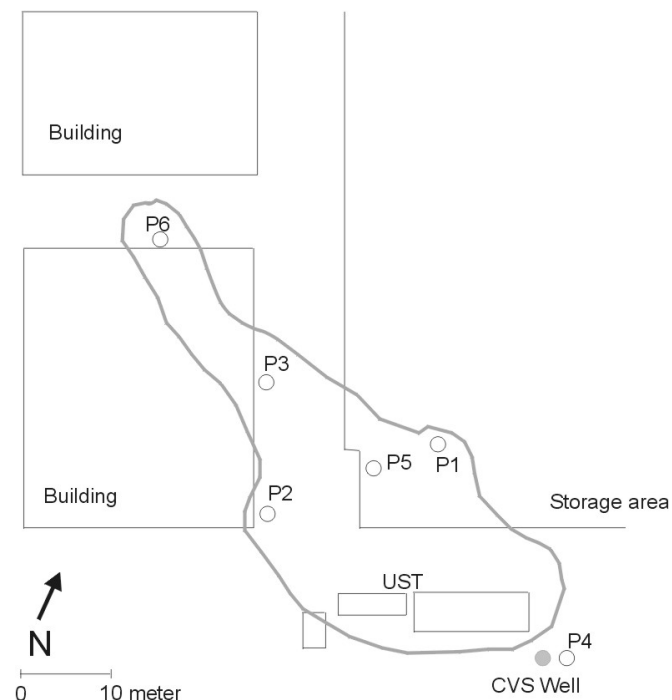
Dissolved CO₂

mg/l	62.5	103.9	40.4	1160	62.3	45.0
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Water temperature: 8°C

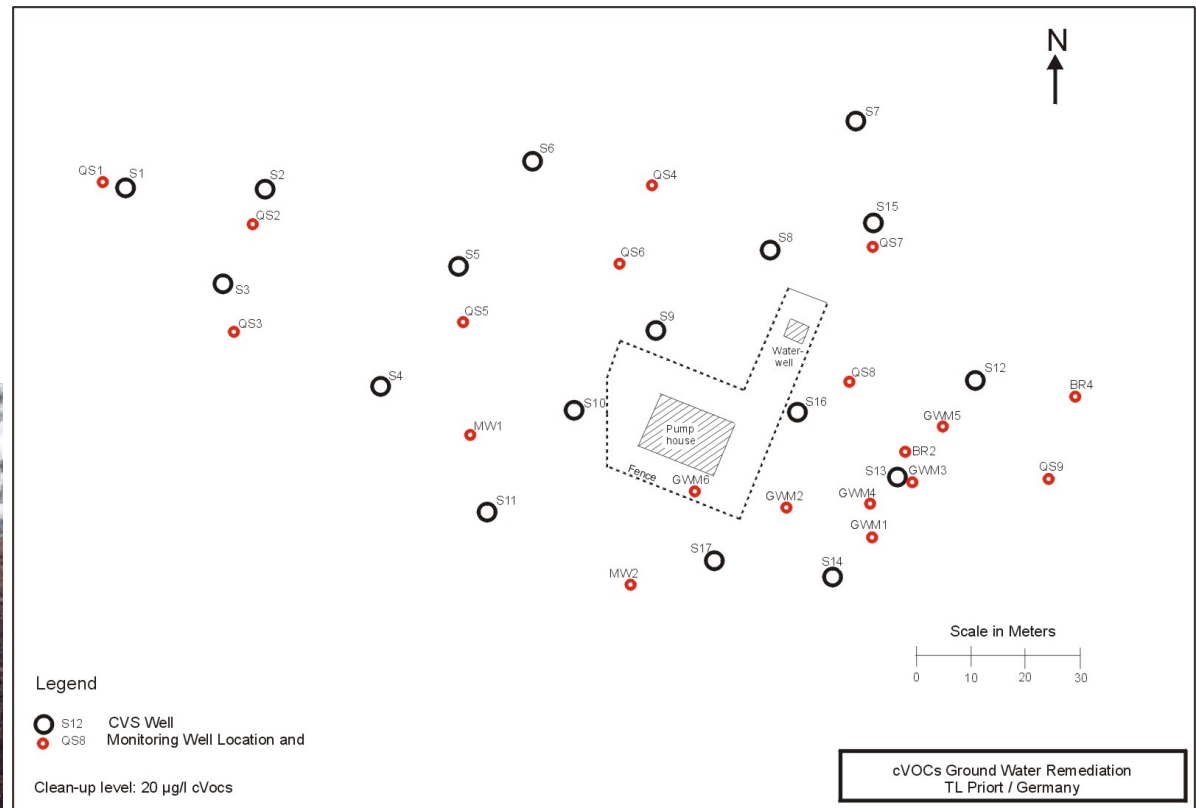
Theoretical solubility of CO₂ in water at 8°C: 6.4 g/l

