Environmental Technology in Mining

CHAPTER 3.2 SOIL POLUTION

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DPTO. DE CIENCIAS Y TÉCNICAS DEL AGUA

Y DEL MEDIOAMBIENTE

INDEX

INDEX

Environmental Technology in Mining

SOIL POLLUTION

https://www.straitstimes.com/asia/east-asia/china-to-enact-its-first-soil-pollution-law

«La descontaminación de suelos es una nueva línea laboral más allá de la habitual minera»

«Los ingenieros, independientemente del trabajo que realicen, deberían seguir complementando su formación»

FELIPE GONZÁLEZ COTO Doctor en Ingeniería de Minas

Mieres del Camino, J. VIVAS

Pocos conocen las múltiples salidas laborales que ofrece la titulación en Ingeniería de Minas, que no siempre va ligada a la extracción del mineral. Este no es el caso de Felipe González Coto (Oviedo, 1978), doctor en Ingeniería de Minas desde hace tan sólo unos meses. González Coto realizó una tesis sobre la descontaminación de suelos con la aplicación de tecnologías mineralúrgicas, un método poco común, pero que cuenta con numerosos beneficios, sobre todo económicos. Su tesis, dirigida por los profesores Juan María Menéndez Aguado y José Luis Rodríguez Gallego -ambos ejerciendo la docencia en la Escuela Politécnica de Mieres- tiene como uno de sus objetivos «iluminar» a los futuros ingenieros de Minas sobre las diferentes alternativas profesionales que tendrán una vez que acaben la carrera.

-¿Por qué decidió orientar su tesis hacia la descontaminación de suelos?

Felipe González Coto, a las puertas del campus de Mieres. j. r. silveira

http://www.lne.es/cuencas/2011/11/06/descontaminacion-suelos-nueva-linea-laboral-habitual-minera/1152785.html

EL MUNDO

MEDIO AMBIENTE

La huella minera e industrial de Huelva, un peligro potencial para la salud

LAURA RAMÍREZ (EFE)
Huelva

Actualizado Domingo, 20 noviembre 2022 - **19:02**

https://www.elmundo.es/andalucia/2022/11/20/637a6bc8e4d4d8651b8b45ae.html

Investigadores de la Universidad de Huelva concluyen que hay zonas que "suponen un riesgo cancerígeno a largo plazo"

El bagaje minero-industrial que desde hace un siglo marca la actividad económica de la capital de Huelva está dejando suelos potencialmente peligrosos para la salud de sus vecinos por la presencia de **arsénico y plomo**.

Paseo Marítimo de Huelva, donde se construye un carril bici. JULIÁN PÉREZ EFE

elDiario.es

Los suelos contaminados de la Sierra Minera

Pedro Belmonte Espejo 26 de octubre de 2018 -1

https://www.eldiario.es/murcia/murcia-y-aparte/suelos-contaminados-sierra-minera_132_1869728.html

Los metales pesados pueden pasar a nuestro organismo de varias maneras. La primera es por el contacto dérmico a través de nuestra piel, otra forma es a través de la ingesta directa por alimentos contaminados

Los suelos contaminados de la Sierra Minera Cartagena-La Unión son un problema arrastrado desde el siglo pasado con la decadencia de la actividad minero industrial y la permanencia de sus secuelas de vertidos y residuos. Cualquier persona que se desplace ahora por las sierras mineras, incluido Mazarrón, verá este paisaje de cortas mineras, de ramblas con lodos y balsas de estériles, como testigos inmutables de la contaminación minera en las cercanías de entorno urbanos de la zona. Cuando alguna voz discordante planteaba este grave problema medioambiental, se enfrentaba a la desidia de décadas de abandono de las administraciones locales y a la pasividad de los sucesivos gobiernos regionales.

Sierra Minera

THE CONVERSATION
Rigor académico, oficio periodístico

El peligro oculto en los suelos contaminados

Publicado: 4 junio 2020 21:37 CEST

Mina abandonada en Mazarrón, Murcia. Pabkov / Shutterstock

La Opinión DE MURCIA

La descontaminación de los suelos mineros de la Región costará 85 millones

La Comunidad pone en marcha un plan de diez años para recuperar los suelos afectados

EFE

10·10·18 | 14:21

Las 30 actuaciones previstas en el plan, a desarrollar **hasta 2028**, están orientadas a la recuperación ambiental de los 29 depósitos mineros que hay en Cartagena, La Unión y Mazarrón y que han sido catalogados por el Instituto Geológico y Minero de España en su inventario sobre gestión de residuos mineros y rehabilitación de esos espacios.

No obstante, Celdrán ha recordado que en la Región hay un total de 82 depósitos mineros, pues esa actividad se desarrolló también, aunque en menor medida, en los municipios de Cehegín y Águilas.

https://www.laopiniondemurcia.es/comunidad/2018/10/10/descontaminacion-suelos-mineros-region-costara-31597321.html

EL PAÍS

18 MAY 2019 -

El estado de la bahía de Portmán

La ensenada de Portmán (La Unión) está anegada desde hace años por los residuos de una mina que los tiró directamente al mar. En 2016 comenzó una esperada recuperación que ahora se ha parado por una sentencia judicial

https://elpais.com/elpais/2019/05/17/album/1558113700_703088.html

vertidos de la mina Peñarroya que sacaba plomo, plata y pirita

4. Imagen de cómo salían los residuos que se asemejaban a un lodo en 1965. El chorro se cambiaba de sitio cuando se sepultaba el mar de una zona

Torrelavega tiene más de 991.000 metros cuadrados de zonas degradadas

EL DIARIO MONTAÑÉS

Miércoles, 18 de julio 2018

La zona del Río Besaya es el área que peor se encuentra, debido a las especies invasoras y los vertidos de las fábricas

https://www.eldiariomontanes.es/torrelavega/torrelavega-hara-inventario-20180717181729-nt.html

Además, se han incorporado a este estudio cerca de 20 hectáreas de **antiguos depósitos mineros** con suelos contaminados como consecuencia de la actividad de la mina de Reocín, así como vertederos y escombreras del municipio.

El arsénico de una antigua mina amenaza los acuíferos de Guadalix

EL PAÍS

Científicos del CSIC hallan restos en torno a un viejo yacimiento de wolframio

BÁRBARA SÁNCHEZ | Madrid | 21 OCT 2014 - 19:59 CEST

Archivado en: CSIC Guadalix de la Sierra Contaminación suelo Minería Contaminación agua Organismos públicos investigación Provincia Madrid Política científica Comunidad de Madrid Segunda Guerra Mundial España Contaminación Investigación científica Historia contemporánea Guerra

La mina abandonada en Guadalix. La línea morada marca el recorrido del agua de lluvia y los puntos blancos, las zonas donde se tomaron las muestras. / FERNANDO GARRIDO

