EJP SOIL
European Joint Programme

Czech University of Life Sciences Prague

SOIL CONTAMINATION

Luboš Borůvka
Department of Soil Science and Soil Protection
Faculty of Agrobiology, Food and Natural
Czech University of Life Sciences Prague
Czech Republic
E-mail: Boruvka@af.czu.cz

SOIL CONTAMINATION (POLLUTION)

- Increased content of dangerous or xenobiotic substances in soils

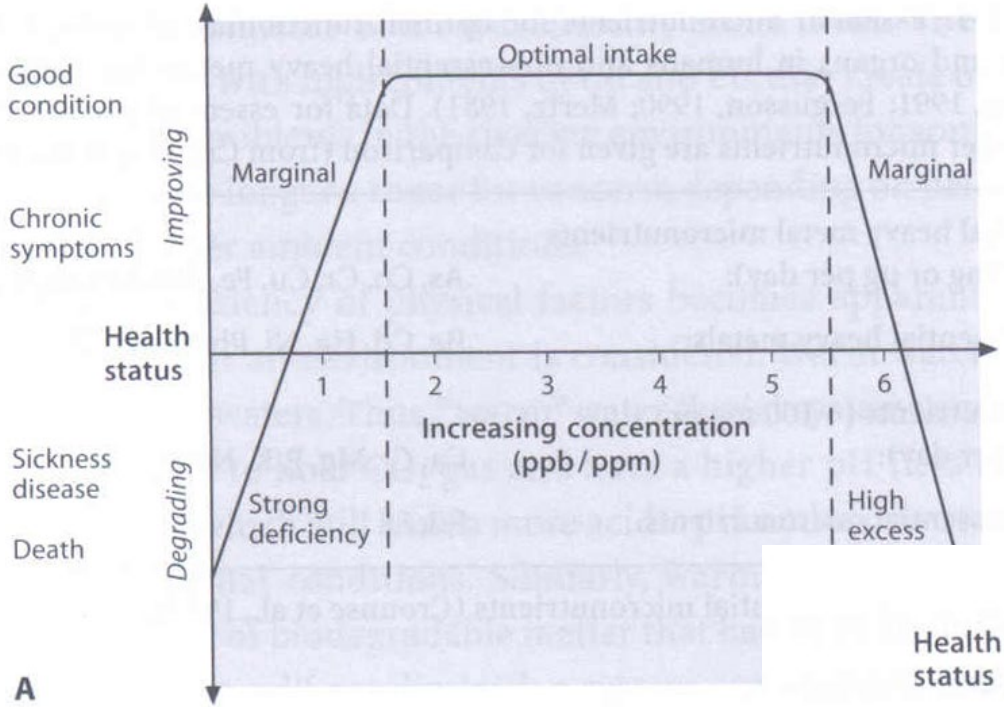
- **Occurrence of contaminants in soil above a certain level causing deterioration or loss of one or more soil functions**, which can be in the form of point pollution or diffuse pollution. Soil pollutants can consist of various forms, such as organic and inorganic or particulate pollutants (EJP SOIL: SERENA)

SOIL POLLUTANTS (1)

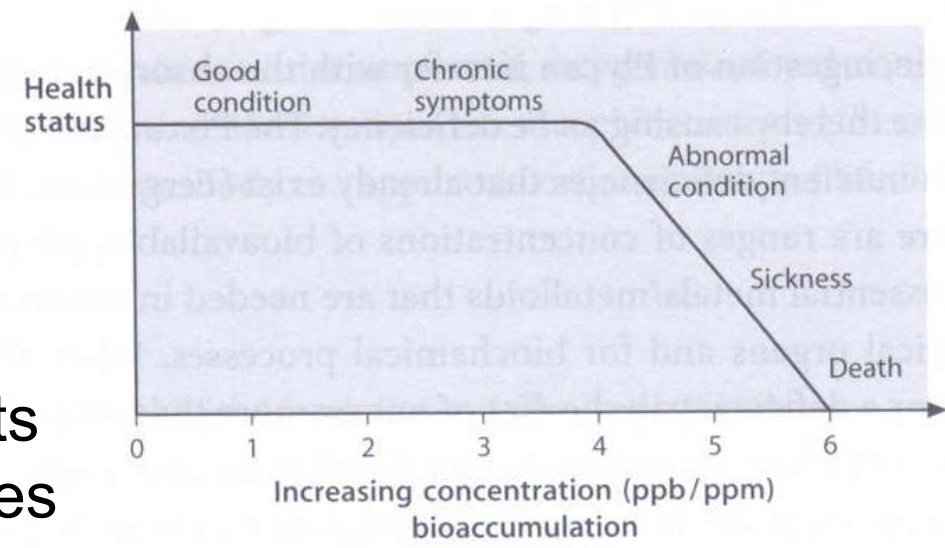
Potentially toxic elements (PTE):

- alternative terms:
  - trace elements, risk elements, metals and metalloids (heavy metals)
- include:
  - As, Cd, Hg, Pb, Mn, Ni, Tl…
  - some essential elements (B, Cu, Cr, Zn, Mo, Se)
  - radionuclides
- both natural and anthropogenic origin
- cannot be decomposed

Essenciality and toxicity



Nutrients,
essential elements



Toxic elements
and substances

SOIL POLLUTANTS (2)

Organic pollutants (organic xenobiotic substances):

- include:
  - petroleum-derived substances
  - polycyclic aromatic hydrocarbons (PAHs)
  - organochlorine compounds (OCPs)
  - dioxins,
  - polychlorinated biphenyls (PCBs)
  - plant protection products (pesticides)
  - volatile oganic compounds (VOC) - trichloroethylene, tetrachloroethylene, 1,1,1- trichloroethane, vinyl chloride
- mainly anthropogenic origin
- possible decomposition (microorganisms)

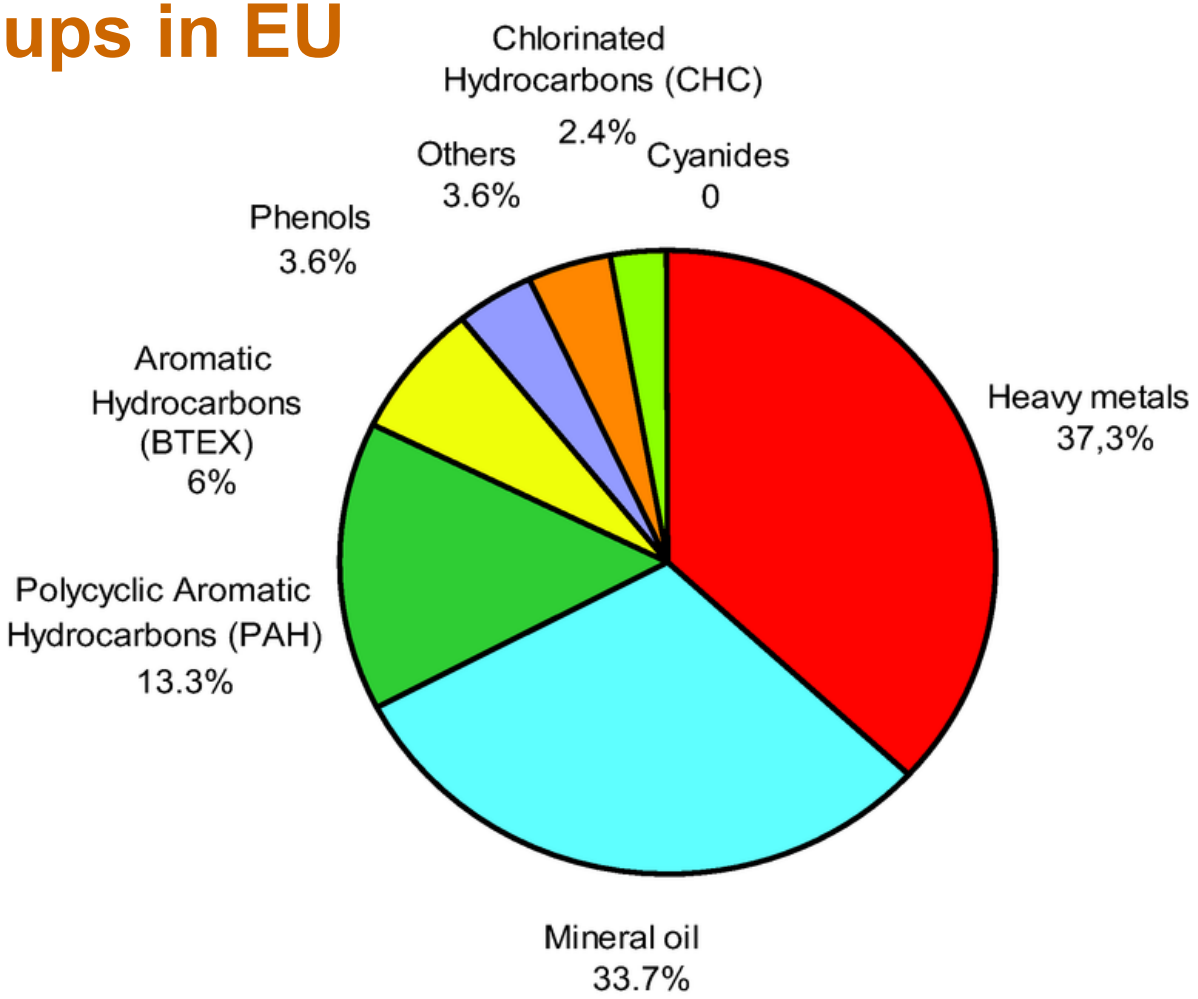
SOIL POLLUTANTS (3)

Emerging pollutants:

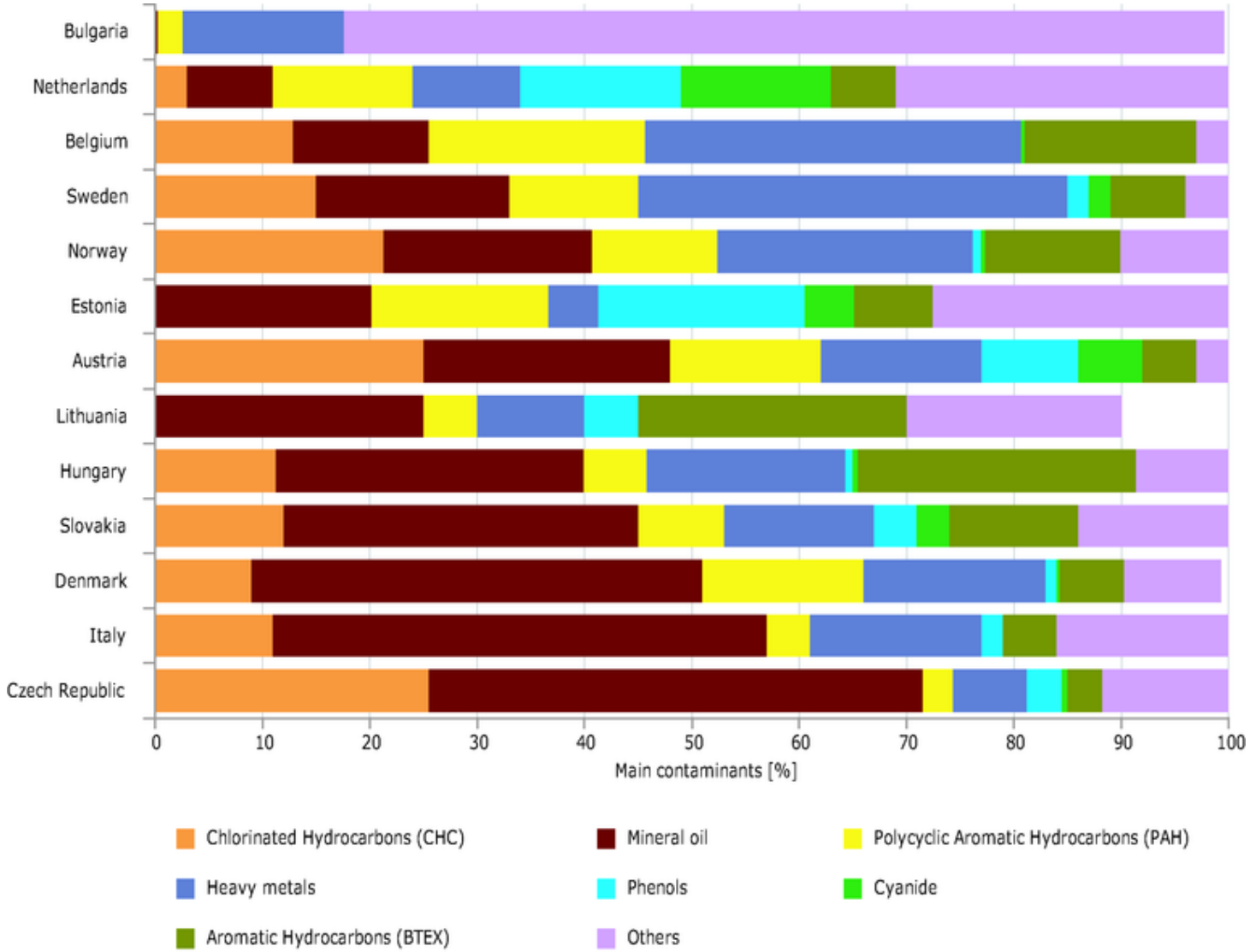
- include:
  - polyfluoroalkyl substances (PFAS),
  - pharmaceuticals (veterinary drug residues and antibiotics)
  - phthalates and other plasticizers (e.g. bisphenol A)
  - disinfectant residues
  - artificial nanomaterials
  - rare earth elements (as new PTE)
  - flame retardants (brominated)
  - plastics (microplastics) and synthetic polymers

SOIL POLLUTION

Relative importance of various soil and water pollutant groups in EU



Relative importance of various soil pollutant groups in EU countries



SOIL POLLUTION

Why a problem:

- Toxicity of pollutants
  - Entering the food chain
    - through plants…
    - human and animal health effects
  - Leaching to ground- and surface waters
  - Effect on ecosystem health and behaviour
    - soil biological aktivity
    - plant growth
    - lower production (yields)
- Impact on soil functions and ecosystem services

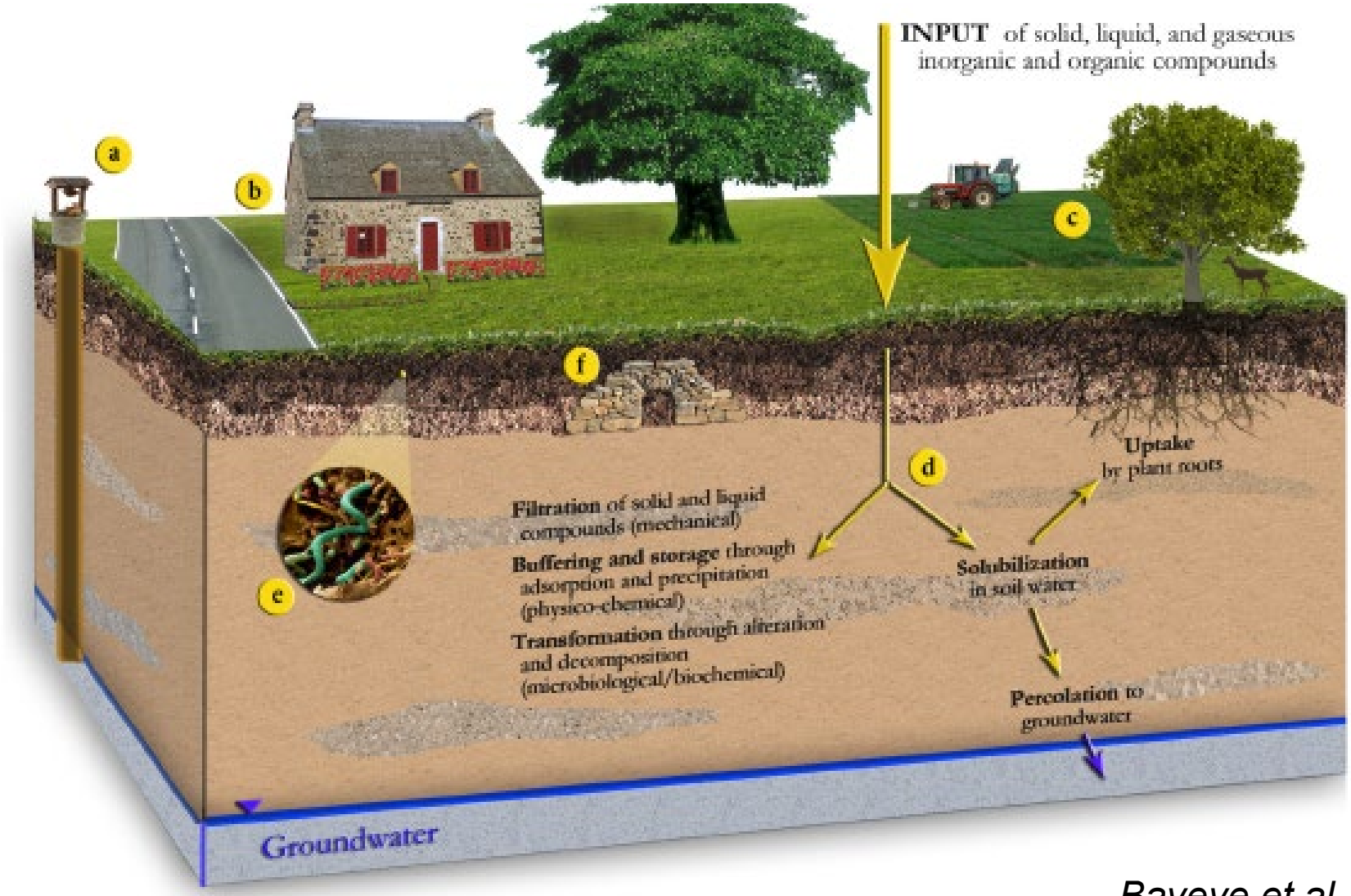
Soil functions

Baveye et al., 2016

Impact of contamination on soil functions and ecosystem services

- food supply
  - soil productivity
  - quality of food produced
- carbon sequestration
- water quality protection
- nutrient cycling
- habitat for soil organisms, biodiversity
  - decrease of the number and activity of soil organisms
  - changes in the soil community structure
  - alteration of biochemical cycles
- secondary source of water contamination