* NI: one liter gas at ambient pressure of 1013 mbar.

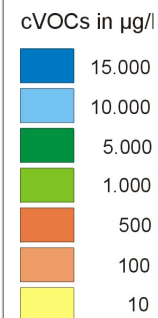
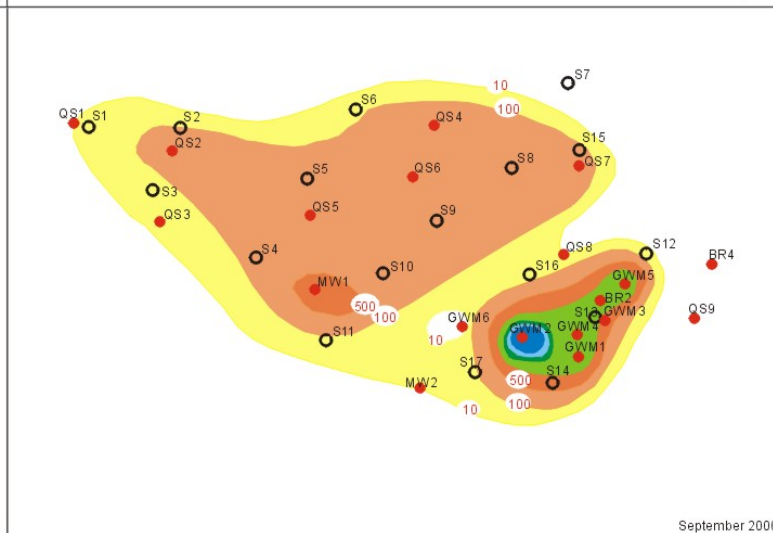