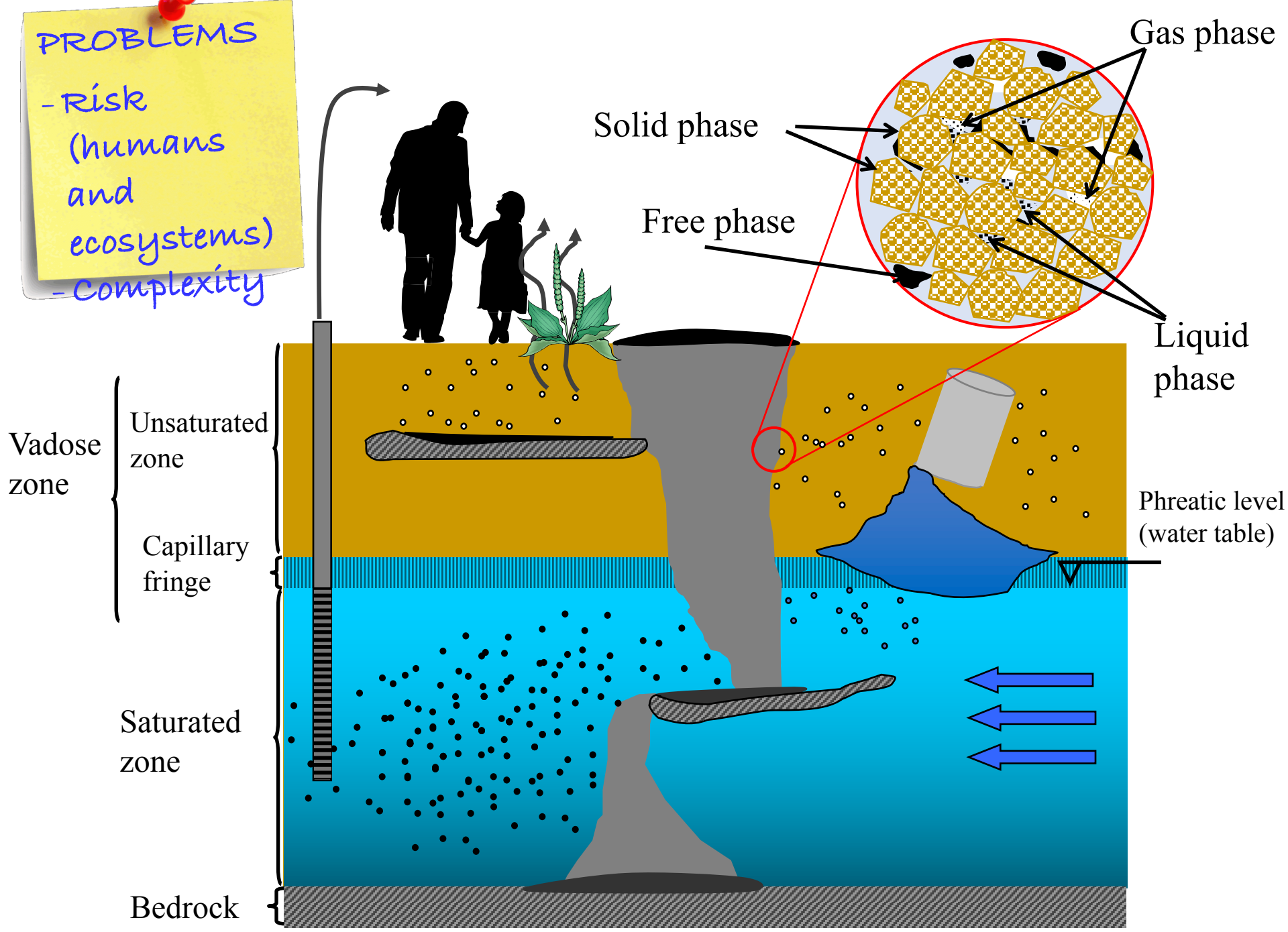
De forma tan imperceptible como constante, década tras década. Así se ha contaminado el suelo cercano a una mina de wolframio de los años treinta abandonada, en el municipio de Guadalix de la Sierra (6.071 habitantes), según una investigación de geoquímicos del Museo Nacional de Ciencias Naturales y del Consejo Superior de Investigaciones Científicas. El trabajo, publicado en la revista científica *Science of the total environment*, alerta de la necesidad de descontaminar la superficie afectada y retirar los residuos, que podrían alcanzar los acuíferos próximos.

La mina se encuentra en una zona accesible, próxima al cerro de San Pedro, entre Guadalix y Colmenar Viejo. En los años treinta sirvió para abastecer a la Alemania de wolframio, un metal que España exportaba y que los nazis empleaban en la fabricación de armamento pesado. La explotación fue abandonada tras la Segunda Guerra Mundial. Pero allí, en plena sierra madrileña, quedaron los restos de arsénico, un elemento químico natural y altamente tóxico en su forma inorgánica, que se libera, por ejemplo, al extraer metales del subsuelo.

INDEX

PROBLEMS

- Risk (humans and ecosystems)
- Complexity



Problems

- The importance of soil
- The concern about soil degradation
- Soil pollution
  - Causes and effects
  - Soil as pollution receptor
  - Contaminants: types, properties and transport

Solutions

- Legislation
- Polluted soils management
- Polluted soils remediation

INDEX

http://fixyoursoftware.com/wp-content/uploads/2013/01/icon_problem_man.jpg

PROBLEMS

INDEX

The importance of soil

The importance of soil as a resource

- The soil as a multi-funcional medium:
  - Ecological
    - Biomass production
    - Water treatment
    - Biological habitat and gene reserve
  - Socio-economic and cultural
    - Foundation for technical, industrial and socio-economical infrastructures
    - Source of raw materials and water
    - Historical medium
- It can be considered a non-renewable resource

INDEX

The concern about soil degradation

Polluted soils: first alarms

- Love Canal (USA, 70's)
  - Residential area built on a dumpsite
  - Health problems
  - 800 families were relocated and reimbursed for their homes
  - It led to new legislation

Lekkerkerk. Netherlands (80's)

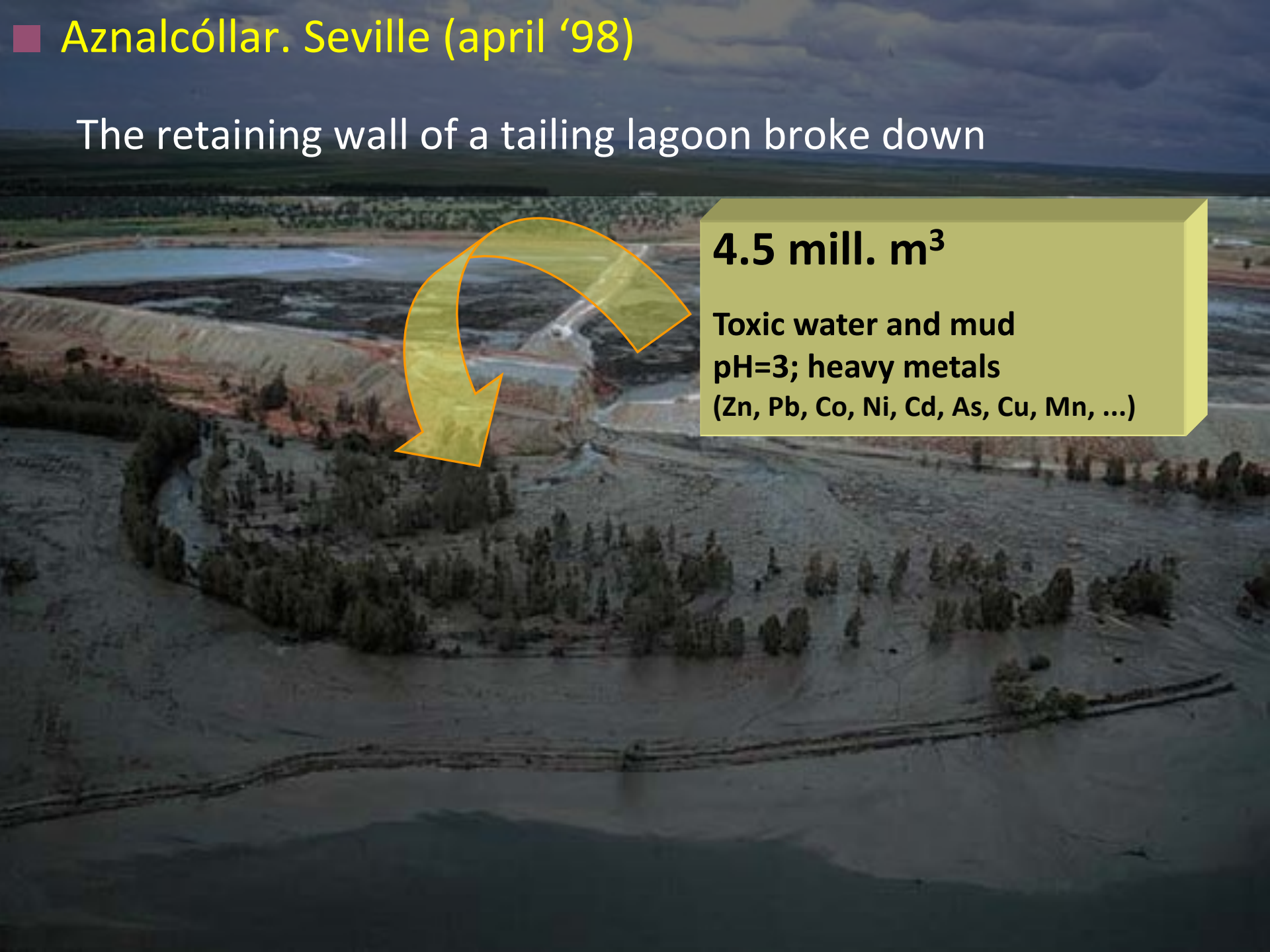
Part of the village built on a contaminanted soil
Soil and groundwater were decontaminated

- Lekkerkerk. Netherlands (80's)

> 800 inhabitants evacuated and rehoused

Aznalcóllar. Seville (april ‘98)