Soil functions related to pollution



Baveye et al., 2016

Indication/determination of soil contamination with PTE

- Microbial / enzymatic activity
- Plant indicators
- Magnetomery
  - magnetic susceptibility

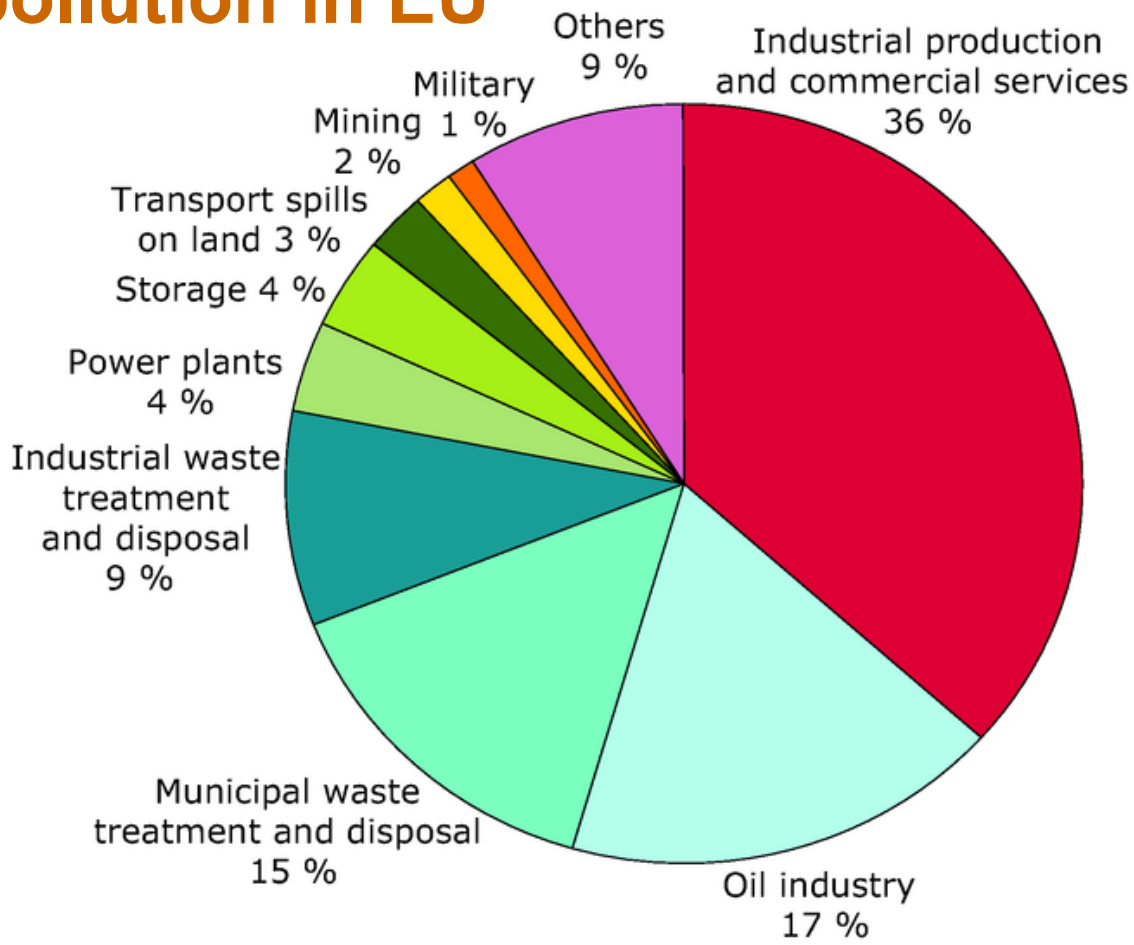
} Non-specific

- **Chemical analysis**
  - X-ray fluorescence spectrometry (XRFS)
  - PTE extraction
  - Total sample decomposition

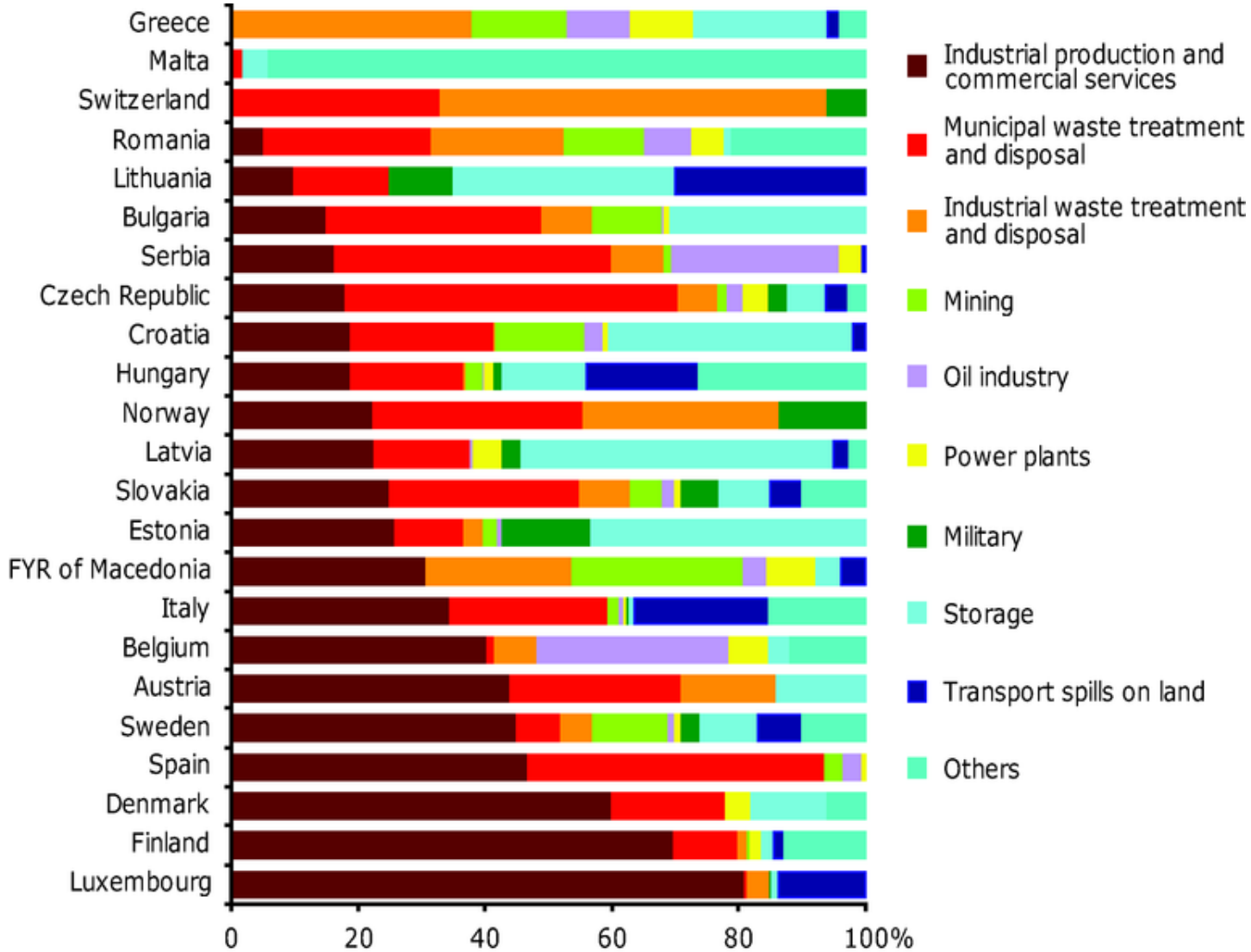
} Measurement on AAS, ICP-OES…

SOIL POLLUTION

Relative importance of anthropogenic activities causing soil pollution in EU



Relative importance of various soil pollution sources in EU countries



Types of soil contamination

Point (local) pollution

- intensive industrial activities, power stations
- inadequate waste disposal
- mining and smelting
- military activities
- accidents

Diffuse (non-point) pollution

- atmospheric deposition
- long-term use of low-quality fertilizers
- uncontrolled use of sewage sludge
- intensive use of pesticides and manure

In Europe ~2.8 million sites are potentially contaminated

POTENTIALLY TOXIC ELEMENTS

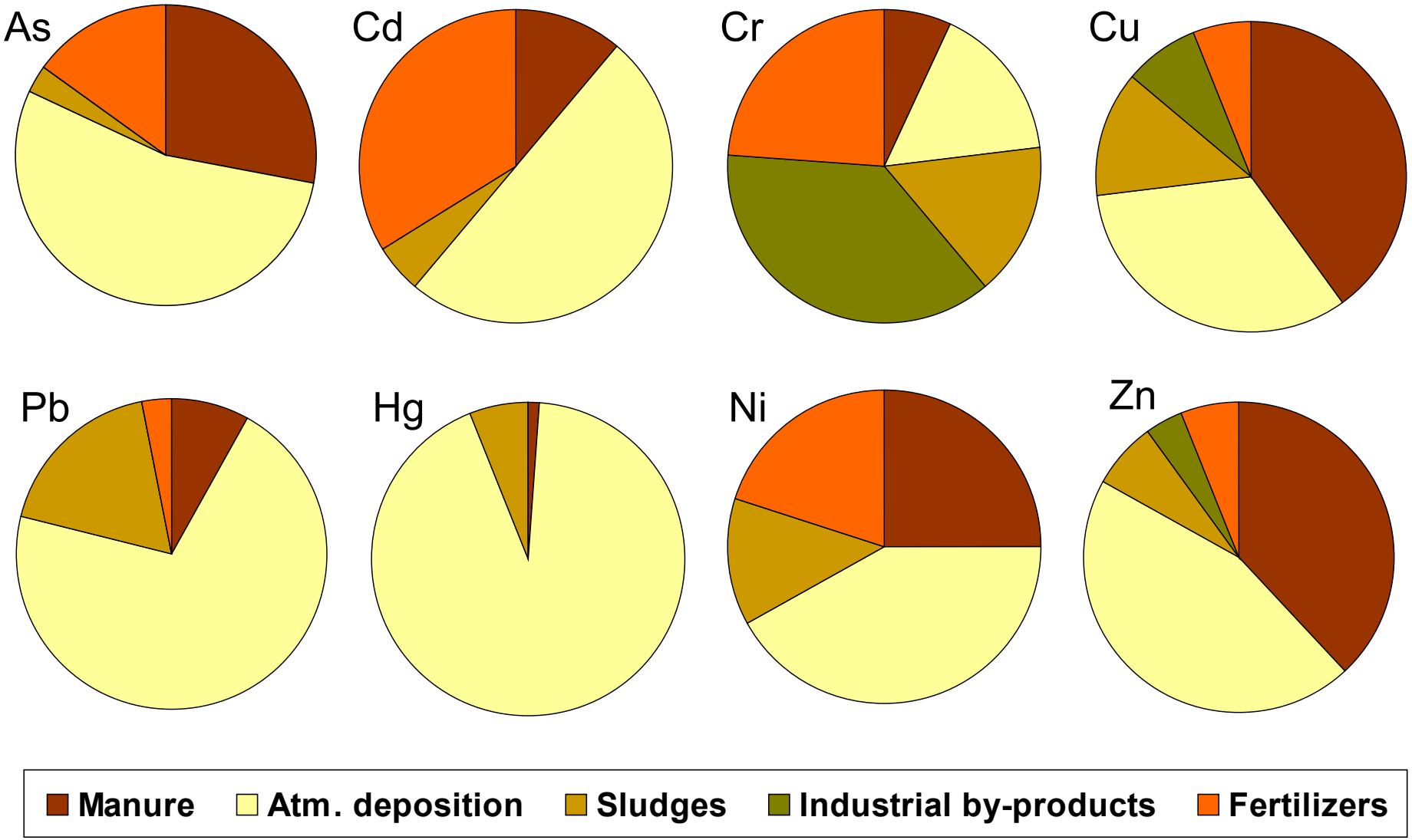
Origin in soil:

- lithogenic (geogenic)
  - natural background
- anthropogenic
    - from human activities
- (pedogenic)

PTE content in materials introduced to soils (mg.kg^{-1} dry wt.; *Kabata-Pendias a Pendias, 1992*)

Elem.	S.sludge	P-fert.	Liming	N-fert.	Manure	Pesticid.
As	2-26	2-1200	0.1-24	2.2-120	3-25	22-60
Cd	2-1500	0.1-**170**	0.04-0.1	0.05-8.5	0.3-0.8	-
Co	2-260	1-12	0.4-3.0	5.4-12	0.3-24	-
Cr	20-40600	66-245	10-15	3.2-19	5.2-55	-
Cu	50-3300	1-300	2-125	<1-15	2-60	12-50
Hg	0,1-55	0.01-1.2	0.05	0.3-2.9	0.09-0.2	0.8-42
Mo	1-40	0.1-60	0.1-15	1-7	0.05-3	-
Ni	16-5300	7-38	10-20	7-34	7.8-30	-
Pb	50-3000	7-225	20-1250	2-27	6.6-15	60
Se	2-9	0.5-25	0.08-0.1	-	2.4	-
Zn	700-49000	50-1450	10-450	1-42	15-250	1.3-25

Relative proportion of anthropogenic sources of potentially toxic elements in agricultural soils in the UK (*Adriano, 2001*)



Mean values and common ranges of PTE concentrations in world soils (mg.kg^{-1}; *Bowen, 1979*)

Element	Median	Range	Element	Median	Range
As	6	0.1-40	Ag	0.05	0.01-8
Cd	0.35	0.01-2.0	Ba	500	100-3,000
Co	8	0.05-65	Be	0.3	0.01-40
Cr	70	5-1,500	Cs	4	0.3-20
Cu	30	2-250	*Ga*	30	0.4-300
Hg	0.06	0.01-0.5	*Rb*	100	20-600
Mo	1.2	0.1-40	Sn	4	1-200
Ni	50	2-750	Sr	250	4-2,000
Pb	35	2-300	Ti	5,000	150-25,000
Se	0.4	0.01-12	*U*	1	0.9-9
Zn	90	1-900	V	90	3-500

Processes affecting PTE behavior in soils

- Adsorption/desorption
- Dissolution/precipitation
- Binding by organic substances
- Formin inorganic and organic complexes
- Occlusion, diffusion to minerals
- Uptake by organisms
- Volatilisation (Hg, methylated metals)
- Transport

Retention rate in soils:

Pb > Sb > Cu > Cr > Zn > Ni > Co > Cd

Soil pollution

Forms of potentially toxic elements in soils:

- water-soluble
- exchangeable
- organically bound
  - bound on stable humic substances
  - complexed with dissolved organic matter
- bound on iron and manganese oxides
- in defined compounds (carbonates, sulfides, phosphates...)
- bound in silicates (residual fraction)

Concentration of bioavailable forms is more important than the total content in soil