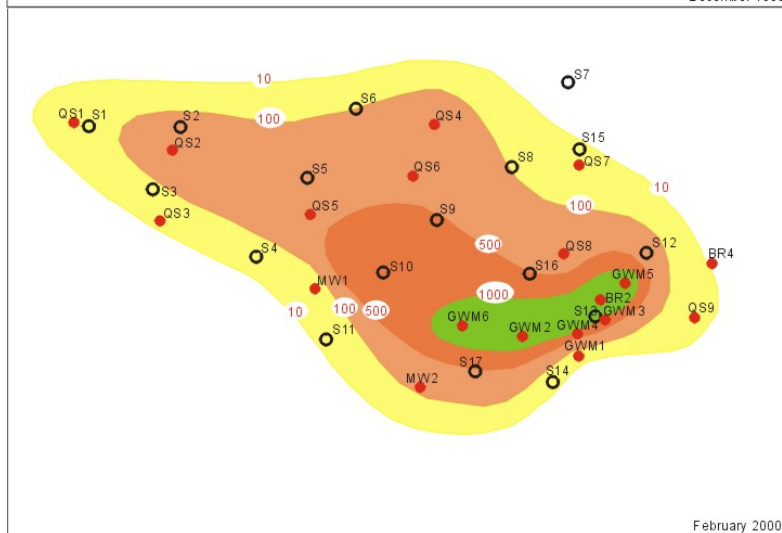
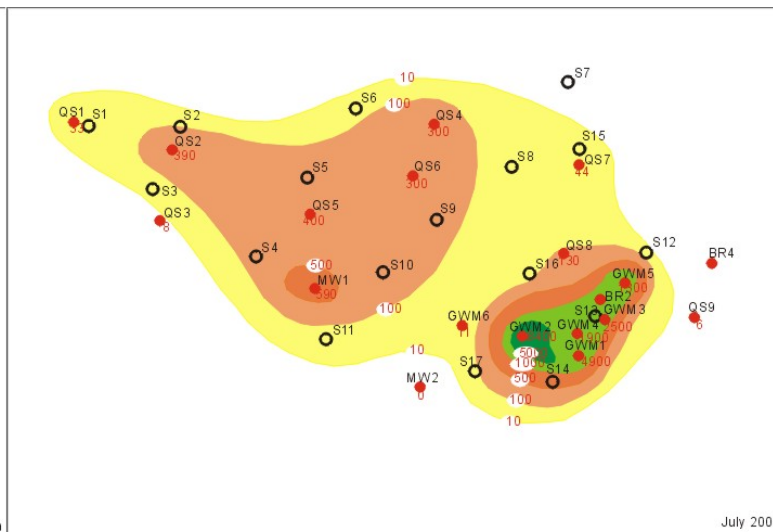
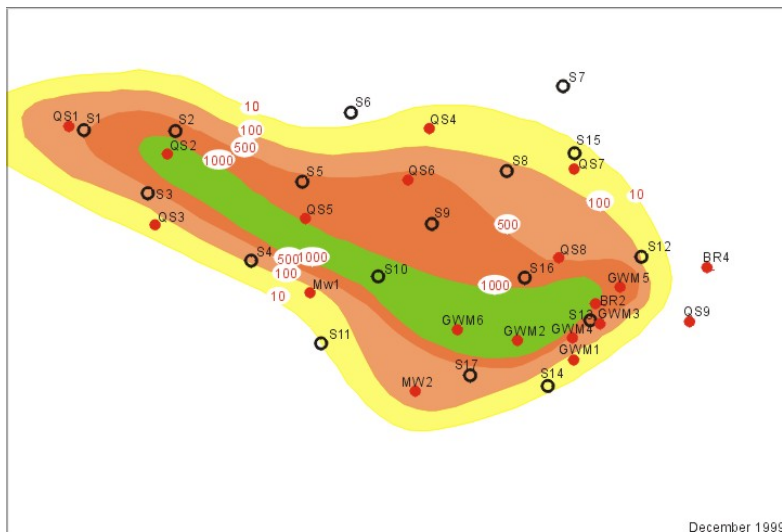