The retaining wall of a tailing lagoon broke down



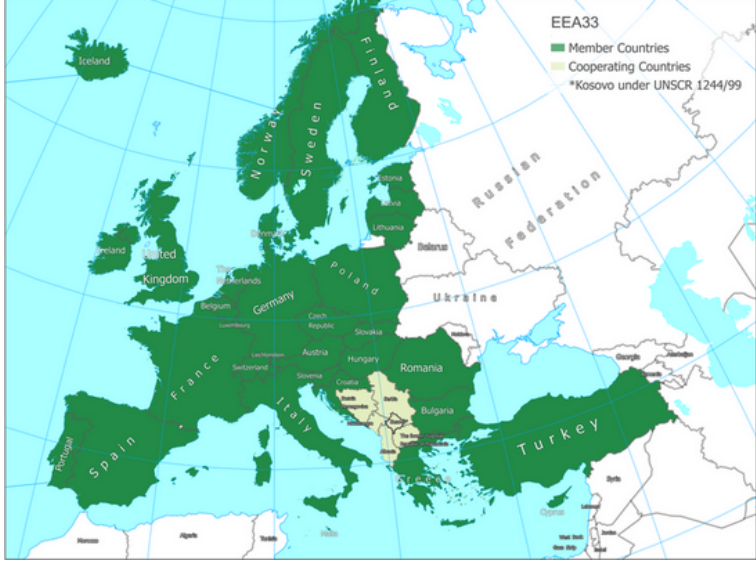
Aznalcóllar. Seville (april ‘98)

- 4.634 ha affected
- 135 million € spent in cleaning

INDEX

Soil pollution

Polluted soils in UE



European Environment Agency 2014

Sources of soil pollution

Point pollution include:

- The deposition of residues in the soil
- Accidental spills
- Losses and leaks during the operation of industrial plants
- Storage of raw materials above ground or in underground tanks
- Mining activities (related to sludge storage, generation of acidic mine water and the use of certain chemical reagents such as cyanide)
- Industrial ruins

Sources of soil pollution

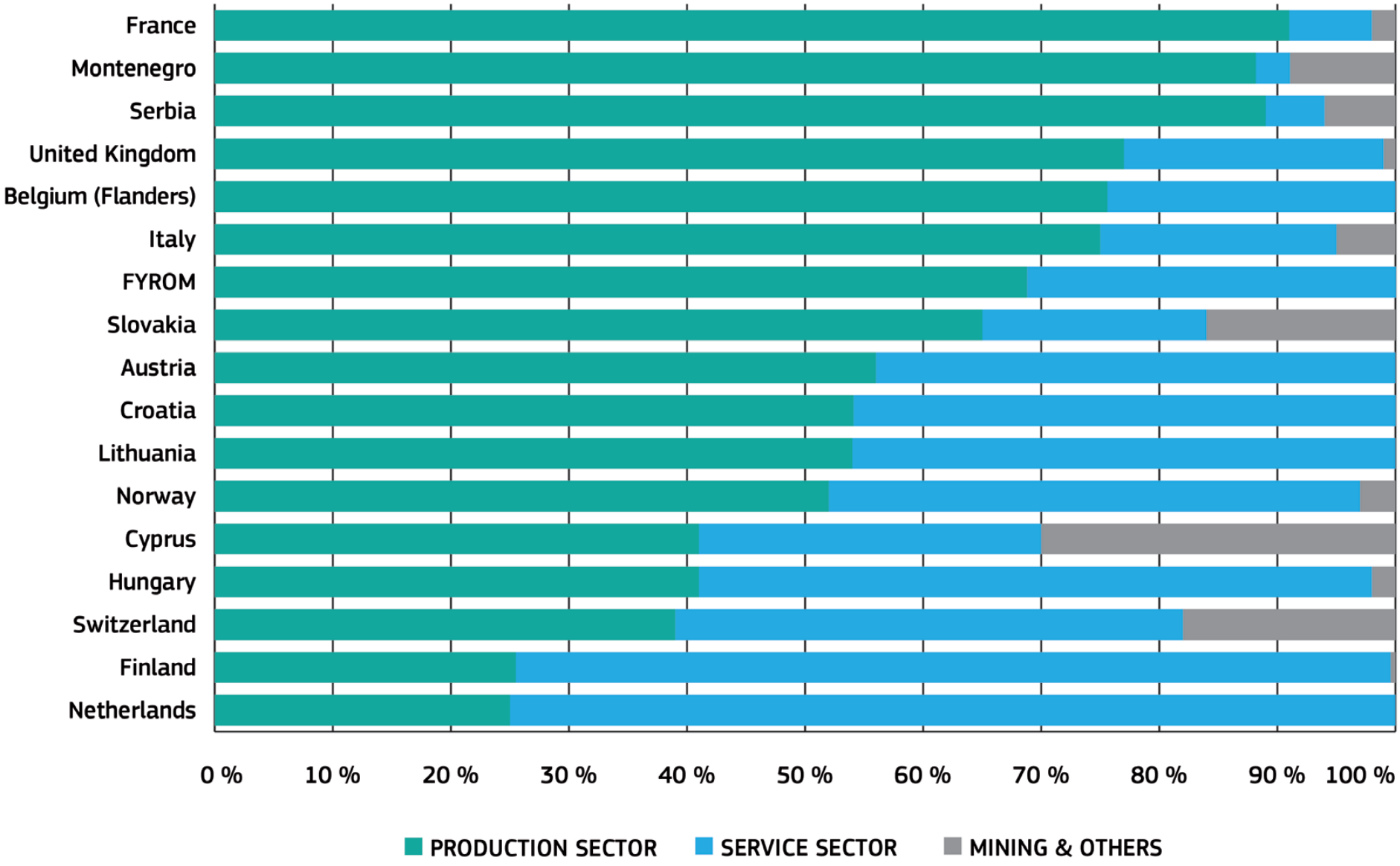
Diffuse pollution include:

- The deposition of particulate pollutants from atmospheric emissions
- Inappropriate use of phytosanitary products (fertilizers and pesticides)
- The application of sewage sludge and/or wastewater to the field
- Deposition of contaminants from soil erosion.

Consecuences of soil pollution

- Surface and groundwater water pollution
- Pollution of river and lake sediments
- Pollution of the atmosphere by evaporation of volatile compounds present in the soil
- Indoor air pollution from dwellings built on contaminated soil
- Use of contaminated water (surface or groundwater) for supply, with the consequent risk to health.
- Ingestion of contaminated soil (health risk)
- Recreational use of contaminated surface water (health risk)
- Effect on the working conditions of construction sites on contaminated land (e.g. excavations)
- Contamination of vegetables and farm animals by the use of contaminated water (health risk)
- Disqualification of land for certain uses

Activities causing soil contamination: overview



European Environment Agency 2014

Soil as pollution receptor

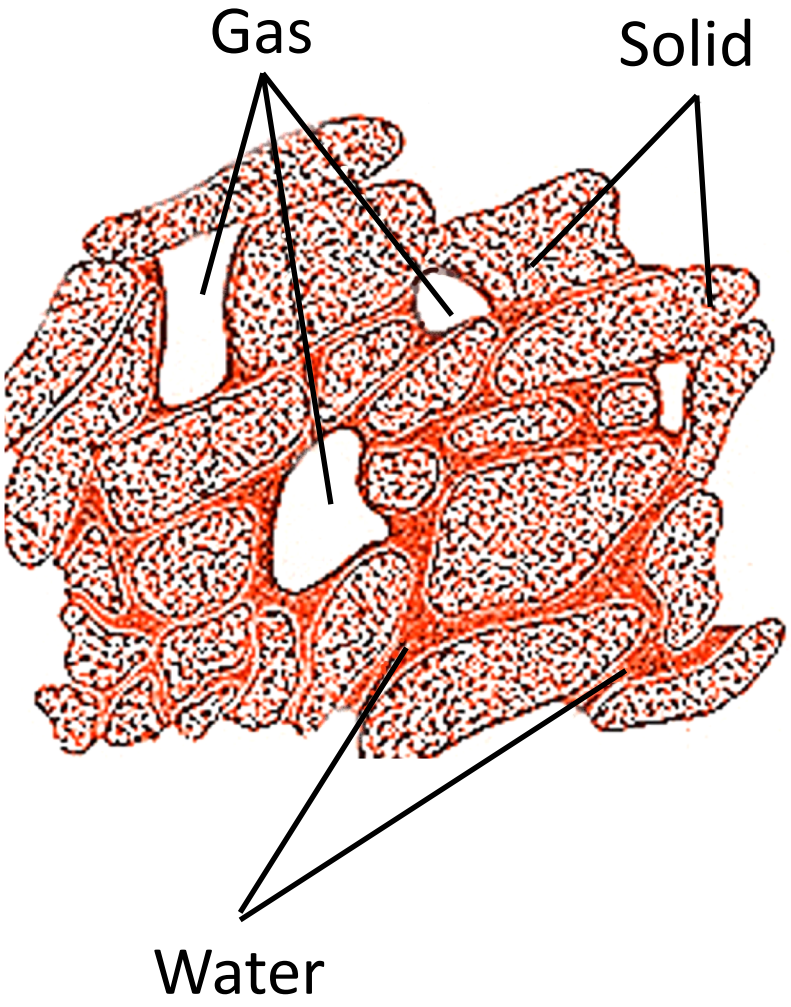
http://static.panoramio.com/photos/large/62868462.jpg