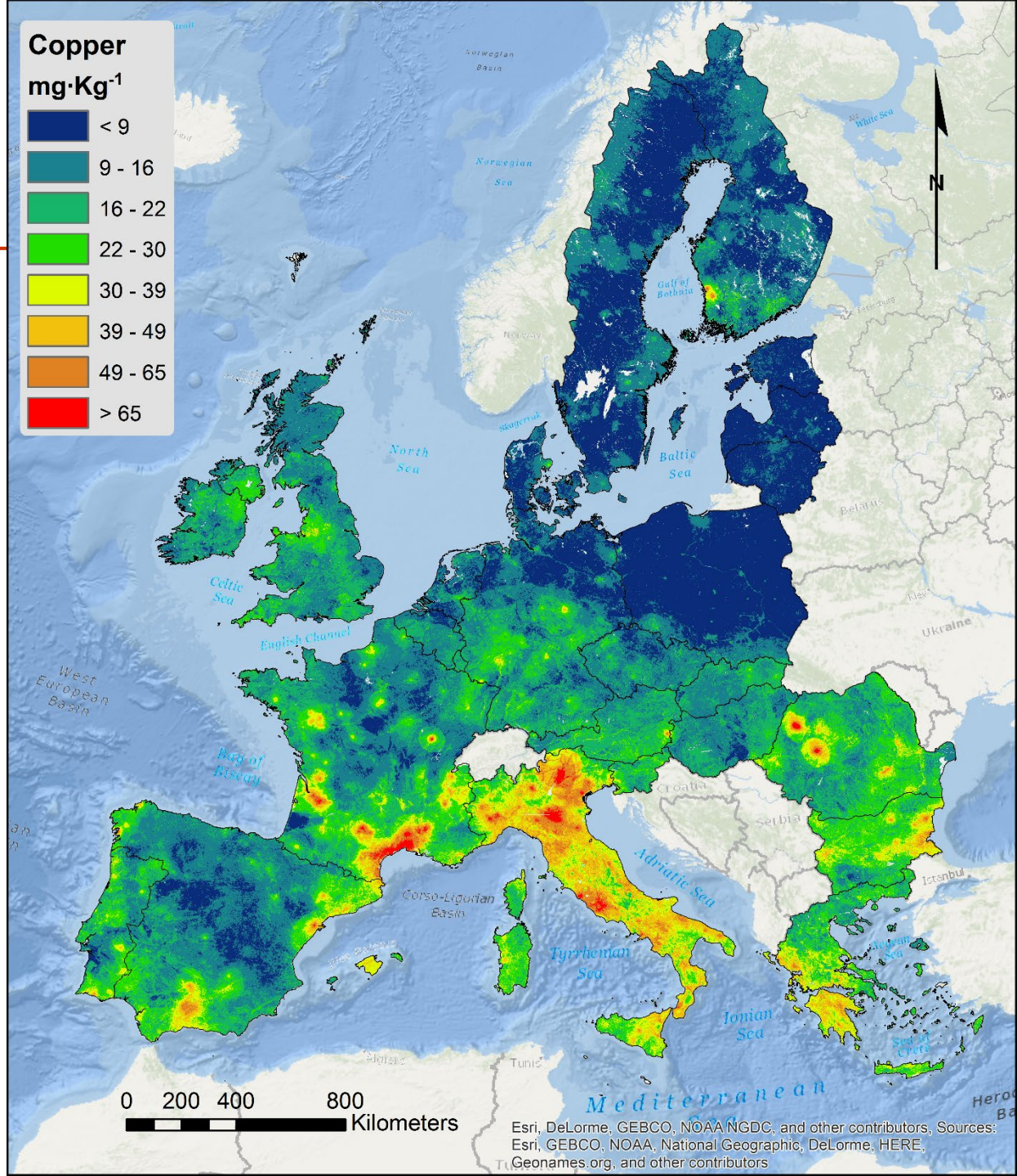
Prevailing PTE forms in soil solution and the most toxic species *(Adriano, 2001)*

Elem.	Acid soils	Alkaline soils	Tox. spec.
Ag(I)	Ag^+, $AgCl^0$	Ag^+	Ag^+
As(III)	$As(OH)_3$	AsO_3^{3-}	AsO_4^{3-}
As(V)	$H_2AsO_4^-$	$HAsO_4^{2-}$	
B(III)	$B(OH)_3$	$B(OH)_4^-$	$B(OH)_3$
Be(II)	Be^{2+}	$Be(OH)_3^-$, $Be(OH)_4^{2-}$	Be^{2+}
Cd(II)	Cd^{2+}, $CdSO_4^0$, $CdCl^-$	Cd^{2+},$CdCl^-$, $CdSO_4^0$, $CdHCO_3^+$	Cd^{2+}
Co(II)	Co^{2+}, $CoSO_4^0$	$Co(OH)_2^0$,	Co^{2+}
Cr(III)	$Cr(OH)^{2+}$	$Cr(OH)_4^-$	Cr^{6+}
Cr(VI)	CrO_4^{2-}	CrO_4^{2-}	
Cu(II)	Cu^{2+}, $CuCl^-$, fulvates	$CuCO_3^0$, $CuHCO_3^+$	Cu^{2+}
Hg(II)	Hg^{2+}, $HgCl_2^0$, CH_3Hg^+	$Hg(OH)_2^0$	CH_3Hg^+
Mn(II)	Mn^{2+}, $MnSO_4^0$	Mn^{2+},$MnSO_4^0$,$MnCO_3^0$,$MnHCO_3^+$	Mn^{2+}
Mo(V)	$H_2MoO_4^0$, $HMoO_4^-$	$HMoO_4^-$, MoO_4^{2-}	MoO_4^{2-}

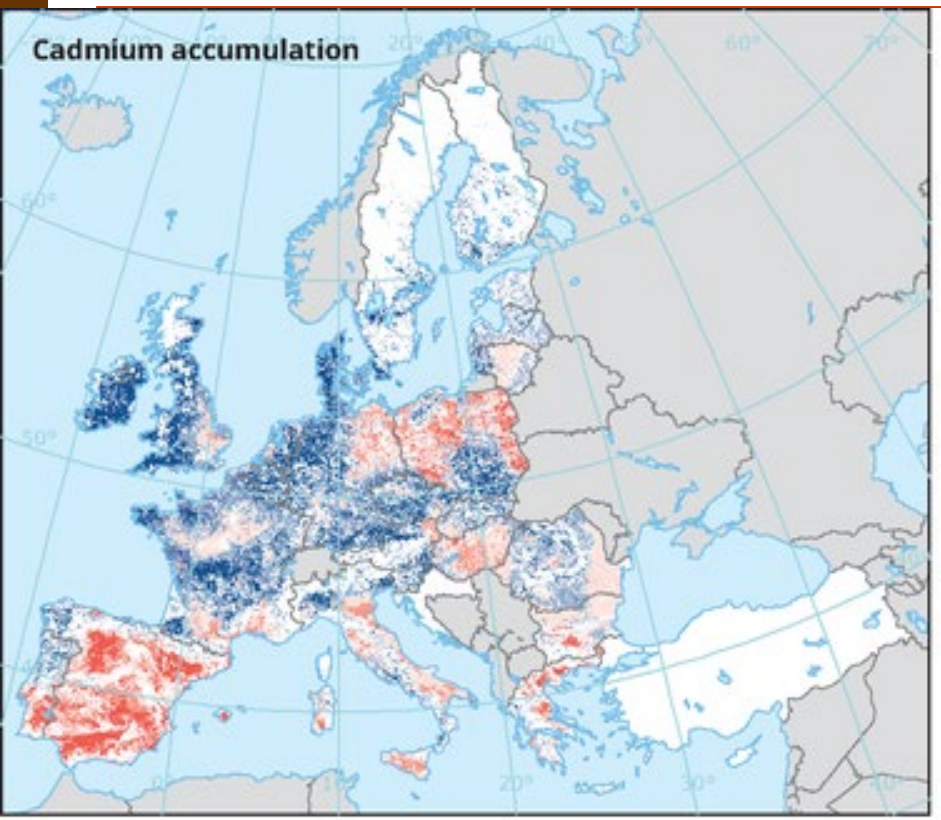
Prevailing forms of PTE in soils and their effect on plants and animals

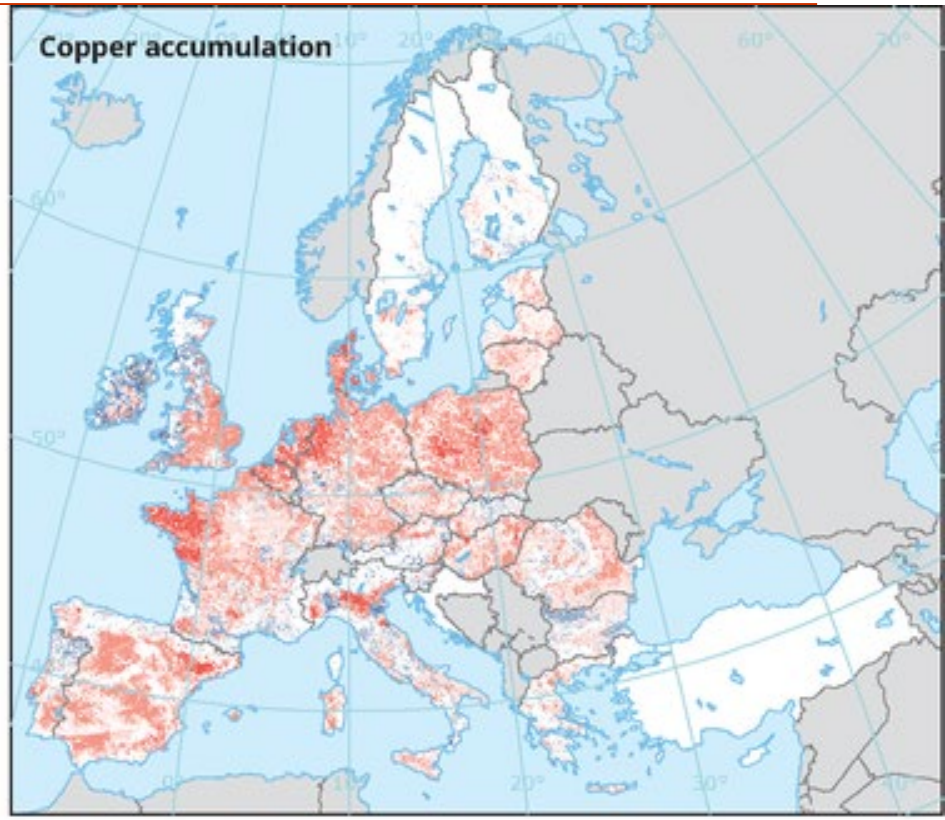
Element	Forms	Effect
As	AsO_4^{3-}	toxic for plants and animals
Be	Be^{2+}	toxic for plants and animals
Cd	Cd^{2+}	toxic for animals
Co	Co^{2+}	toxic for plants and animals
Cr	Cr^{3+}, CrO_4^{2-}	essential for animals, Cr^{6+} carcinogenic
Cu	Cu^{2+}	essential/toxic for plants and animals
Hg	Hg^{2+}, $(CH_3)_2Hg$	toxic for animals
Mo	MoO_4^{2-}	essential/toxic for plants and animals
Ni	Ni^{2+}	essential/toxic for plants and animals
Pb	Pb^{2+}	toxic for plants and animals
Se	SeO_4^{2-}	essential for animals, toxic for plants and anim.
Sn	Sn^{4+}	essential/toxic for animals
Zn	Zn^{2+}	essential/toxic for plants and animals

Copper concen-tration in European topsoils ($mg.kg^{-1}$)



Accumulation rates of Cd and Cu in European soils (g/ha/yr)





Accumulation rates of Cadmium (left) and Copper (right), 2010

g/ha/yr

< -1 | -1 to -0.5 | -0.5 to 0 | 0 to 0.5 | 0.5 to 1 | > 1

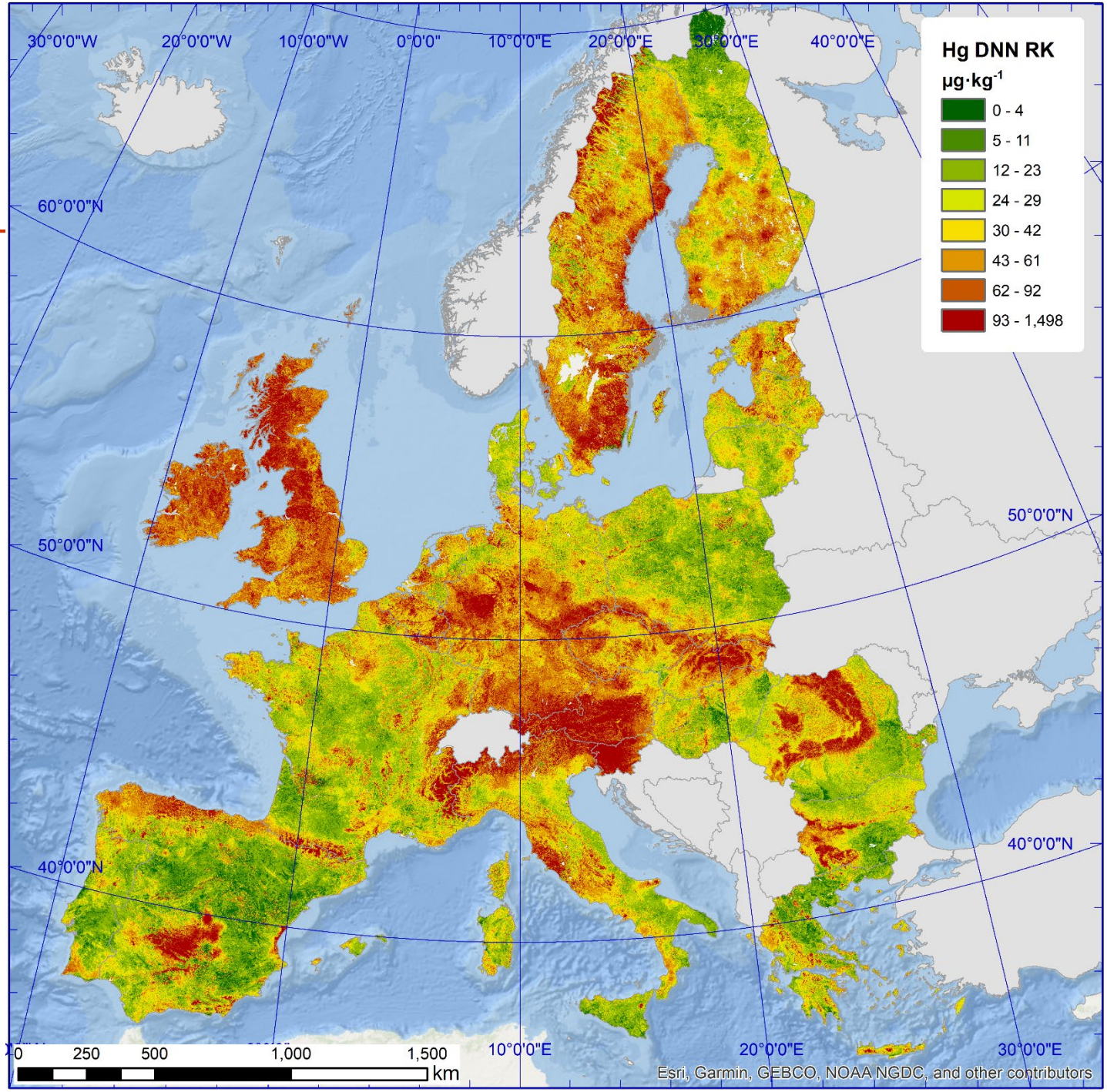
0 500 1 000 1 500 km

No data | Outside coverage

g/ha/yr

< -100 | -100 to -20 | -20 to 0 | 0 to 20 | 20 to 100 | > 100

Mercury concen-tration in European topsoils ($\mu g.kg^{-1}$)



Radiactive isotopes in soil

- various isotopes of natural or anthropogenic origin
  - Ce, Cs, Kr, Pu, Ra, Rn, Ru, Th, Sr, U etc.
  - I, Co, Fe, Zn
  - Ba, C, H, P, S

Forms in soil:

- cations, oxyanions, salts…
- organic complexes and compounds

Behaviour in soil:

- common reactions and processes according to their chemical and physical nature
- **radioactive decay**

ORGANIC POLLUTANTS IN SOILS

Origin – mostly anthropogenic:

- oil processing and petroleum products
- sewage sludge, waste waters and other wastes
- plant protecting products (pesticides)
- solvents, detergents
- atmospheric deposition

Behaviour of organic pollutants in soil

Factors:

– properties of OP:

- solubility and mobility
- sorptivity
- degradability
- toxicity

– soil properties:

- texture, clay content
- pH
- SOM content and quality
- sorption characteristics
- biological activity

Processes:

- accumulation
- sorption/desorption
- uptake by organisms
- degradation
  - chemical
  - <u>biodegradation</u>
  - photolysis
- volatilisation
- leaching
- runoff, erosion

Biodegradability of organic pollutants in aerobic conditions

Easy and rather fast:

- Petroleum hydrocarbons (benzene, toluene, ethylene, xylene, petrol)
- Volatile org. compounds (tri- and perchlorethylene)
- Current pesticides
- Organic solvents

Difficult and long-term:

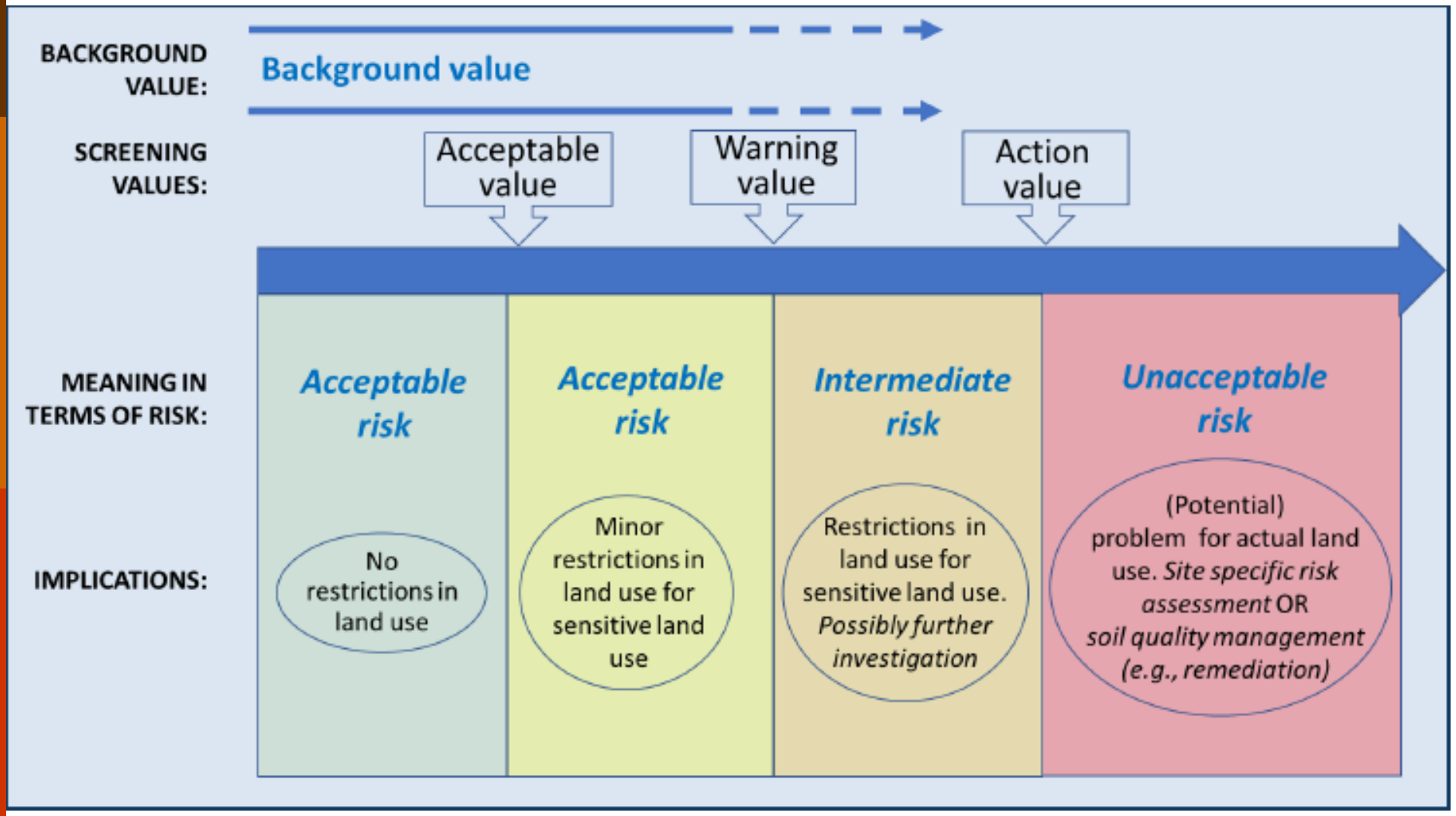
- PCB – polychlorinated biphenyles
- PAH - polycyclic aromatic hydrocarbons
- DDT
- Plastics

Criteria for soil pollution assessment

Should take into account:

- potential risk
  - phyto-, zoo-, humanotoxicity
  - impact on the ecosystem
- transfer pathway
    - soil – plant – animal – man
    - soil – plant – man
    - soil – water – man
    - soil – man
  - land use (agriculture, forest, playground, water sources...)
- soil properties:
  - soil texture, organic matter
  - pH, sorption characteristics

Different levels of risk posed by soil contamination



Criteria for soil pollution assessment

A-B-C values:

Preventive values (A)

- based on natural background (PTE) and common diffuse contents (OP)

Indication (warning) values (B)

- maximum tolerable contents
- based on ecotoxicology and risk analysis

Intervention (action, intoxication) values (C)

- serious risk, action necessary

QUESTIONS?

Control questions

Most potentially toxic elements like heavy metals (Cd, Zn, Cu, Pb, Ni etc.) are more soluble:

a) at alkaline reaction
b) at low pH
c) in clayey soils

Control questions

Which elements are resent in soil solution mostly in anionic form (as oxyanions)?

a) As, Mo
b) Pb, Zn
c) Cd, Hg

Control questions

Which of the following forms of PTE is most mobile?

a) bound on iron and manganese oxides
b) bound in defined compounds (sulfides, phosphates...)
c) exchangeable

Control questions

Unlike PTE, organic pollutants in soil:

a) are only of natural origin
b) can be completely decomposed
c) can be present as simple cations in soil solution

Control questions

Which transfer pathway of soil pollutants is the most typical for agricultural land?

a) soil – plant – man
b) soil – water – man
c) soil – man

Thank you for your attention

See you after the break!

PREVENTING SOIL CONTAMINATION

European Green Deal

- by 2050, soil pollution should be reduced to levels no longer considered harmful to human health and natural ecosystems and respect the boundaries our planet can cope with, thus creating a toxic-free environment

Preventing soil contamination

- clean industry
- sustainable product design
- improved recycling, waste management and nutrient recovery
- efficient fertilizer application
- reduced pesticide use and risk
- reducing use of antimicrobials and microplastics and the per- and polyfluoroalkyl substances (PFAS)

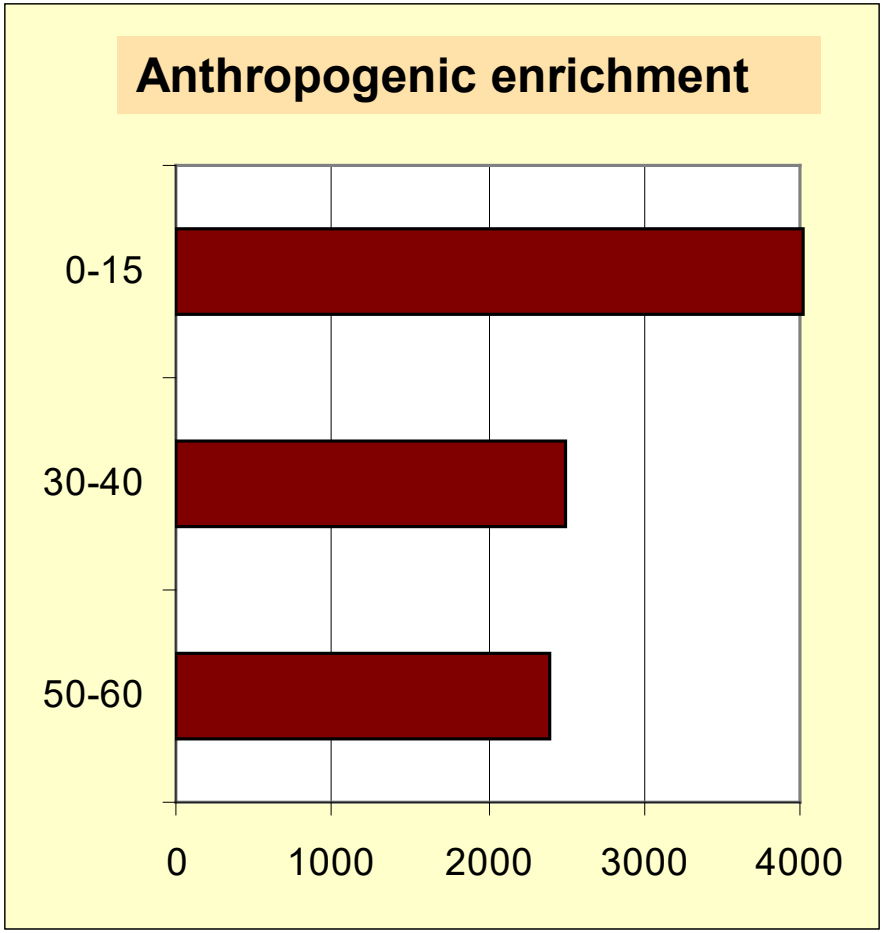
Determination of PTE origin in soils

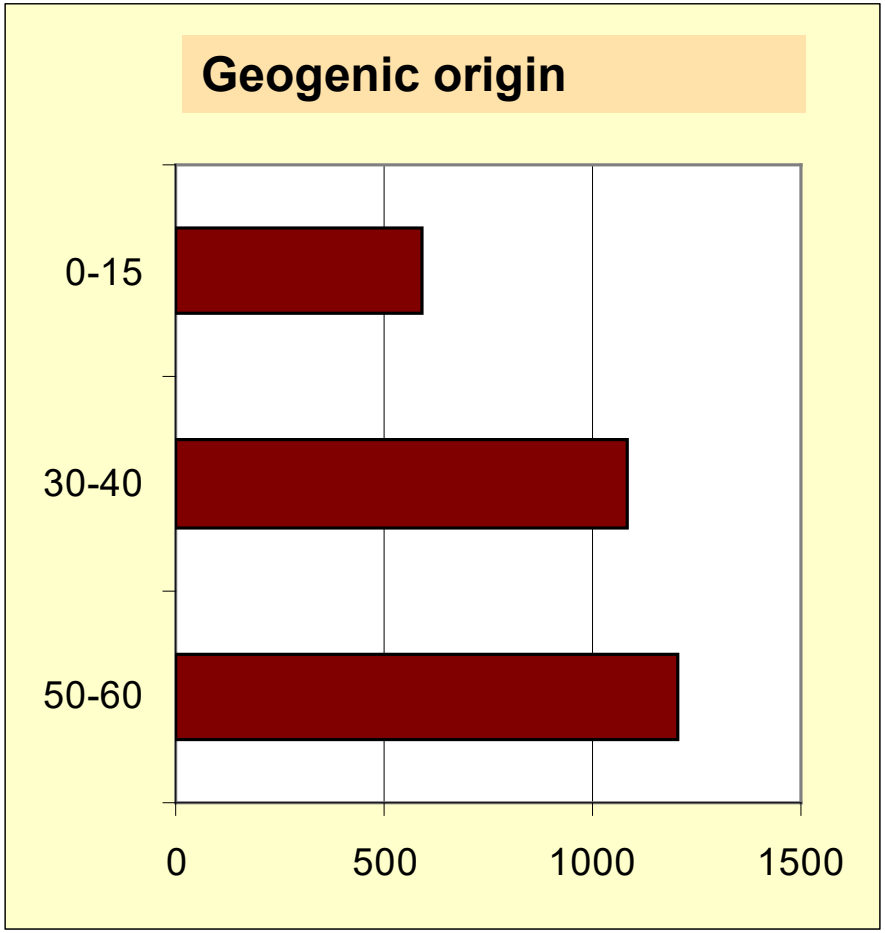
PTE origin determination:

- distribution in soil profile
  - anthropogenic pollution – higher concentration at the topsoil
- spatial distribution
  - in case of point pollution sources
- proportion of mobile forms
  - recently entering PTE are usually less bound
- isotopic signature
  - supposing we know the potential pollution sources

Complete distinction of the PTE origin is almost impossible.

Pb distribution in soil profile (mg.kg^{-1})