References CVS I Tank Farm Greater Berlin, FRG

Client: Trust company for and on the behalf of the Federal Treasury
 Site: Former tank farm and storage area for the former Soviet army
 Pollutants: cVOCs
 Geology: Quaternary (Diluvial) sands to 20 m depth, clay from 20 to 40 m, diluvial sands from 40 to ? m
 Remediation Array: 17 CVS I wells to 20 m depth (6" ND) arranged in 6 galleries (rows)

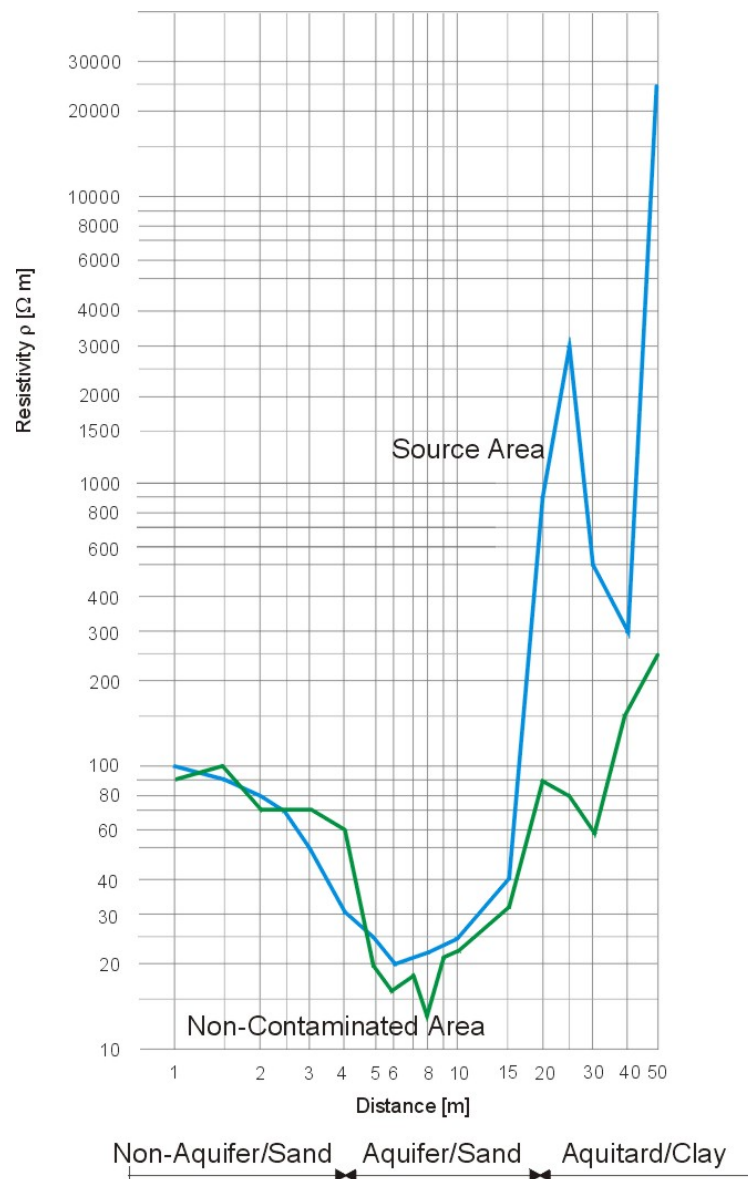


References CVS I Tank Farm Greater Berlin, FRG



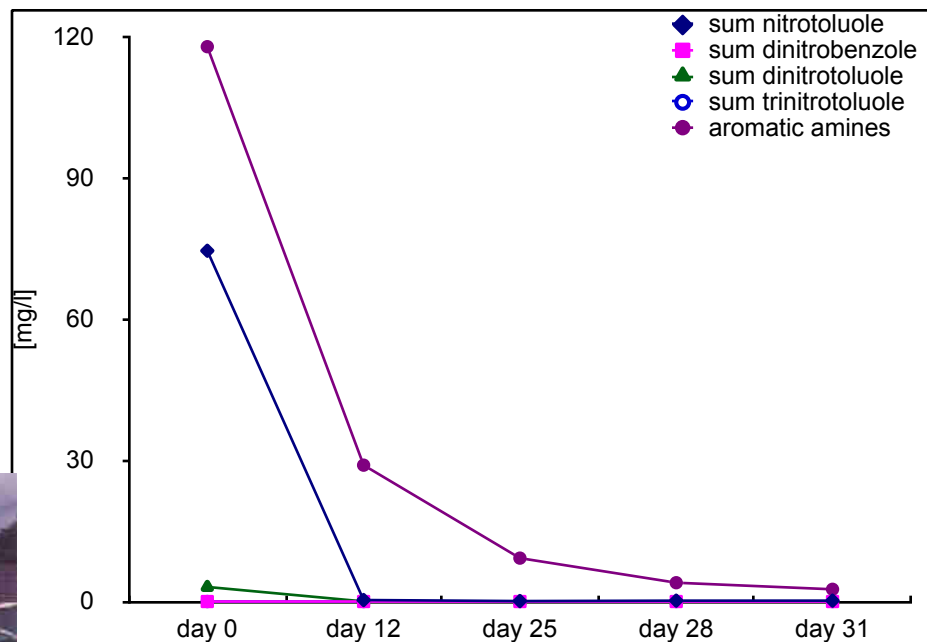
References CVS I Tank Farm Greater Berlin, FRG