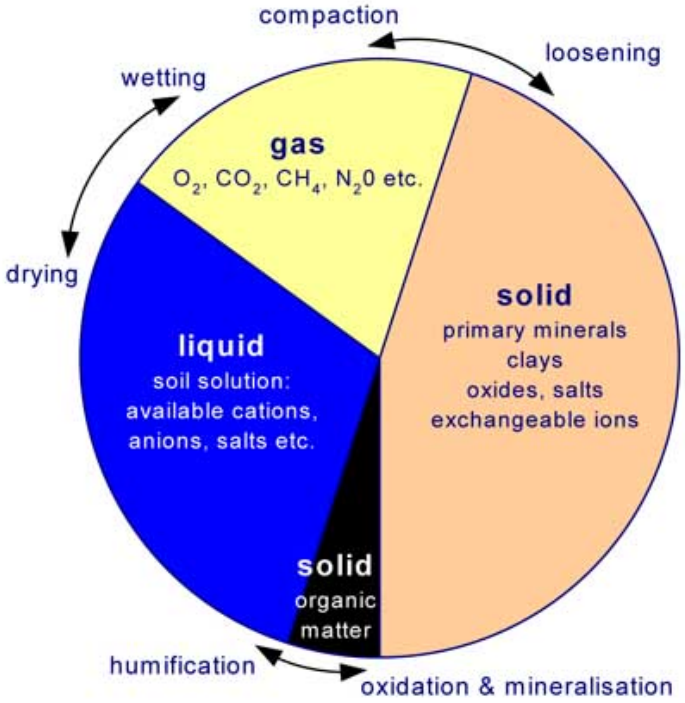
Soil as pollution receptor

- The fate of contaminants in soil depends on:
  - Soil properties
  - Contaminant properties

Soil as pollution receptor

- Soil is a triphase-dynamic system





https://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/soil_health_mis7898_4

Soil as pollution receptor

- Some important soil properties

  - Physical properties
    - Grain size (granulometry, texture)
    - Structure

  - Chemical properties
    - Cation exchange capacity
    - pH
    - Redox potential

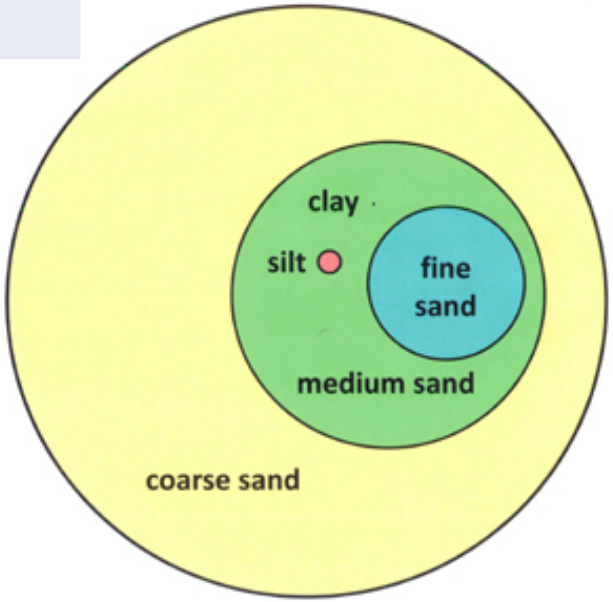
Soil as pollution receptor

- Grain size

Granulometric fraction	USDA (mm)	ISSS (mm)
Gravel	>2	>2
Sand	2-0.05	2-0.02
Silt	0.05-0.002	0.02-0.002
Clay	<0.002	<0.002

USDA: United States Department of Agriculture

ISSS: International Society of Soil Science



Soil as pollution receptor

- Grain size

Importance in properties of soil

Property	Sand	Silt	Clay
Voids size	High	Medium	Low
Total volume of voids	Low	Medium	High
Permeability	High	Medium	Low

Soil as pollution receptor

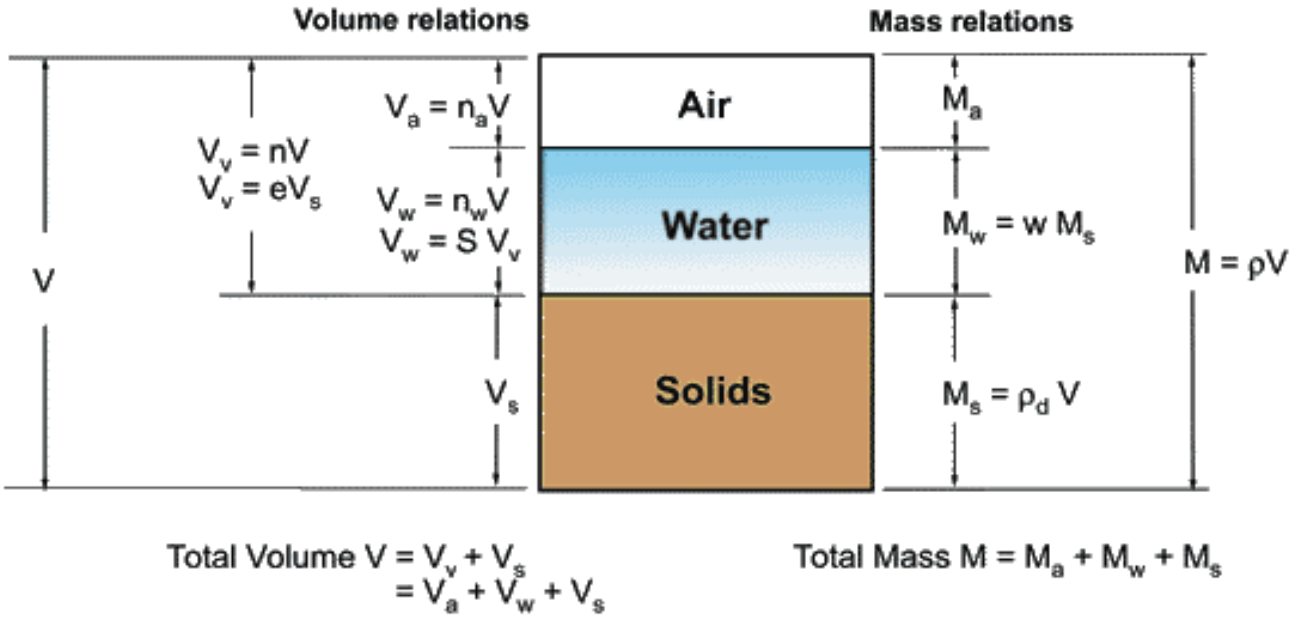
- Grain size

  Importance in soil behaviour

Behaviour	**Sand**	**Silt**	**Clay**
Water-holding capacity	Low	Medium to high	High
Aeration	Good	Medium	Poor
Pollutant retention potential	Low	Medium	High
Pollutant leaching potential	High	Medium	Low

Soil as pollution receptor

- Structure: arrangement of solids and pore spaces



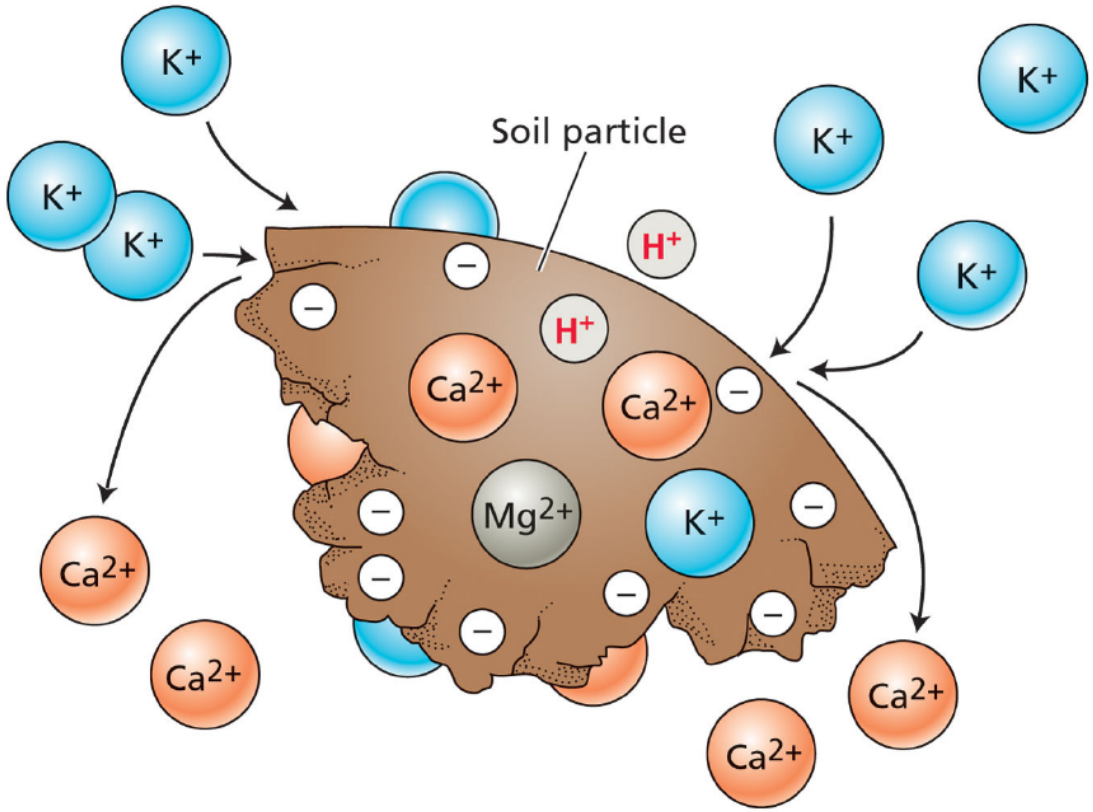
$\rho=\rho_b=$	bulk density
$\rho_d=$	dry density
n=	porosity (n_a: air porosity; n_w: water porosity
e=	void ratio (v: void, open space)
w=	water content (mass humidity)
S=	degree of saturation