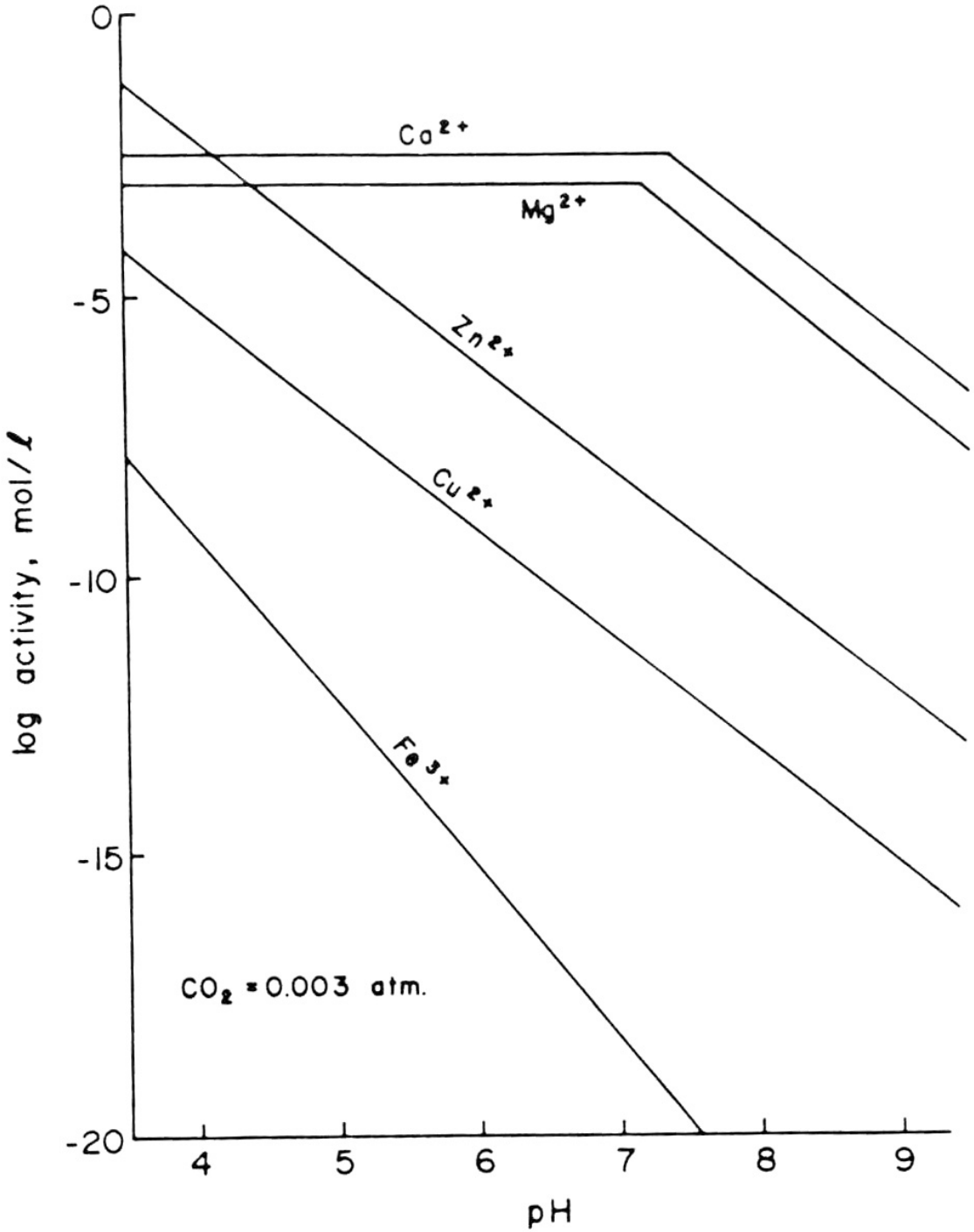




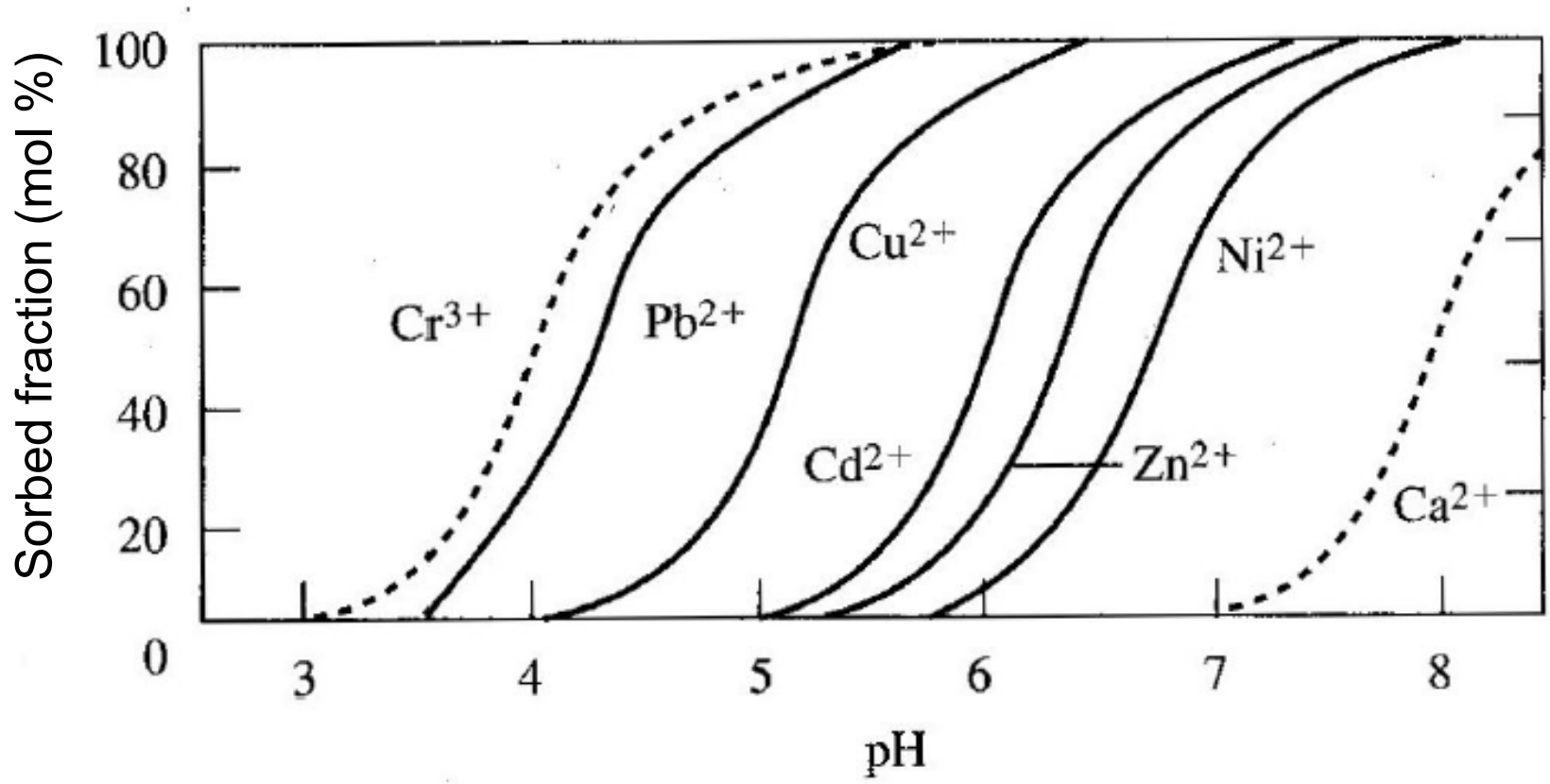
Factors controlling behaviour and speciation of PTE in soil

- Element characteristics
- Soil conditions
  - soil pH, redox
  - presence of ions
  - content and quality of soil organic matter
  - mineral composition
  - soil texture
- Biological factors
- Climatic conditions
  - precipitation, evapotranspiration, temperature
- Human activity

Stability diagram



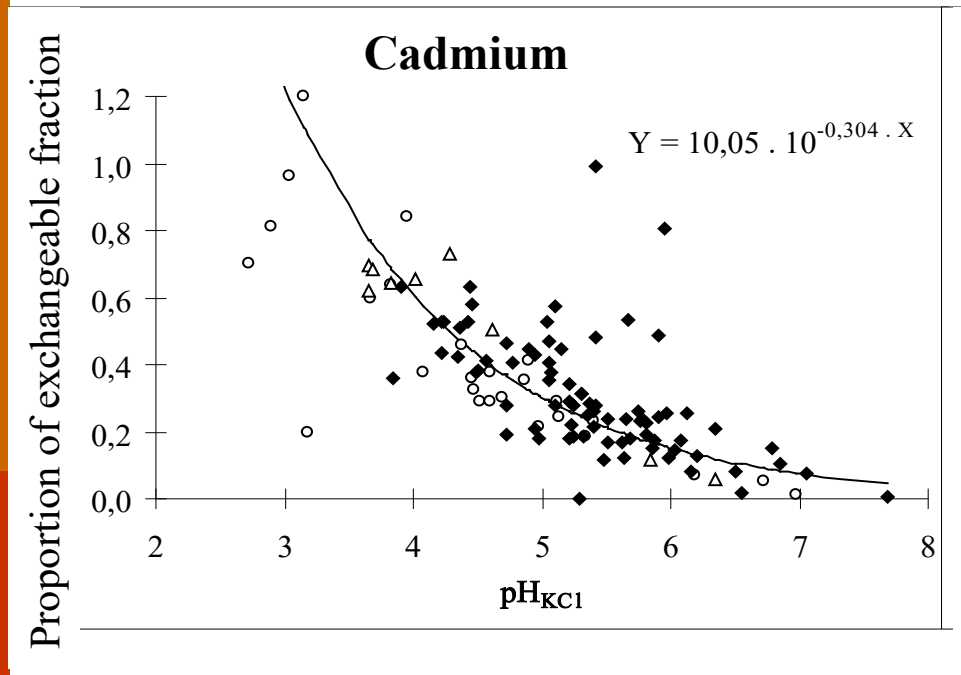
pH effect on PTE sorption

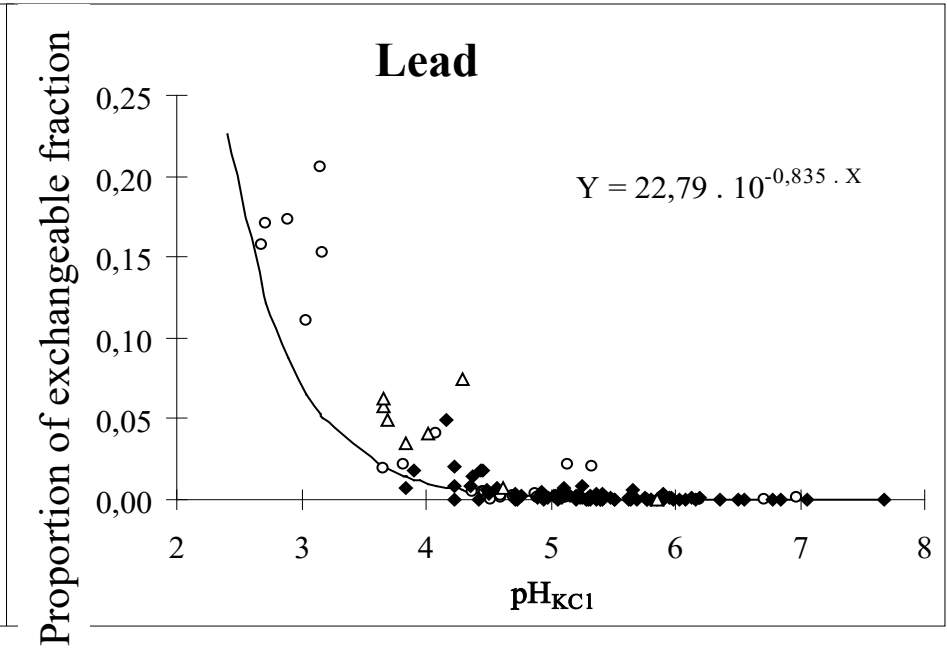


Relative immobilization of PTE in soils:

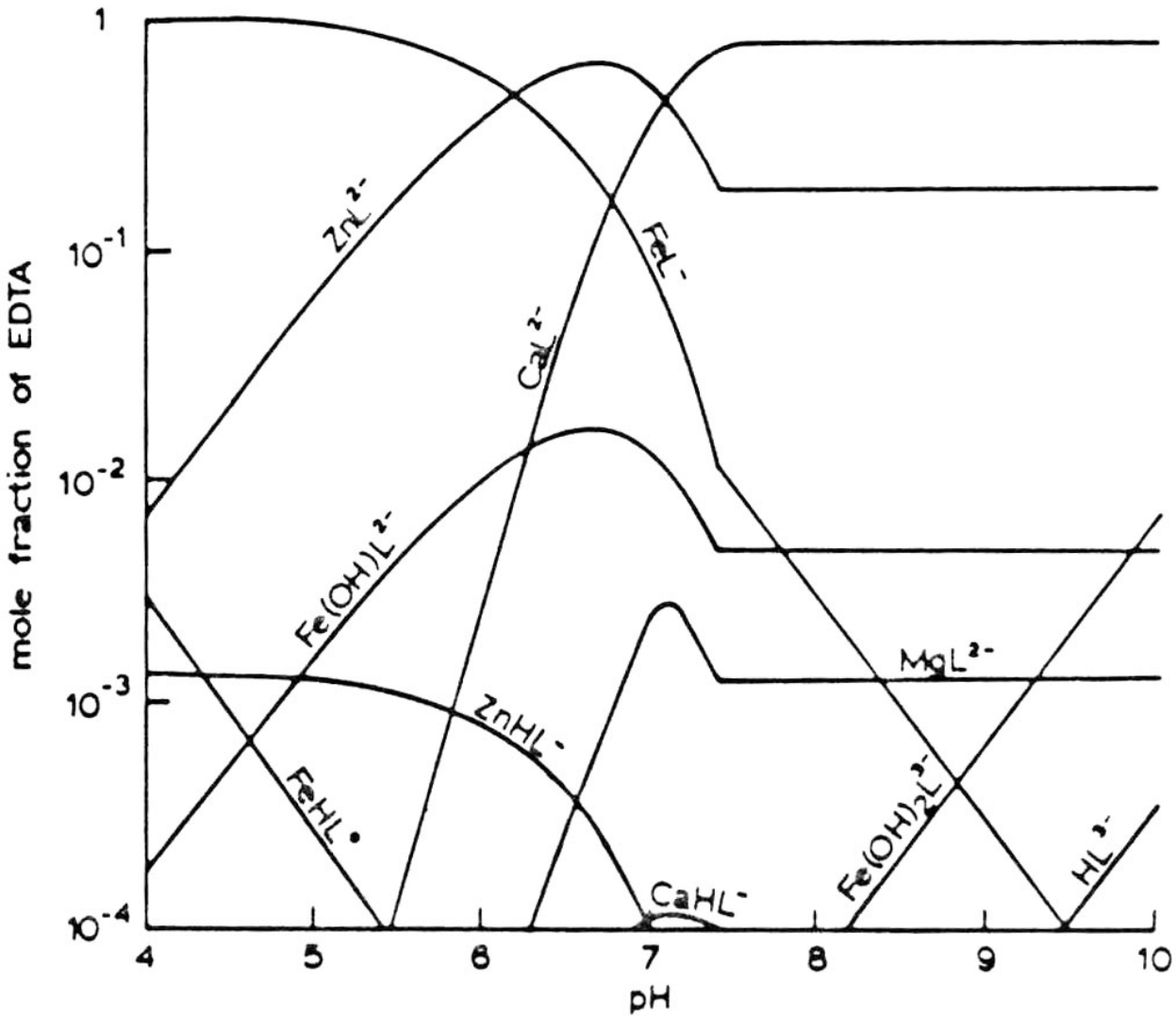
Pb > Sb > Cu > Cr > Zn > Ni > Co > Cd

pH effect on PTE – case study





Metal binding on EDTA (complexing agent) as dependent on pH



Soil vulnerability to pollution

Soil vulnerability:

- buffering ability of soil to resist pullution vs. contamination – real loading of soil
- based on:
  - mobility of pollutants
  - pollutant uptake by plants
  - soil properties

SOIL REMEDIATION

- A way to reduce or eliminate soil degradation and restore its basic functions
  - → elimination of problem sources (prevention)
  - → correction of consequences

- Engl. *remedy* (accord. to Collins English Dict.)

  = put right

  = means of curing, counteracting or relieving disease, trouble

  → correction of current state (esp. pollution)

Soil remediation

Methods for soil remediation:

- in situ x ex situ (on excavated soil)
- gentle x harsh
- stabilization x decontamination

Methods:

- physical – classification/sorting, vaporization, thermal degradation, melting, vitrification, solidification, isolation, electro-kinetic methods...
- chemical – immobilization, extraction, degradation...
- biological – bioremediation, bioaccumulation, phytoextraction, phytostabilization, natural attenuation...

Factors to be considered (1)

- type of pollution
- pollutant type and amount
- pollutant form and its properties
- origin – source and age of pollution
- importance of pollution
- the area and its exploitation

Factors to be considered (2)

- effectiveness and time
- ease, technical demands of the method
- financial costs
- possible consequences of the method
- local conditions, soil properties and environmental conditions
- ownership, activists …

Exploited properties of pollutants

- volatility
- solubility and polarity
- chemical and thermal (in)stability
- biological degradability, bioavailability
- sorption and precipitation
- electro-magnetic properties
- size, shape, mass density

Remediation *in situ*

- **Natural attenuation**
  - leaving soil without treatment (only monitoring)
  - soil self-cleansing

  Processes: decomposition, sorption, precipitation, volatilisation etc.

  Problems – pollutant transport, possible toxic products, changes of conditions, long duration

- **Dilution**
  - mixing with non-polluted soil

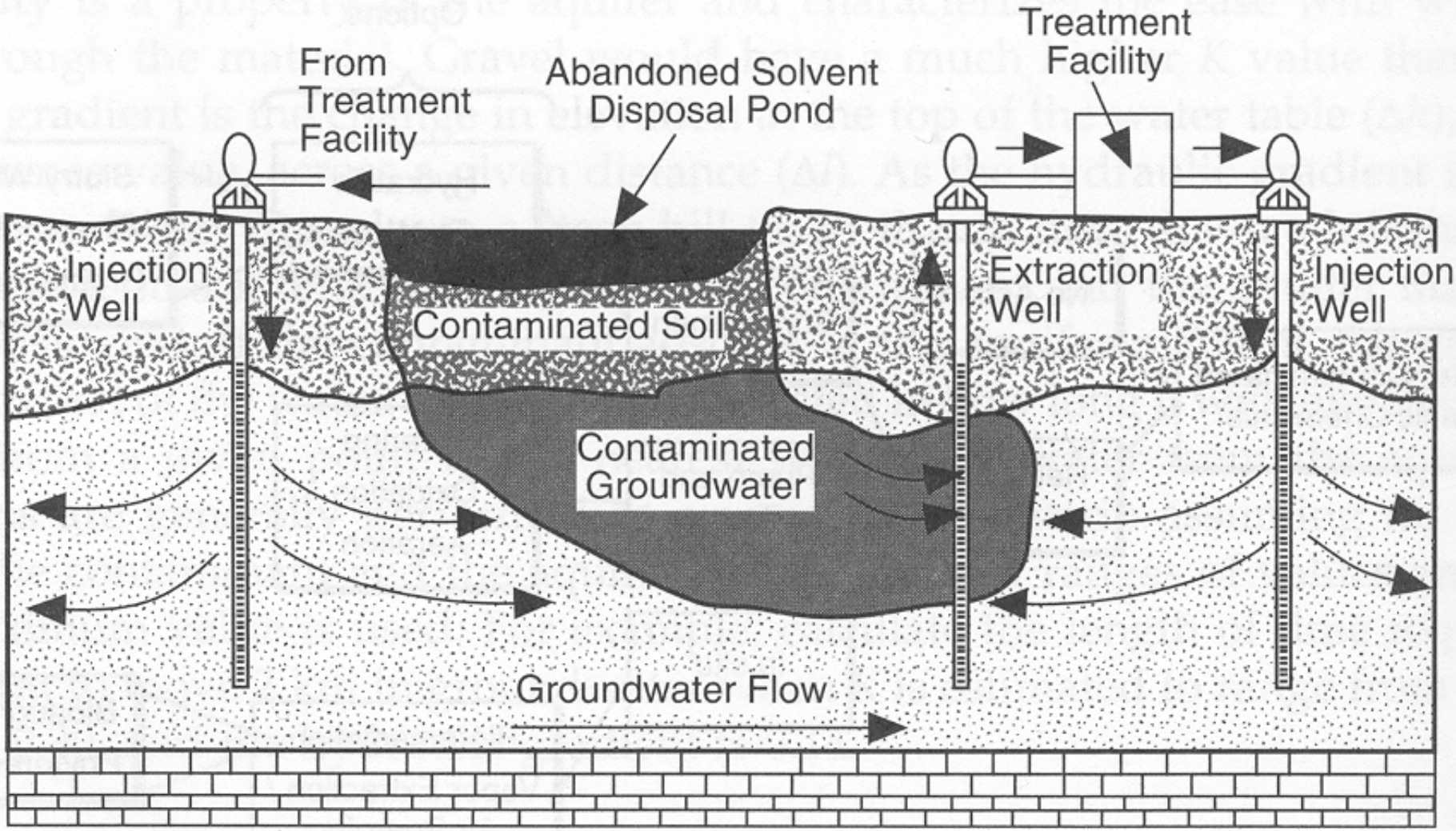
Remediation *in situ*

- **Extraction (leaching, washing, flushing)**
  - 3 steps: 1) extraction by leaching
    2) collection of extract
    3) extract treatment
  - extractants: water (optionally diluted acids, chelating agents, surfactants …)
  - application: - PTE
    - anions, salts
    - organic pollutants
    - radioactive substances