Schlumberger Survey:



References CVS II Ammunition Factory, FRG - Test

Client: State regulating agency
Former ammunition factory in the Harz mountains
Geology: neutralization gypsum at a barrage of a small creek
Duration: one month
Pollutants: MNT, DNT, aromatic amines

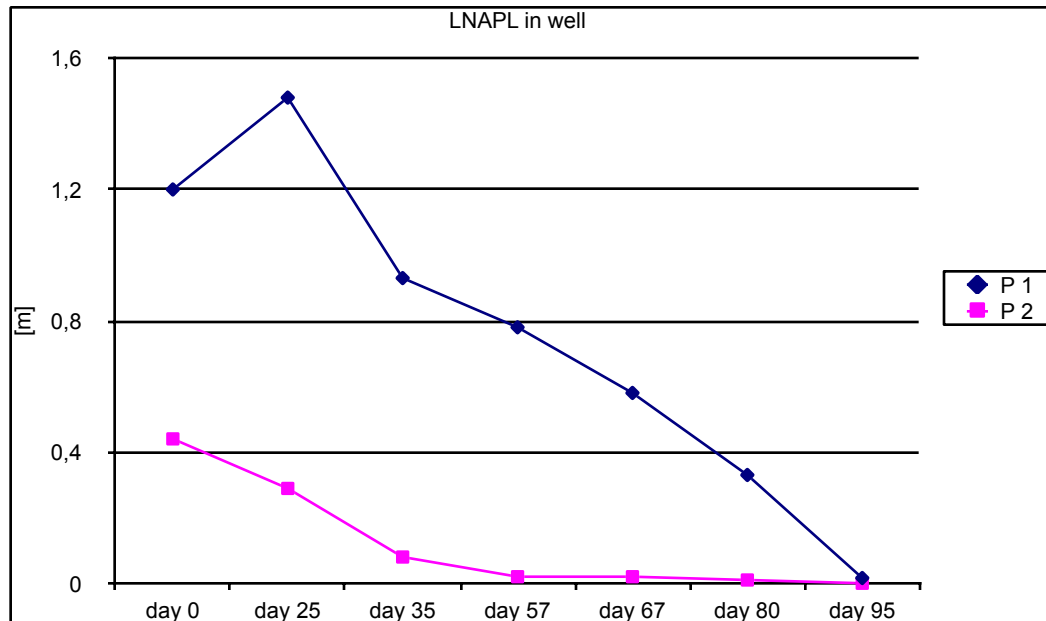


Client: waste recycling company

Pollution: 60 000 liters of Diesel fuel forming a LNAPL of 1.2 m thickness

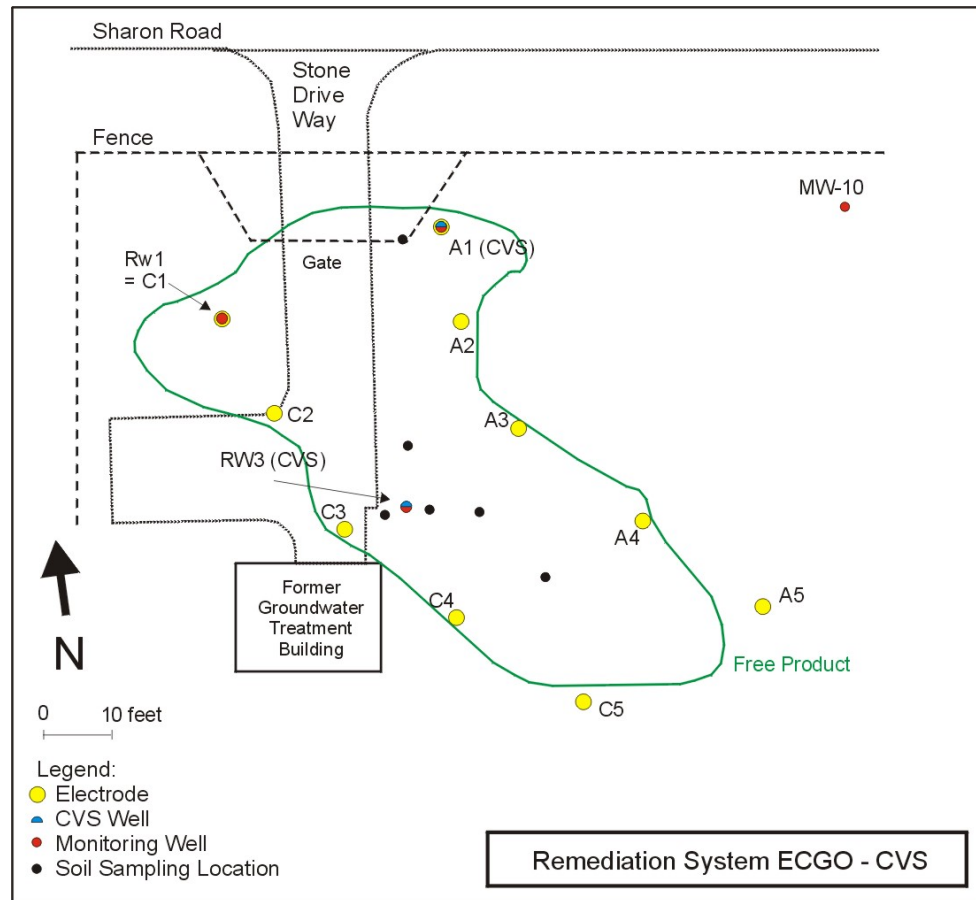
Geology: 0 – 6 m diluvial sand

Phase I: Remediation of the LNAPL

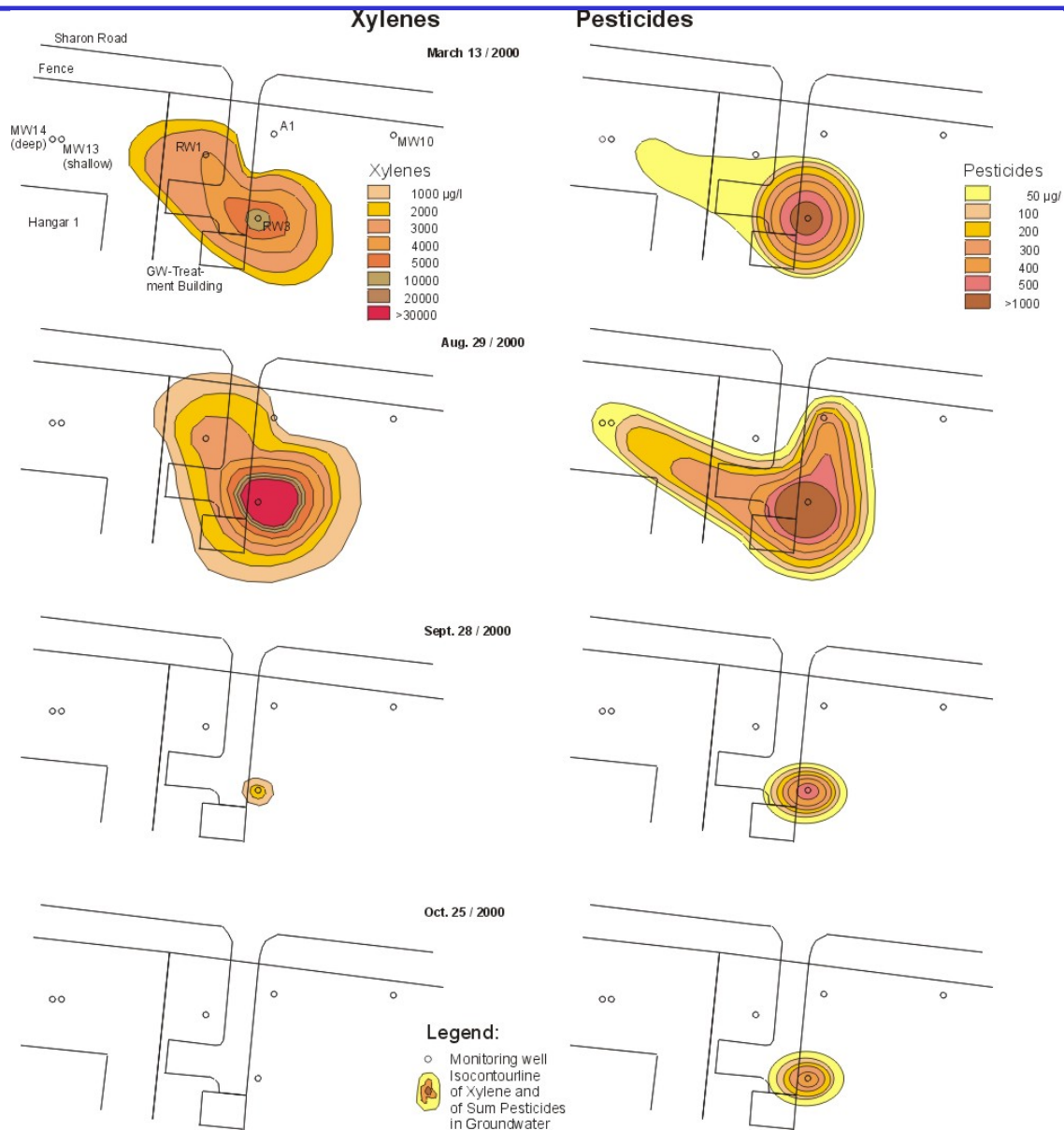


References CVS II LNAPL and Pesticides, NJ, USA