Soil as pollution receptor

- Cation exchange capacity

  Definition: maximum quantity of cations that a soil can adsorb

  Important for positively charged pollutans (e.g. heavy metals)



PLANT PHYSIOLOGY, Third Edition, Figure 5.5 © 2002 Sinauer Associates, Inc.

Soil as pollution receptor

- Cation exchange capacity

Material	CEC (cmol/kg)
Sand	1-4
Fe, Al and Mn oxides and hydroxides	4
Clay-kaolin	3-15
Clay-montmorillonite	29-150
Organic matter	130-500

Behaviour (due to CEC)	**Sand**		**Clay**
Pollutant retention potential	Low		High
Pollutant leaching potential	High		Low

Soil as pollution receptor

- pH-acidity
  - Definition: negative logarithm of hydrogen-ion concentration

$$pH = -\log[H^+] = 1/\log[H^+]$$

  - pH<7 (acidic soil); pH> 7 (basic soil)
  - Affects the type of organisms present in soil
  - Strongly affects pollutants mobility
    - In general, CEC increases with an increase in pH
    - Most heavy metals increase their mobility when pH is reduced

      Cadmium, Lead, Mercury, Zinc

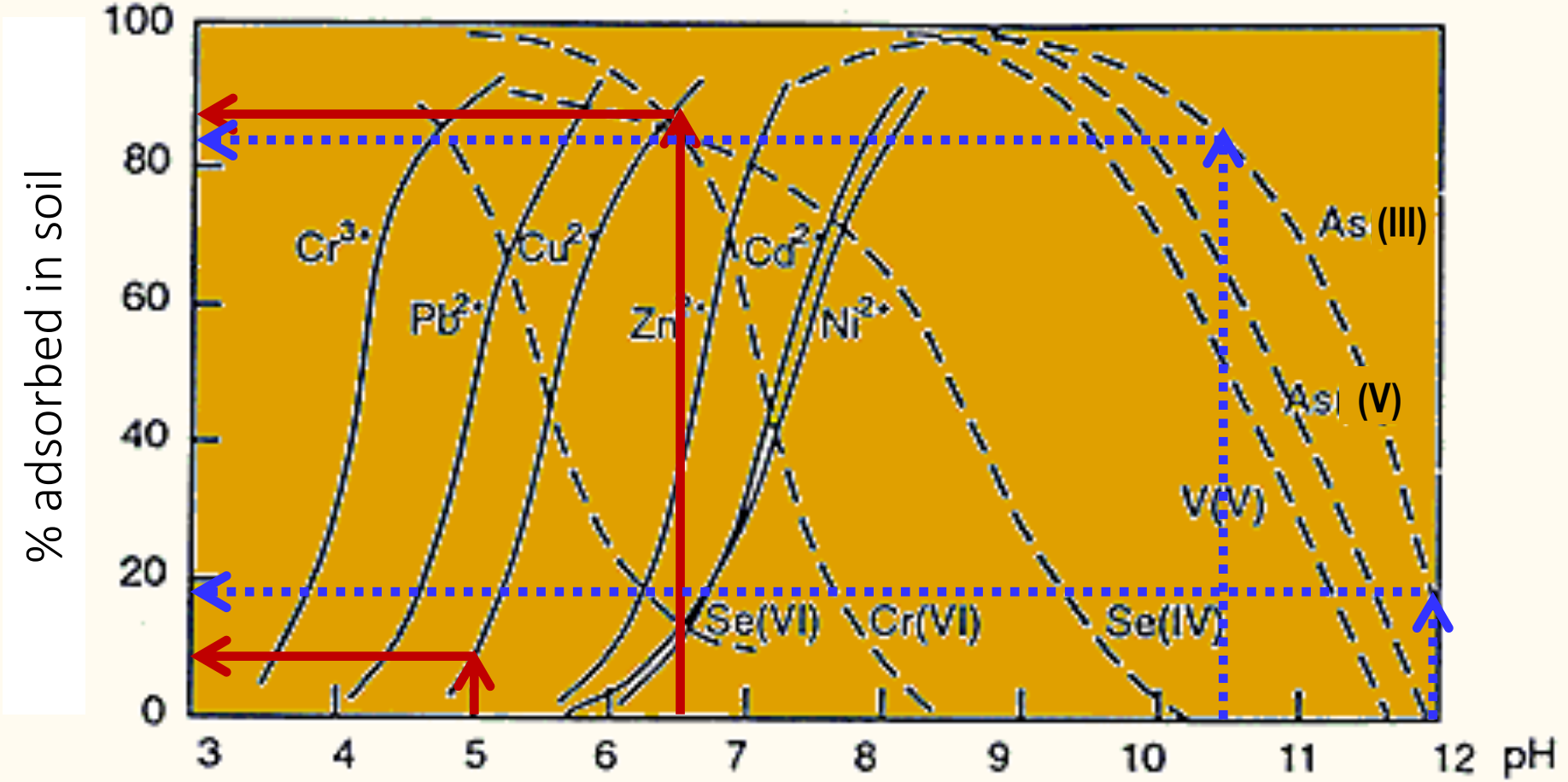
      (Exceptions: Hexavalent chromium, arsenic)

Soil as pollution receptor

For most heavy metals:

if ↓ pH (more acidic soil) => ↑ mobility (more risk)

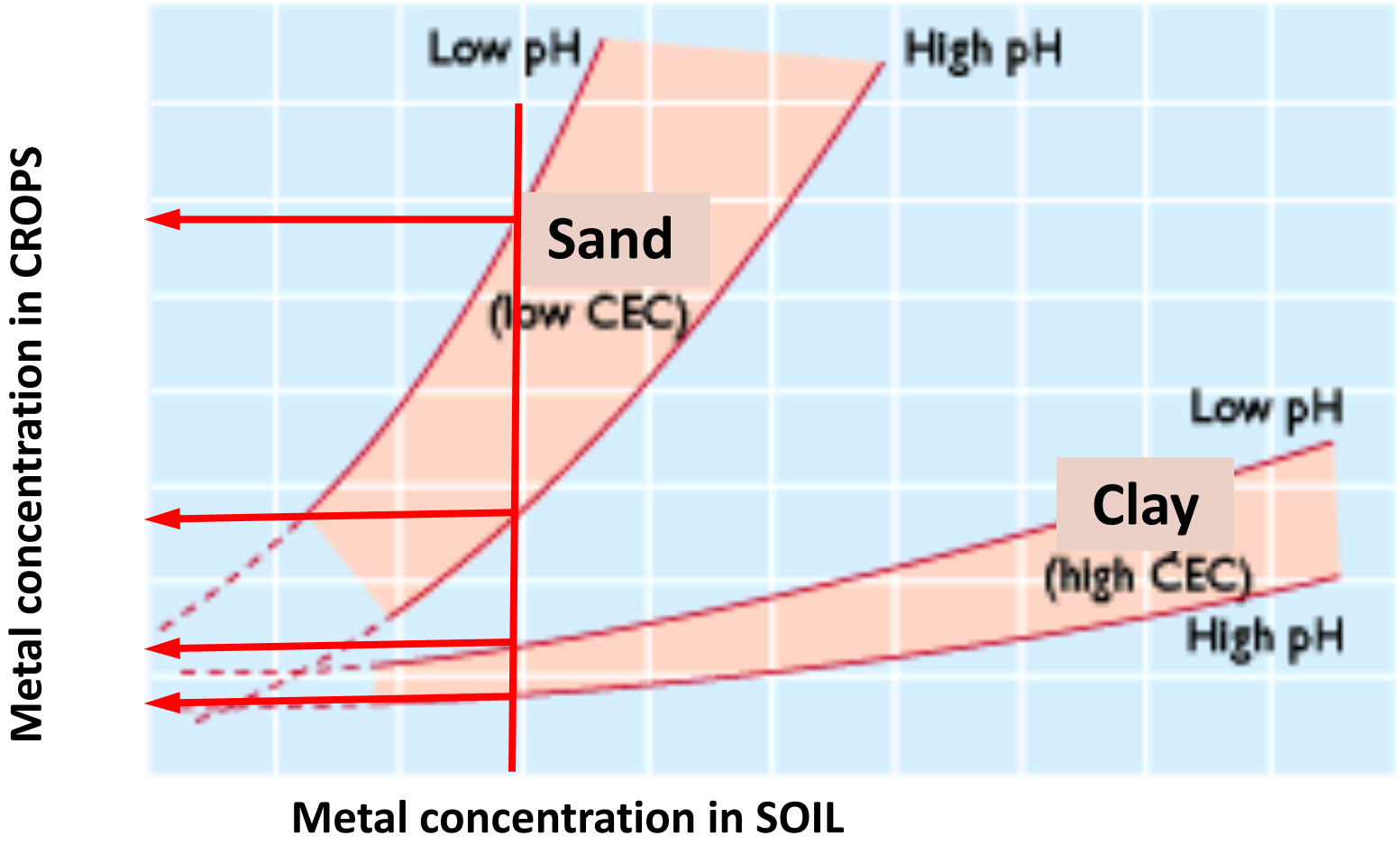
(with exceptions)