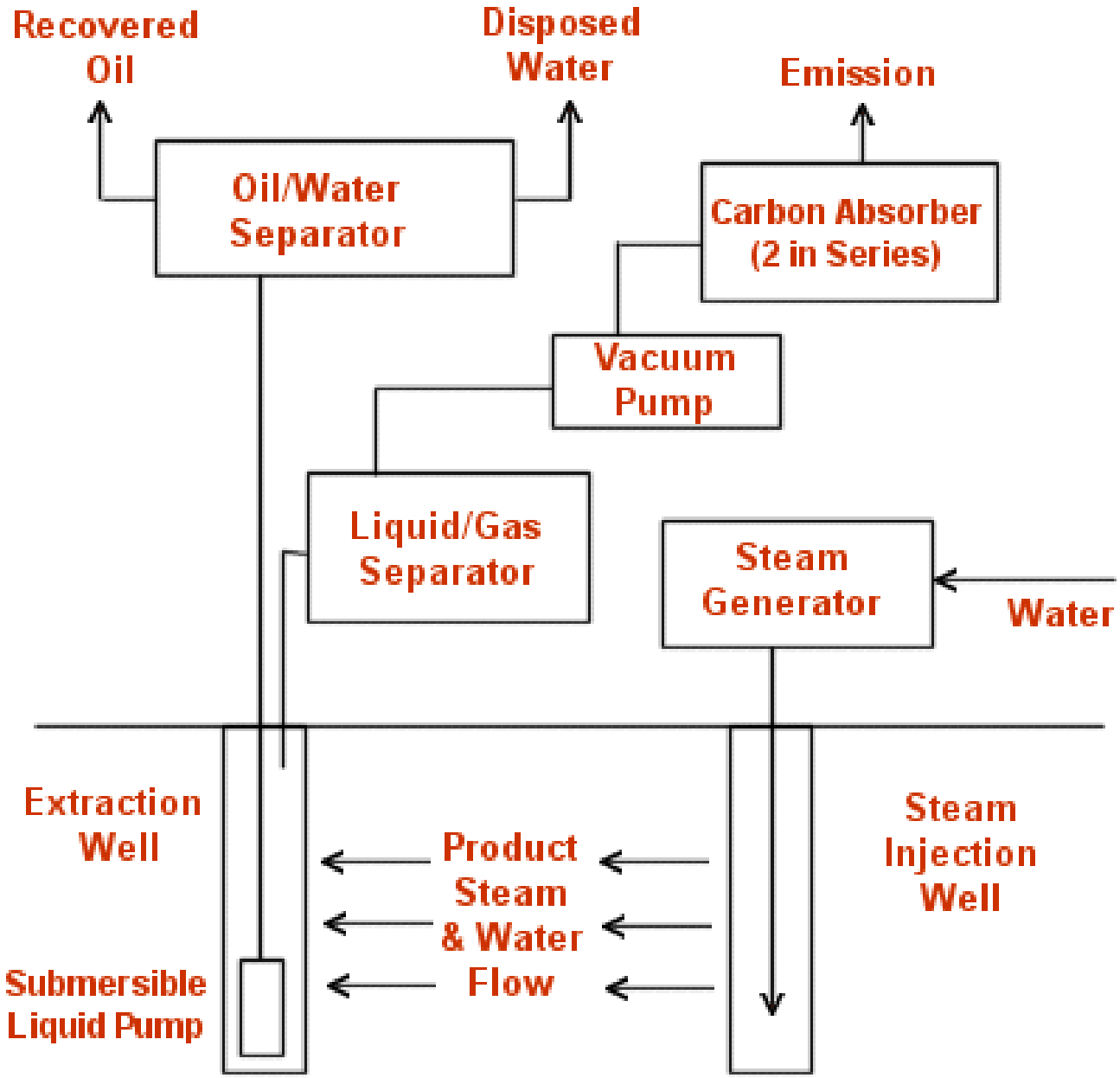
Remediation *in situ*

- **Extraction (leaching, washing, flushing)**
  - <u>critical factors:</u>
    - pollutant solubility
    - hydraulic conductivity of soil
    - sorption properties and specific surface of soil
    - soil pH and buffering capacity
    - content and quality of SOM
    - bedrock (subsoil) permeability

  → <u>limitation:</u> sandy soils with impermeable subsoil



Scheme of a pump-and-treat process for polluted groundwater



Scheme of oil-products extraction from soil with steam

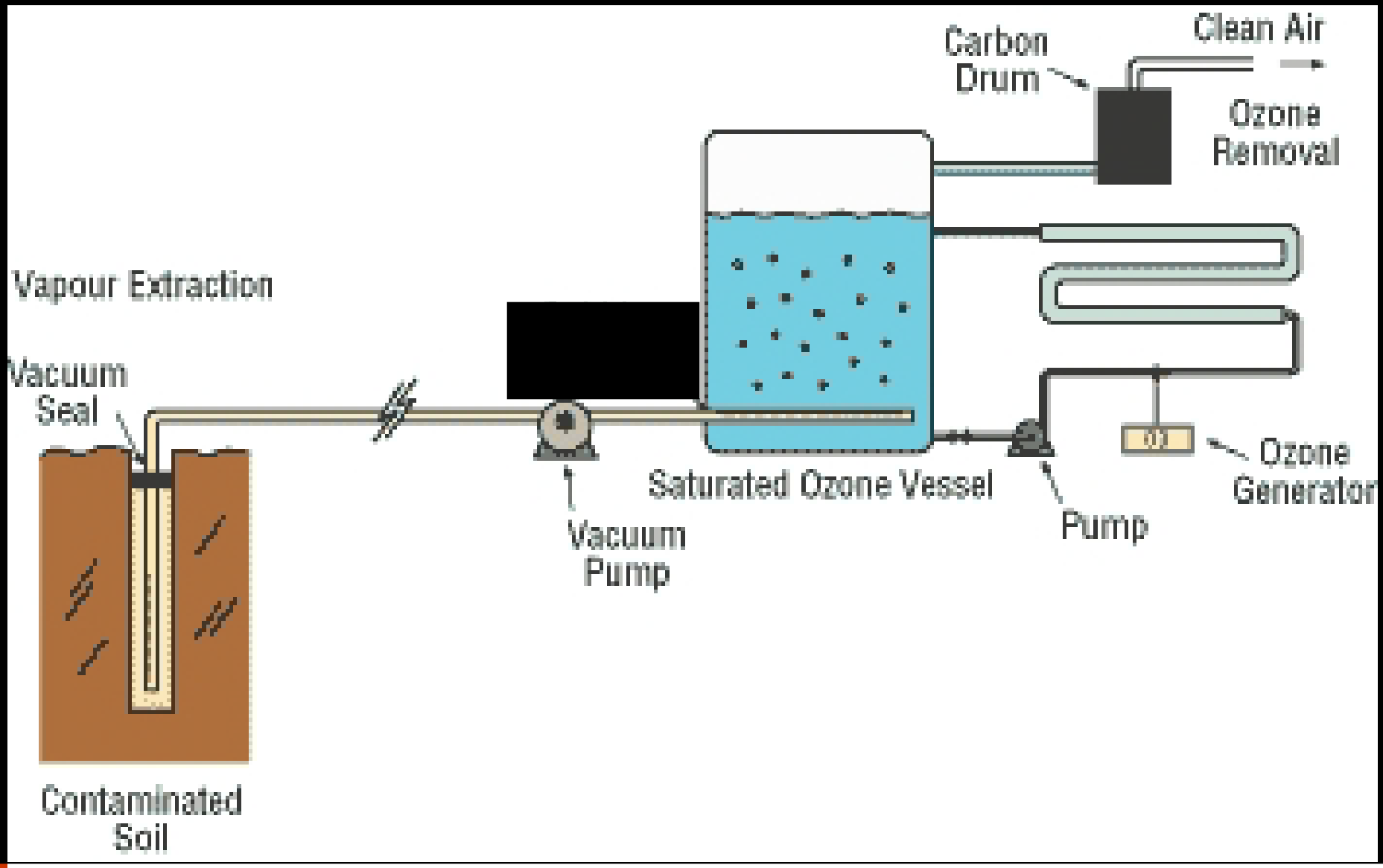
Remediation *in situ*

- **Vapour extraction (vapour stripping)**
  - volatile organic substances – exhaustion

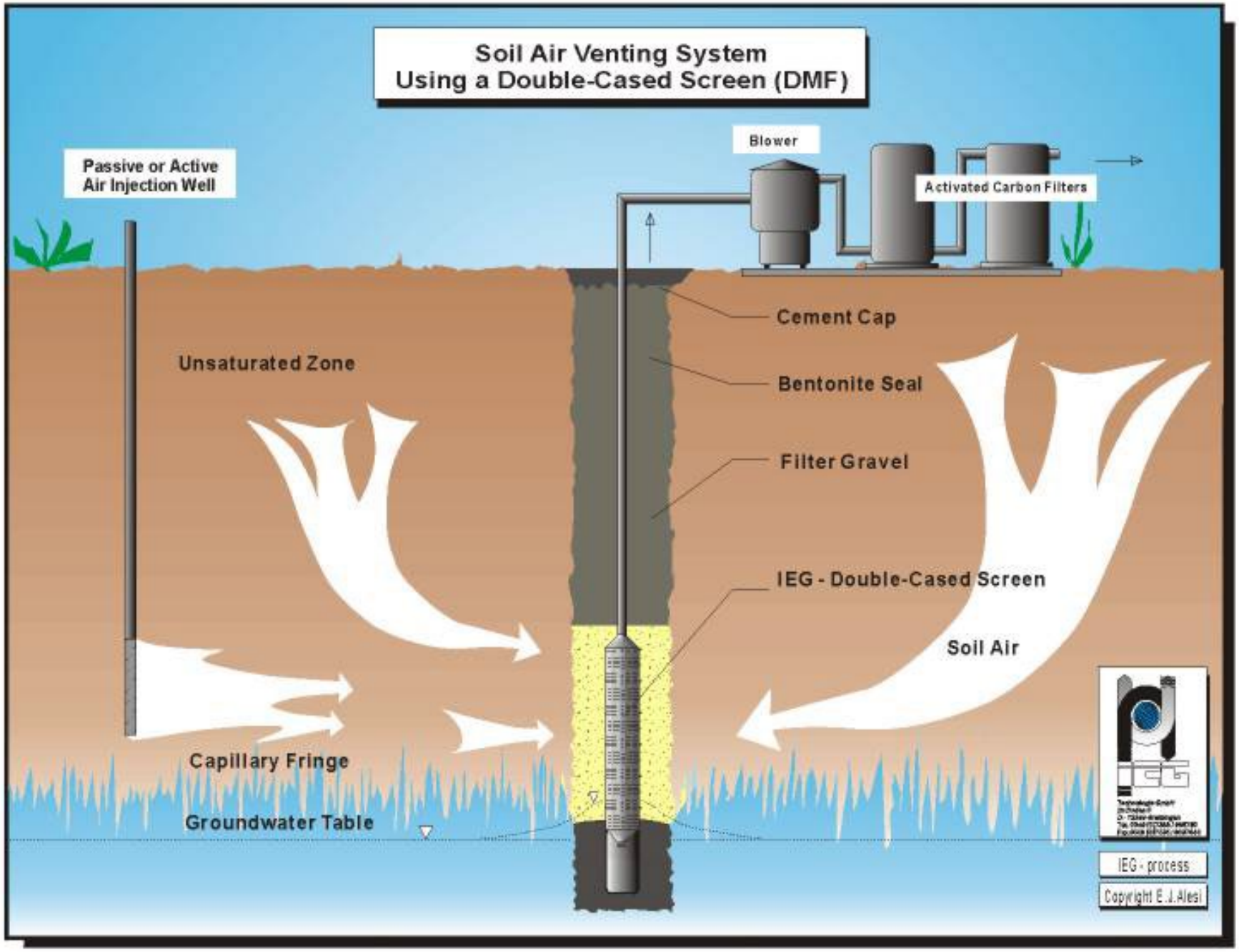
  <u>Pre-requisites:</u>

  - pollutant volatility, soil permeability (sandy soils)
  - low pollutant solubility or low soil moisture
  - pollution above groundwater table

- **Air sparging**
  - for saturated soils and groundwater pollution
  - volatilization of pollutants by air injected below the water table



Scheme of soil vapour extraction


Soil Air Venting System
Using a Double-Cased Screen (DMF)
Passive or Active
Air Injection Well
Blower
Activated Carbon Filters
Cement Cap
Unsaturated Zone
Bentonite Seal
Filter Gravel
IEG - Double-Cased Screen
Soil Air
Capillary Fringe
Groundwater Table
IEG - process
Copyright E. J. Alesi

Remediation *in situ*

- **Heating technologies**
  - can improve vapour extraction
  - stimulate biodegradation

  Methods of heating:

  - thermal conduction (x limited radius)
  - radio-frequency heating (electromagnetic radiation)
  - electrical heating (clays and silts)
  - steam flooding

Remediation *in situ*

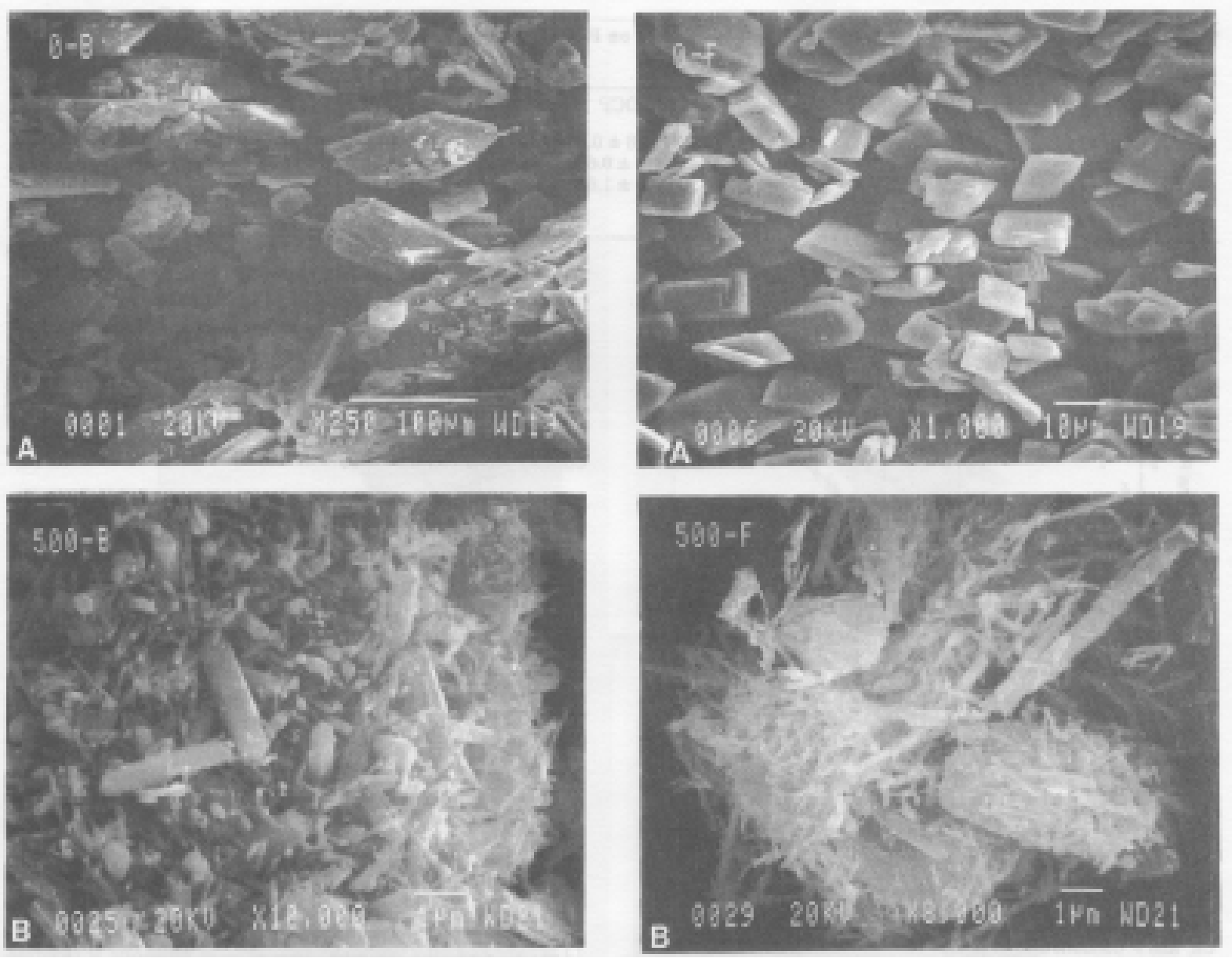
- **Immobilisation**
  - **by soil adjustment** (e.g. pH - liming)
  - **<u>soil additives:</u>**

    - simple inorg. compounds - sulphides, carbonates, phosphates…

    - inorganic sorbents – zeolites (natural or synthetic), bentonites, clay minerals, slags, goethite, steel dust, apatites etc.