Client: Wholesaler of pesticides and fertilizers
 Pollution: Xylene, Lindane + Isomers, heptachlor,
 DDT+ degradation products, Chlordane,
 Toxaphene, Aldrin, Endrin, LNAPL (max 9')
 Geology: 0-10 m medium gravel (partly refill)
 10-50 m clay/loam
 Plan: contour line of LNAPL
 Period covered: Mar. 2000 – Oct. 2000
 (Phase I: Elimination of LNAPL)



References CVS II LNAPL and Pesticides, NJ, USA



Experimental: Kærgård Klitplantage (Esbjerg, Denmark)

Analyte	Baseline	after 24 hrs.	effects in %
Benzene	4400	70	98,4
Toluene	5000	99	98
Ethylbenzene	7,9	0,88	88,9
m-Xylene	31	1,4	95,5
o-Xylene	110	5,4	95,1
C6H6-C10	11000	340	96,9
>C10-C25	1000	210	79
TPH	12000	540	95,5
2-Methylphenol	0,24	0	100
3-Methylphenol	0,43	0	100
4-Methylphenol	3,4	0,058	98,3
2,4 Dimethylphenol	0,31	0	100
2,5 Dimethylphenol	0,38	0,049	87,1
2,6 Dimethylphenol	0,26	0,047	81,9
Amobarbital	1200	600	50
Barbital	2100	1700	19
Butabarbital	260	190	26,9
Pentobarbital	570	340	40,4
Secobarbital	3	4	-33,3
Sulfaguanidine	4200	4600	-9,5
Sulfanilamid	48000	25000	47,9
Sulfanilacid	200000	9600	52
Sulphadiazin	8500	46	99,5
Sulphamerazin	220	3	98,6
Sulphamethazin	14000	900	93,6
Sulphamethiazol	910	80	91,2
Sulphathiazol	3900	11	99,7
Tetrachloroethylen	160	2,9	98,2
Trichloroethylen	1200	21	98,3