http://www.miliarium.com/Proyectos/SuelosContaminados/Anejos/Metales_Pesados7.gif

Soil as pollution receptor

Example: texture + CEC + pH

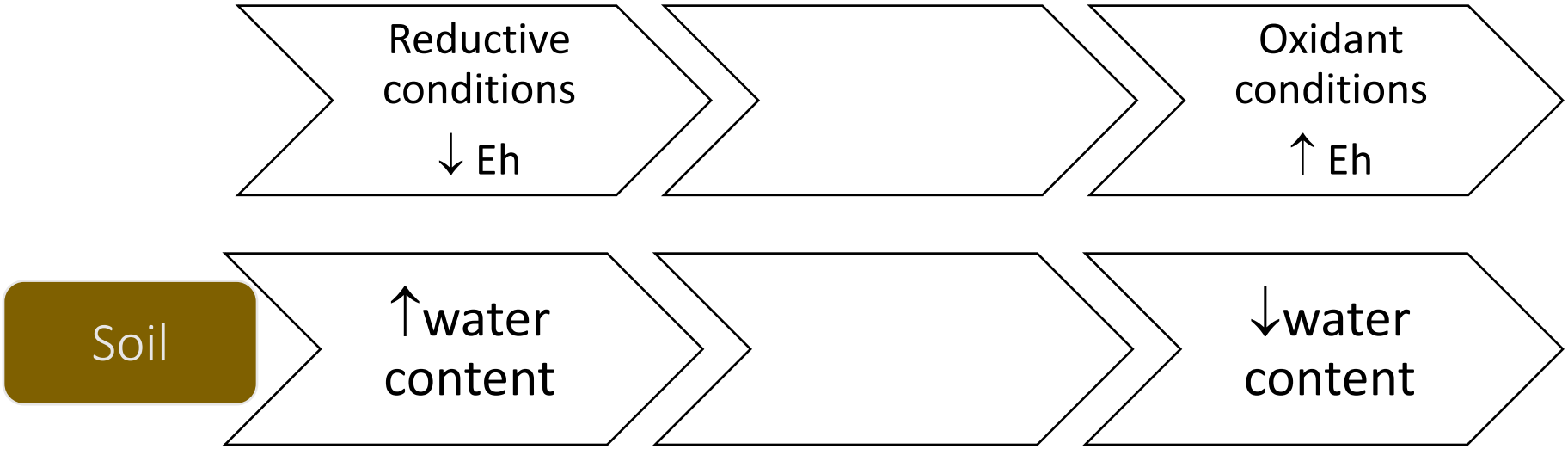


Metal concentration in crops as a function of CEC and pH

Source: Dobris Assessment Report (1995)

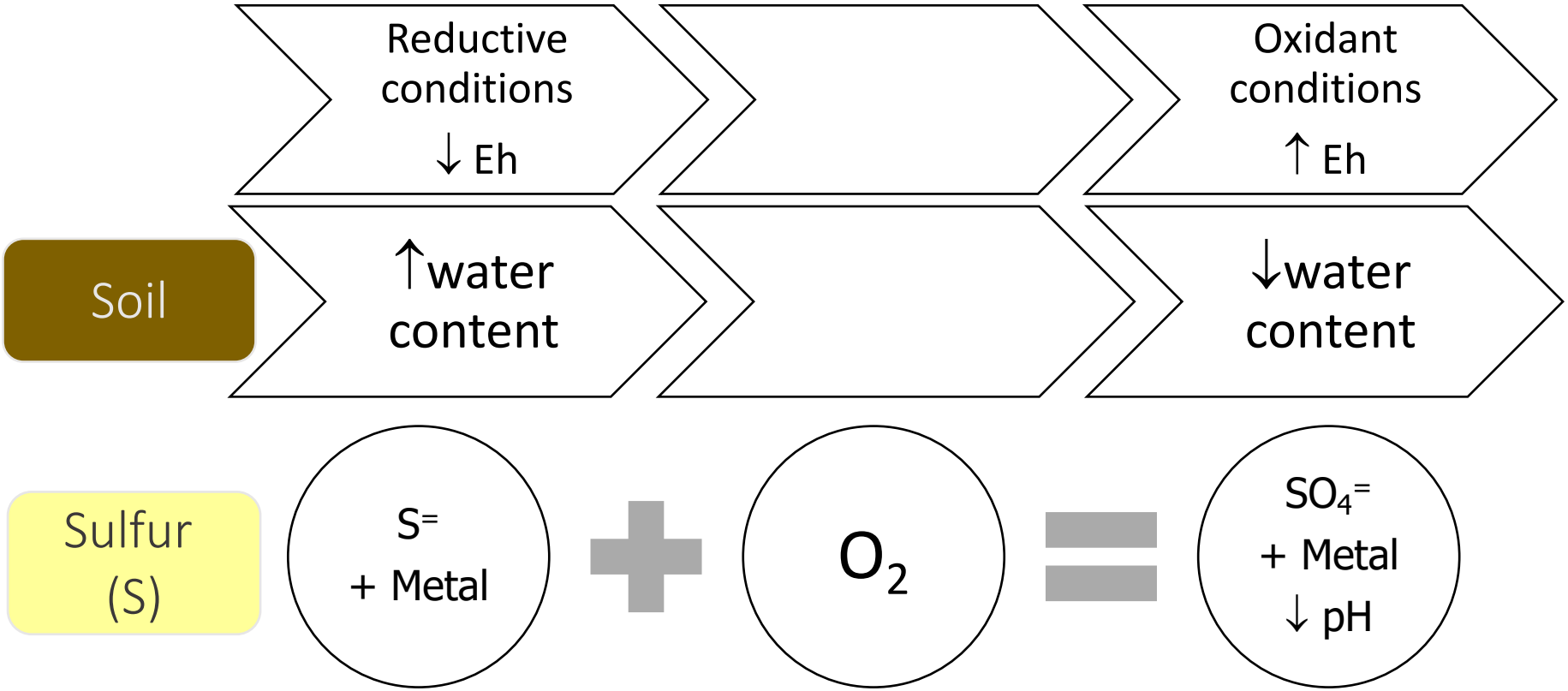
Soil as pollution receptor

- Redox potential Eh
  - Definition: tendency to acquire electrons (be reduced)
  - Oxygen is the main oxidant in soils
  - Eh in soils depends largely on water content



Soil as pollution receptor

- Redox potential Eh



Sulfides (≈ Insoluble)