    - organic sorbents – farm manures, composts, straw, sludges, activated carbon, synthetic resins

    - complexing agents (tetrene)



Microphotography of hydroxyapatite (left) and $CaHPO_4$ (right), separately (top) and after reaction with 500 mg $Pb.L^{-1}$ (bottom)

Remediation *in situ*

- **Chemical degradation**

  - **oxidation**

    - injection of peroxide, permanganate or ozone
    - for organic chemicals

  - **reduction, hydrolysis …**

Potential problems:

- presence of organic matter
- distribution of applied reagents
- toxic by-products, gas evolution etc.

Remediation *in situ*

- **Photolysis**

  - photochemical transformation

  - e.g. UV radiation for PCB, dioxins, PAH, benzene, toluene

- **Bioremediation, biodegradation**
- **Phytoremediation**

Remediation *in situ*

- **Electrokinetic processes**

  Principle: transport of elektrically charged particles in electric field

  - *electroosmosis* (solutions, electrolytes)
  - *electrophoresis* (colloids)
  - *electrolysis* (ions, complexes)

  Applications:

  - both *in situ* and *ex situ*, no soil disturbance
  - even loamy and clayey soils

Remediation *in situ*

- **Electrokinetic processes**

  <u>Applicable for:</u>

  - PTE (Pb, Hg, Cd, Ni, Cu, Zn, Cr)
  - radioactive particles (^{137}Cs, ^{90}Sr, ^{60}Co, U)
  - anions (nitrates, sulphates, cyanides)
  - petroleum hydrocarbons
  - halogenated hydrocarbons (e.g. PCB)
  - polycyclic aromatic hydrocarbons (PAH)
  - …

Remediation *in situ*

- **Electrokinetic processes**

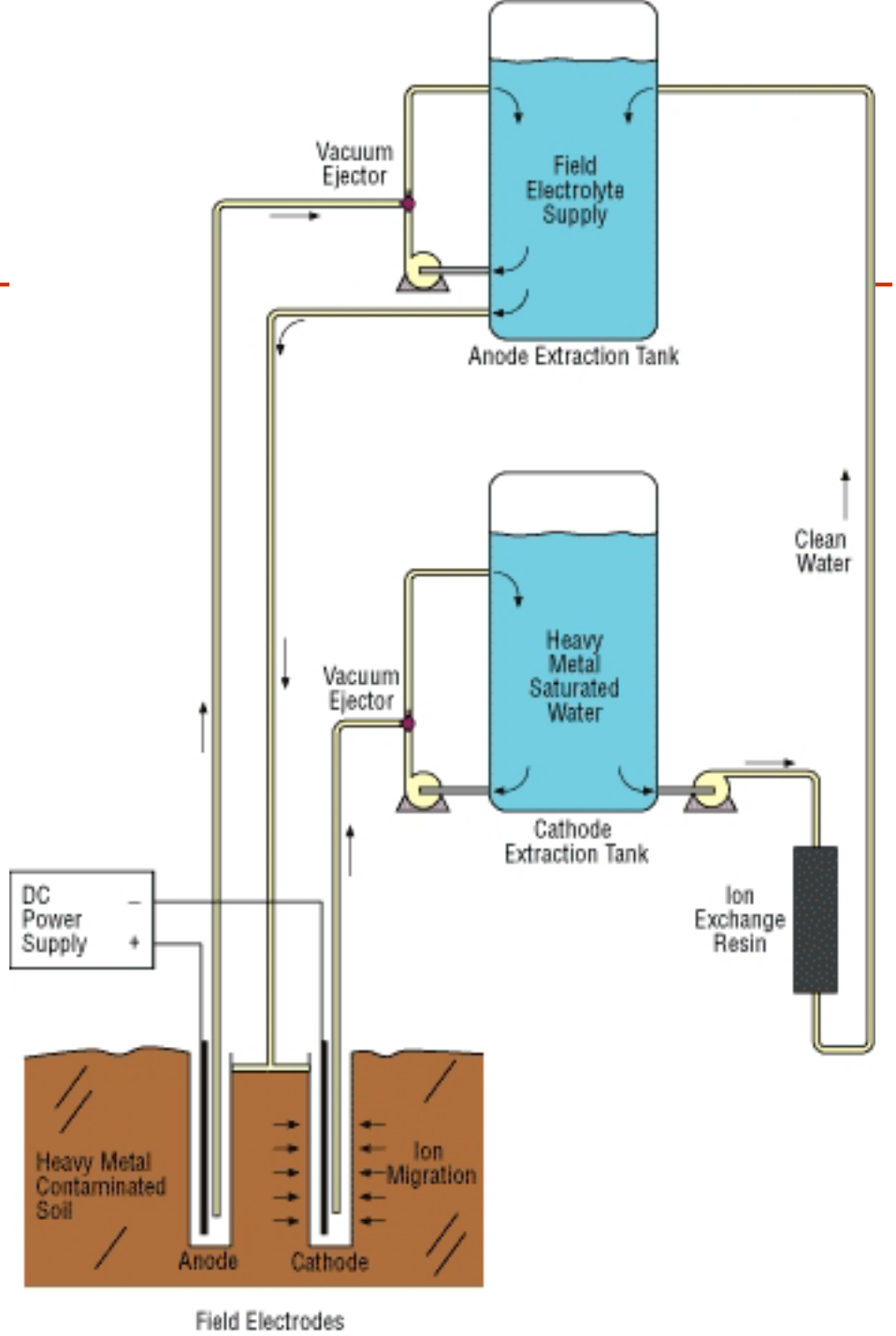
  Possible combinations with:

  - bioremediation (electrokin. biorem, bioelectric rem.)
  - oxidation and other degradation
  - fixation (electrokinetically-deployed fixation)
  - extraction (electroheated extraction)
  - surfactant amendments …

  Potential problems:

  - pollutant solubility and desorption
  - electrode corrosion (esp. in acid conditions)

Scheme of soil remediation by electrolysis
(heavy metal pollution)



Remediation *in situ*

- **Electrokinetic processes**
  - Example of application for PTE polllution:
    - power consumption ~ 500 kWh/m^3
    - distance between electrodes 1-1.5 m
    - average speed of pollutant movement – 2.5 cm/day
    - direct costs ~ \$25/m^3

Remediation *in situ*

- **Grouting**

  – injection of a non-porous material to soil cracks and voids to eliminate pollutant leaching

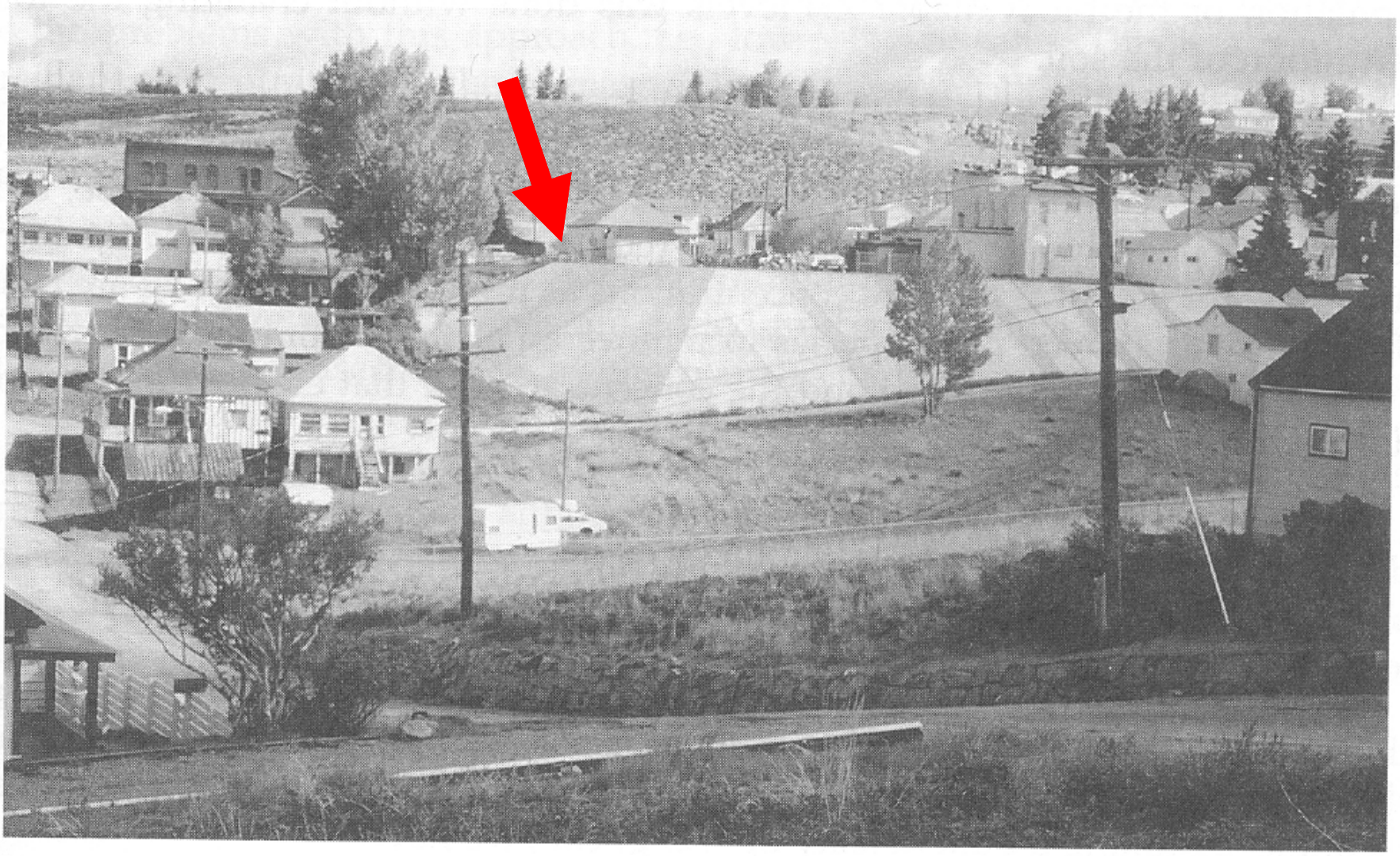
- **Solidification**

  – cement, gypsum, silicates, resins, asphalt

- **Isolation**

  – elimination of pollutant movement

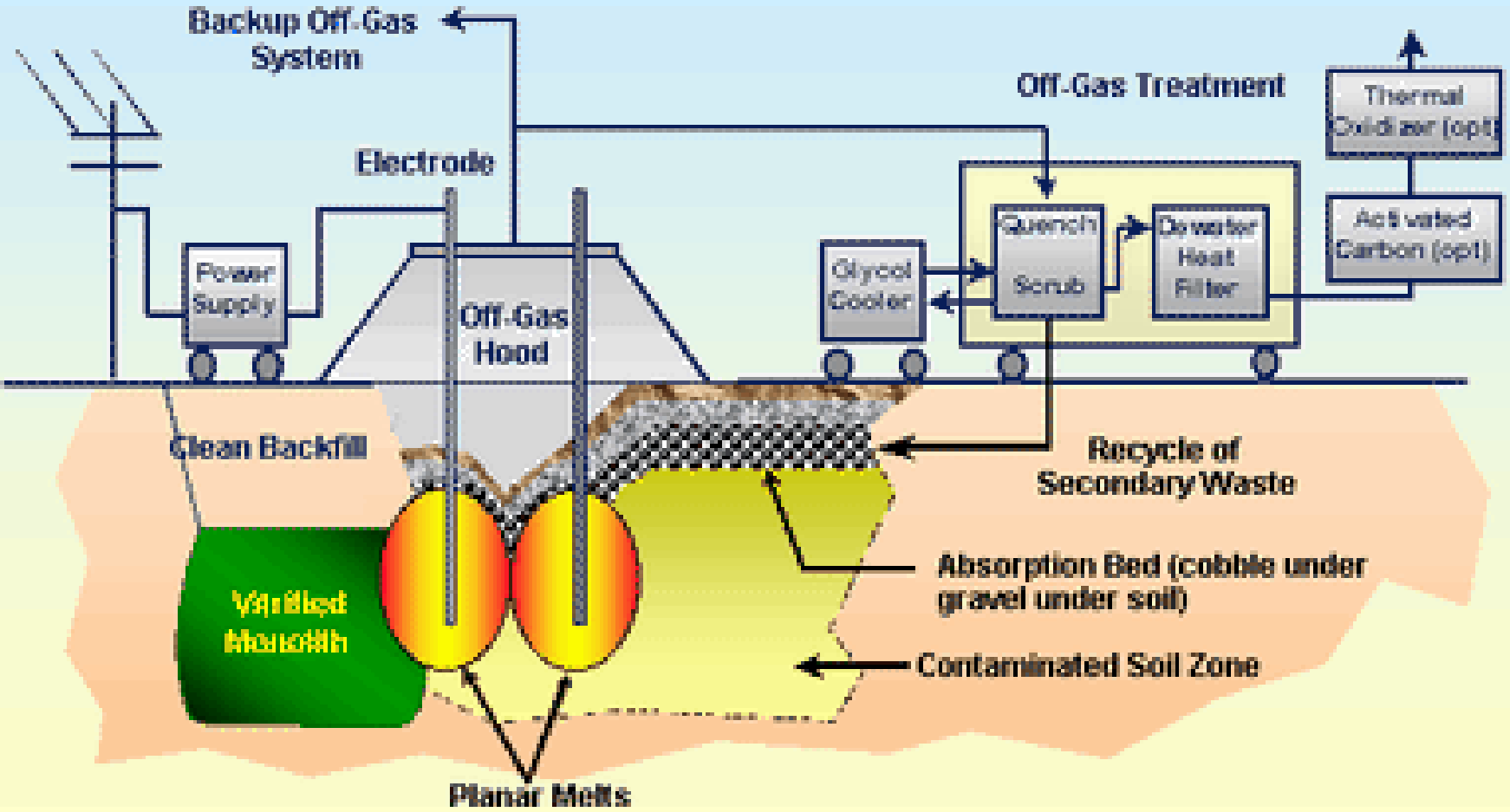
  - barriers, walls, covers, encapsulation, capping



Isolation – encapsulation (Butte, MT)

Remediation *in situ*

- **Vitrification**
  - thermal transformation to a glassy monolith
  - under a strong el. current (graphite electrodes)
  - ~1600-2000°C
  - volume reduction (~ 20-40 %)
  - exhaustion of volatile products necessary
  - costs ~ $140-290/m^3



Scheme of in situ vitrification

Bioremediation

- exploitation of living organisms for soil remediation

Phytoremediation

- exploitation of higher plants for soil remediation

Bioremediation - processes

Biodegradation

- decomposition of high contents of pollutants

Biotransformation

- pollutant transformation to less dangerous forms

Bioremediation - approaches

- Natural attenuation (no treatment)
- Stimulated microbial activity
- Innoculation with specific microorganisms
- Treatment with specific enzymes

Bioremediation - methods

„Land farming“

- spreading of polluted soil in a thin layer
- biodegradation, biotransformation + dilution
- especially for pesticides