FeS, FeS_2

CdS

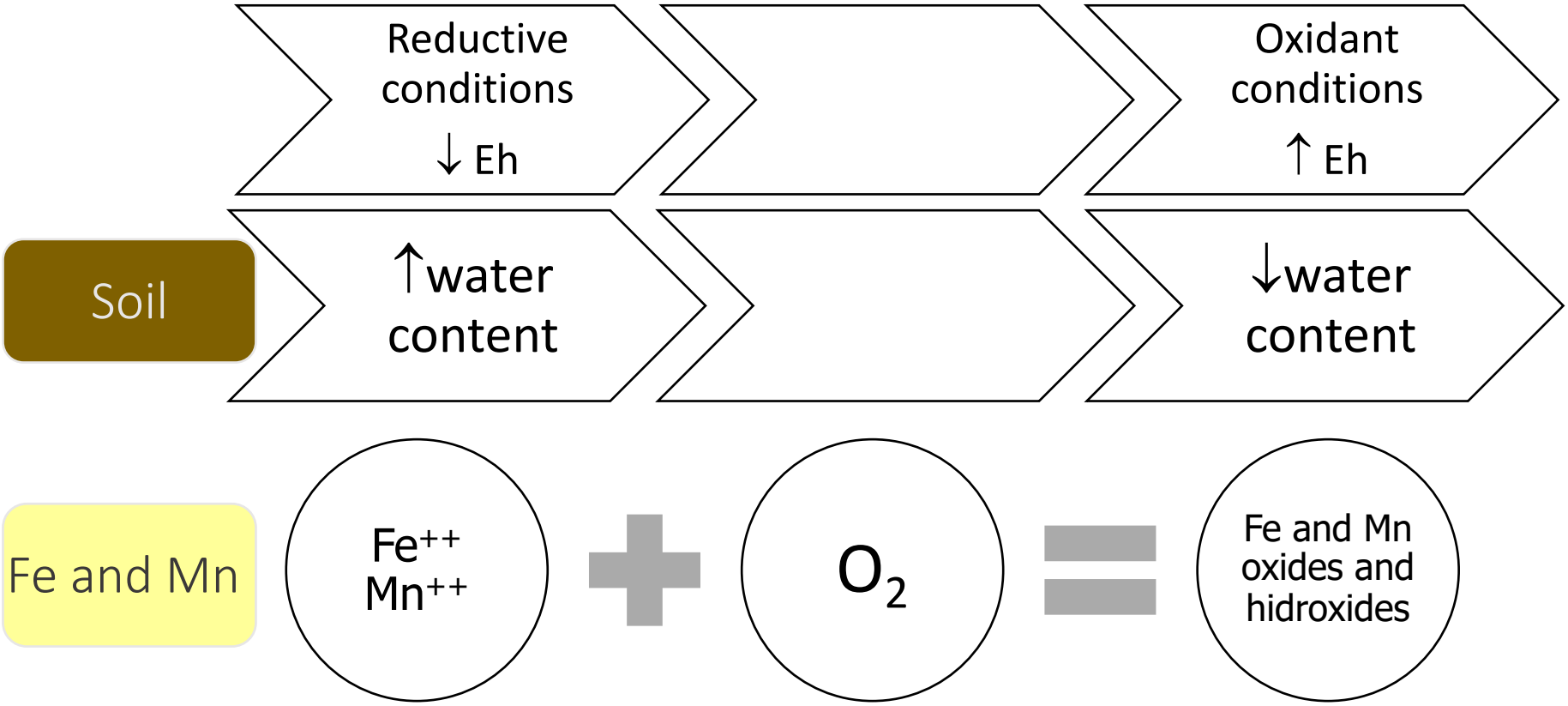
Sulfates (≈ Soluble)

$FeSO_4 + H^+$

$CdSO_4 + H^+$

Soil as pollution receptor

- Redox potential Eh

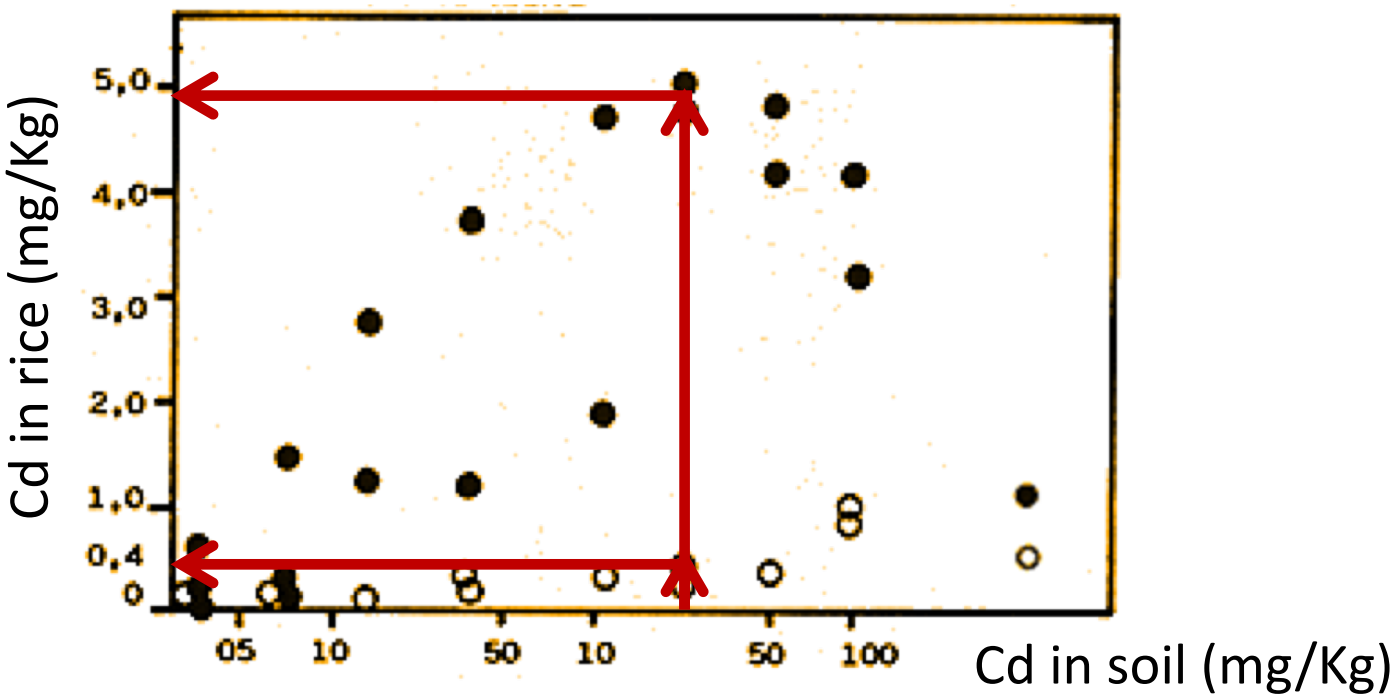


Cannot adsorb Metals

Can adsorb Metals

Example: itai-itai disease

Soil as pollution receptor (Eh)



- ● With drainage
- ○ Submerged during the whole growing period

Example: itai-itai disease (cadmium poisoning due to aeration of soil, transforming Cd sulfides into Cd sulfates)

SOIL AS POLLUTION RECEPTOR

- Behaviour depends on:
  - Physical properties:
    - Texture (sand, silt, clay)
    - Structure (porosity, water content...)
  - Chemical properties
    - Cation Exchange capacity (CEC) (higher for clays and organic matter)
    - pH (in most cases, lower pH => higher mobility)
    - Redox potential (Eh)
      - More w, lower Eh
      - Low Eh => sulfides (insoluble); Fe++ and Mg++ (can't adsorb)
      - High Eh => sulfates (soluble); Fe and Mg hidroxydes (can adsorb)

The soil pollutants

Types

Organics

Inorganics

The soil pollutants

Types

- ORGANIC
  - Alkanes:

    e.g.: gasoline, fuel oil and some solvents
  - Aromatic hydrocarbons:

    e.g.: benzene
  - Chlorinated hydrocarbons:

    e.g.: PCBs: Polychlorinated Biphenyls
  - Polycyclic aromatic hydrocarbons (PAHs)
  - Pesticides: variety (organochlorines, organophosphates ...).