Composting

- stimulation of microbial activity

Bioreactors

- ex situ, controlled conditions

Bioremediation - methods

Bioventing

- gas (air) injection into unsaturated soil
- stimulation of natual processes
- can be facilitated by amendments (e.g. nutrients)

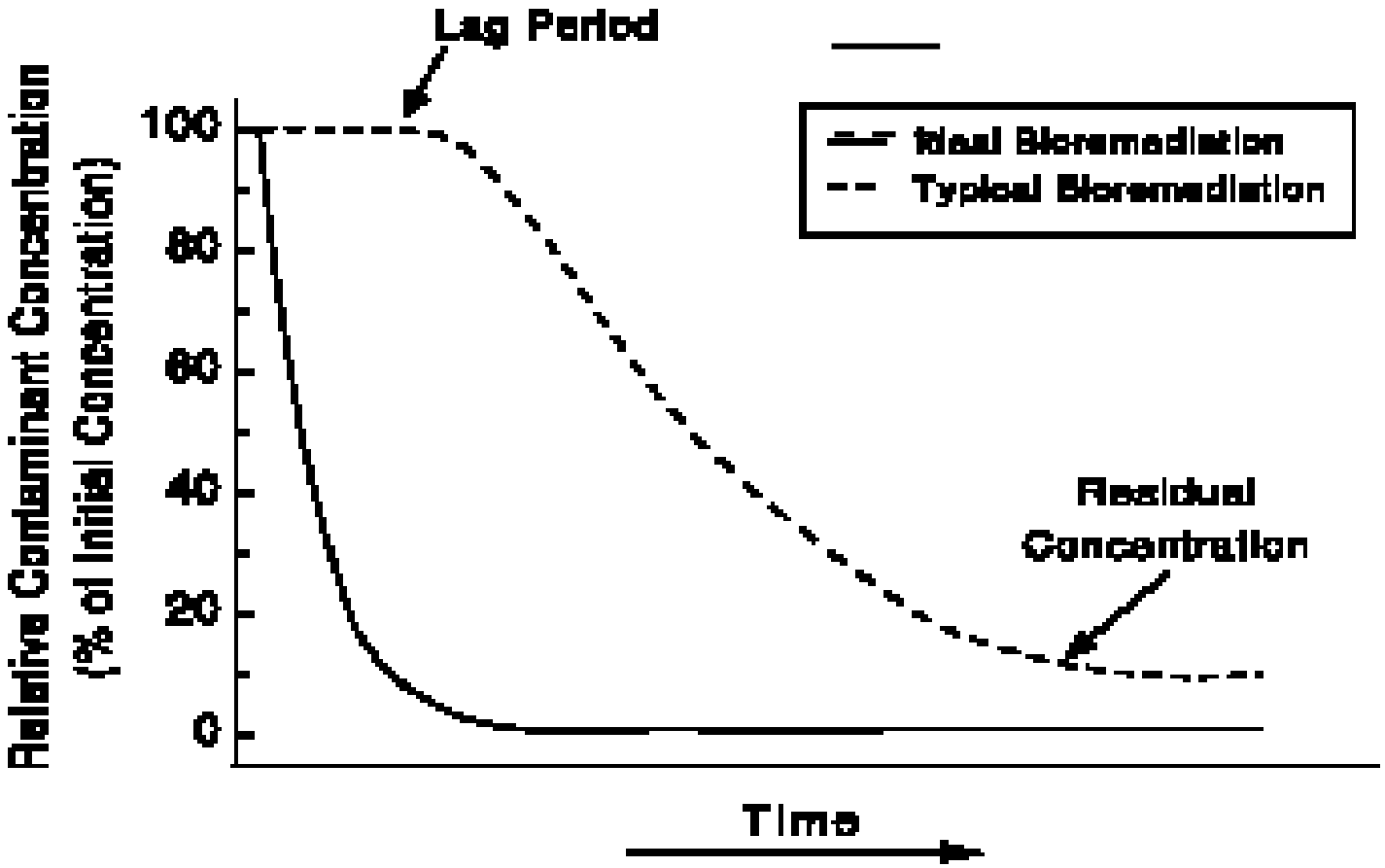
Air Sparging (Biosparging)

- gas (air) injection under pressure into saturated soil
- translocation of volatile compounds to unsaturated zone where they can be decomposed

Stimulated biodegradation – bioventing

Stimulated biodegradation

Bioremediation running



Unfavourable factors for bioremediation

- too high (toxic) pollutant concentrations
- concentration change does not enable adaptation of microorganisms
- insuffiecient number or type of microorganisms
- soil reaction (too acid/alkaline)
- nutrient, oxygen, enzymes or other deficiency
- unfavourable soil moisture

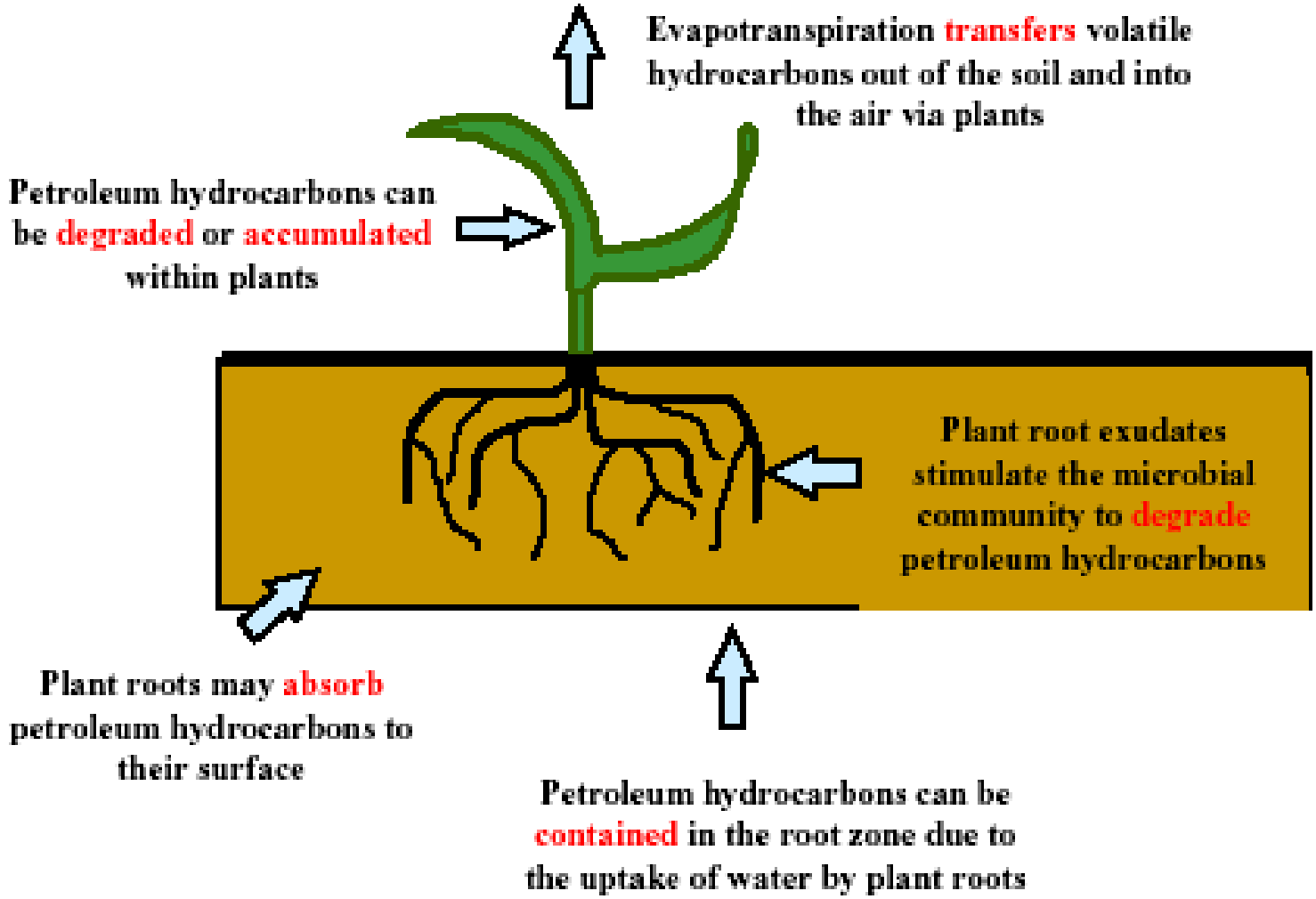
Aspects of method selection

- degradability of pollutant, potential toxic by-products
- pollutant amount and distribution (spatial, profile, between soil phases)
- risk of pollutant leaching
- chemical reactivity
- soil properties, enough O_2 (redox potential)
- presence of other toxic substances
- ability of microorganisms to destroy the pollutant
- depth of water table

Phytoremediation

Applicability:

- PTE (Cd, Cr^{6+}, Co, Cu, Ni, Pb, Se, Zn)
- radionuclides (Cs, Sr, U)
- petroleum hydrocarbons
- chlorinated hydrocarbons (e.g. PCB)
- polynuclear aromatic hydrocarbons (PAH)
- pesticides (chlorinated, organophosphates etc.)
- nutrients (N, P)
- surfactants
- salts



Mechanisms of phytoremediation (petroleum hydrocarbons)

Phytoremediation - methods

Phytostabilisation, phytoimmobilisation

- vegetation cover to reduce erosion and leaching
- can be supported by additives

<u>Plant effects:</u>

- accumulation, chelatation, adsorption…
- changes in the rhizosphere:
  - pH, SOM, redox …
  - element accumulation, precipitation
  - microbial activity

Phytoremediation - methods

Phytostabilisation, phytoimmobilisation

Required plant properties:

- tolerance to the pollutant
- high production of root biomass able to immobilise pollutants
- pollutant retention in roots

Limitations: - low productivity
- unusable or only technical crops

Phytoremediation - methods

Phytovolatilisation

- transformation of pollutants (e.g.. Hg, Se) to volatile forms by plant enzymes

Phytotransformation

- pollutant decomposition in plant metabolism

Phytoextraction

- pollutant removal by plant uptake

Plant classification according to their response to soil pollution with PTE

- **inadaptable (intolerant)**
- **indicators**
- **excluders**
- **accumulators**
- **hyperaccumulators**

  > 0.01 $g.kg^{-1}$ dry weight in case of Hg

  > 0.1 $g.kg^{-1}$ dry weight in case of Cd

  > 1 $g.kg^{-1}$ dry weight in case of Co, Cr, Cu, Ni, Pb

  > 10 $g.kg^{-1}$ dry weight in case of Zn, Mn (tj. > 1%!)

Phytoextraction

a) **Natural:**

- exploitation of hyperaccumulators
  - *in total ~ 400 species from at least 45 families*

b) **Induced (enhanced):**

- using of chemical compounds to increase plant uptake of risk elements
- especially chelating agents (EDTA, DTPA, citric acid…)

x danger of leaching!

Phytoextraction

<u>Advantages:</u>
- rel. low costs (~ \$17-100 per m^3)
- environmentally safe

<u>Problems:</u>
- long duration
- possible pollutant transfer
- introduction of non-native organisms
- biomass liquidation
  - landfills, drying, composting, leaching
  - vitrification, controlled incineration
  (5000 t contam. soil/ha → 25-30 t plant ash)
- only for shallow pollution (20-100 cm)

Phytoextraction

Applicability:

- PTE
- radionuclides
- some organic substances

„***Phytomining***“ – commercial biomass utilisation for metal production

Phytoextraction

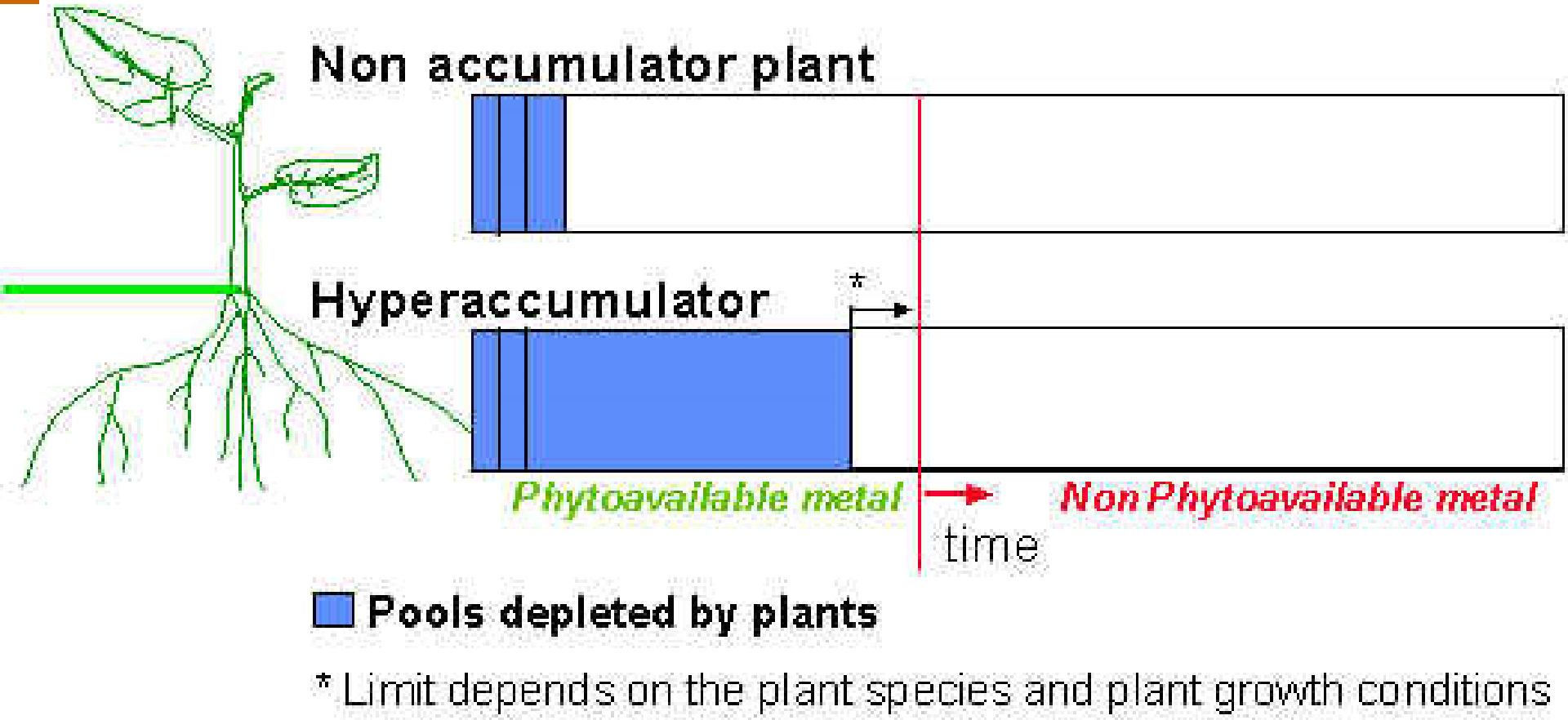
Required plant properties:

- tolerance to pollution
- suitability to given condiions
- high pollutant uptake and its accumulation in above-ground parts
- high yield and easy harvesting

Tolerance to a heavy metal, Cu, was first found at Melandrium album in Piesky, Slovakia (Silvestr Prát, Charles University, 1934)

Phytoextraction

Comparison of metal uptake by hyperaccumulator and non-hyperaccumulator plant



Phytoextraction

Effectiveness:

Total amount of removed risk element =

= (Concentration of RE in plant) x

x (biomass yield)

Thlaspi caerulescens **(Zn, Cd, Pb etc.)**

Response of *Thlaspi caerulescens* to Zn content increase in soil

Basal rosette of *Thlaspi caerulescens*

Salix viminalis

Hyperaccumulating ferns
(*Pteris vittata*)

QUESTIONS?

Control questions

The most important soil properties controlling behaviour of potentially toxic elements are:

a) content of sand and silt

b) soil pH and content and qualtiy of soil organic matter

c) composition of soil microorganisms

Control questions

Extraction as a soil remediation method:

a) can be used only on excavated soil
b) is suitable especially for clayey soils
c) is applicable only for soluble pollutants

Control questions

Immobilisation of pollutants as a method of soil remediation:

a) can be reached by soil adjustment or soil amendments

b) aims in removal of the pollutants from soil

c) ensures complete decomposition of pollutants

Control questions

Which of the following pollutants are readily biodegradable?

a) most potentially toxic elements
b) PCB, PAH
c) petroleum hydrocarbons

Control questions

Phytoextraction as a soil remediation method:

a) is very fast and effective
b) is applicable especially for organic pollutants
c) causes almost no soil disturbance

Thank you for your attention