The soil pollutants

Types

- ORGANIC
  - TPH: Total petroleum hydrocarbons

    All the hydrocarbons based ond petroleum
  - CHC: Chlorinated hydrocarbons
  - VOCs: Volatile Organic Compounds.
  - SVOCs : Semivolatile Organic Compounds
  - BTEX: Benzene, toluene, ethyl benzene and xylens

The soil pollutants

Types

- INORGANIC
  - Heavy metals: (As, Ba, Cd, Co, Cu, Cr, Hg, Mo, Ni, Pb, Zn)
  - Cyanides

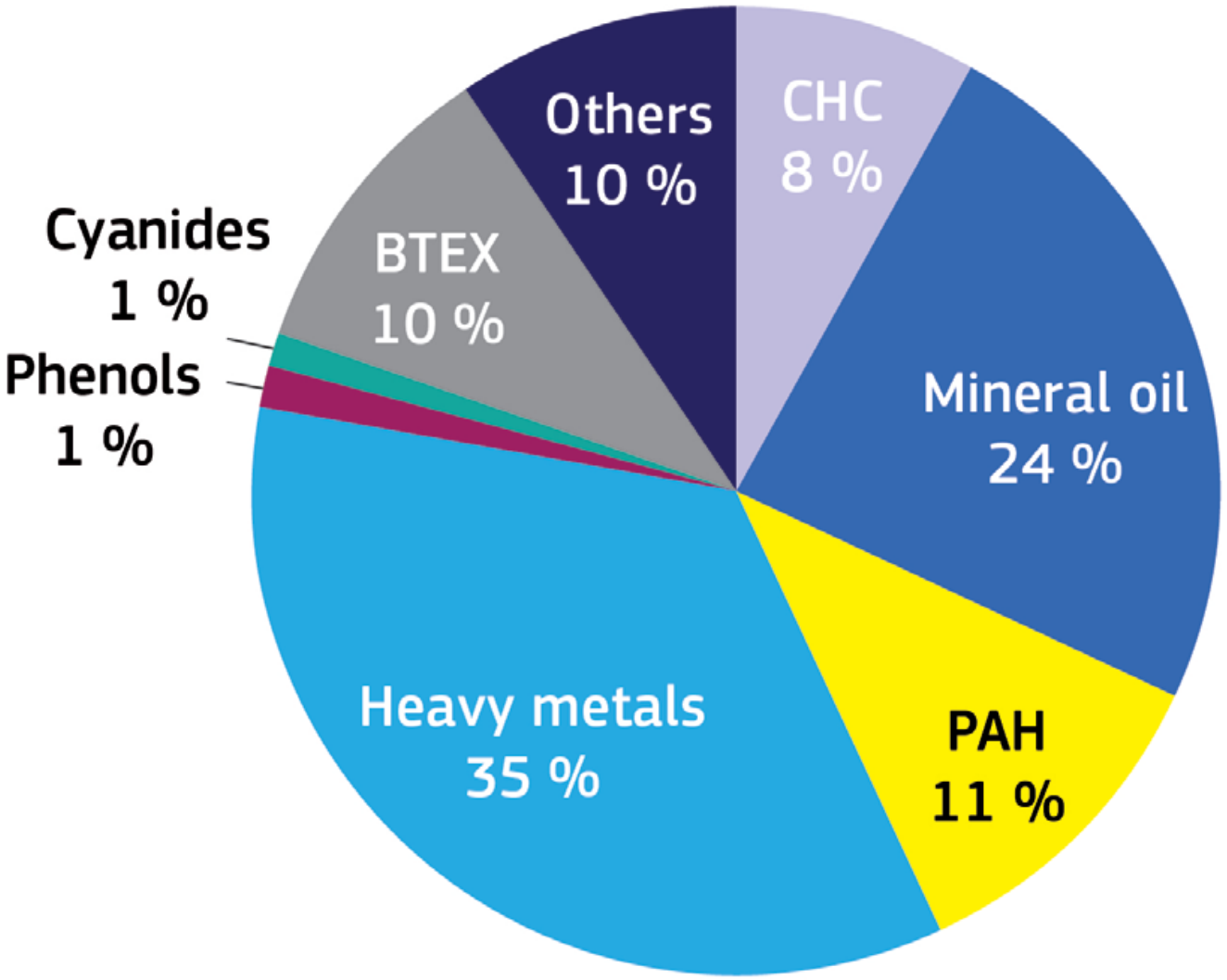
The soil pollutants
Types (summary)

Organic	***Alkanes*** – Alkanes are most components of petroleum products, such as gasoline, fuel oil, and some solvents. – They consist of carbon and hydrogen atoms. As the number of carbons increases, solubility and volatility decrease, and density increases. – Easily oxidized.
	Aromatic hydrocarbons – They include Benzene, Toluene, Ethyl Benzene, Xylenes (BTEX), Phenols and Cresols. – Based on a ring of 6 carbon atoms. – In general, they have low solubility and high volatility.
	Chlorinated hydrocarbons – High volatility and relatively low solubility – They include PCBs: Polychlorinated biphenyls
	Polycyclic aromatic hydrocarbons (PAHs) – They consist of the union of several aromatic rings – In general, low volatility, solubility and reactivity (lower the greater the number of rings)
	Pesticides – Great variety (organochlorines, organophosphates...) – In general, low volatility and low solubility.
Inorganic	The most common inorganic pollutants are **heavy metals** (As, Ba, Cd, Co, Cu, Cr, Hg, Mo, Ni, Pb, Zn) and **cyanides**.

TPH: Total Petroleum Hydrocarbons. A measure of the amount of petroleum-based hydrocarbons in a given medium.
VOCs (VOCs): Volatile Organic Compounds. Ex: aromatic hydrocarbons, chlorinated hydrocarbons and ketones.
SVOCs (COSVs): Semivolatile organic compounds. Ex: PAHs

The soil pollutants

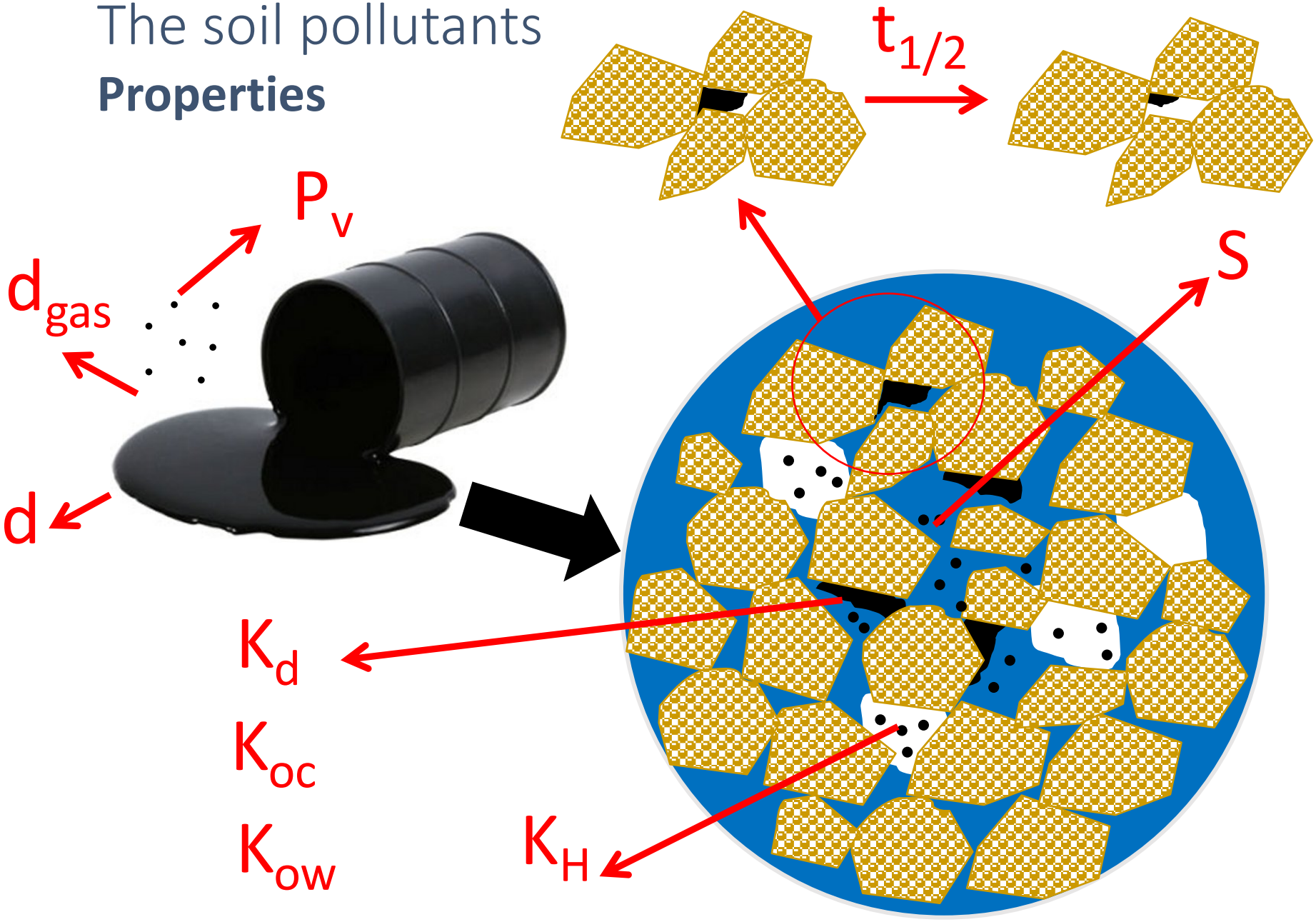
Types



EEA, 2014

The soil pollutants

Properties



The soil pollutants

Properties

- **Solubility**

Definition: Ability to mix with water. Maximum amount of pollutant that can be dissolved in water.

Parameter: Solubility (**S**) (mg/L) at 25 ºC.

E.g. Benzene S=1750 mg/L
Pyrene S=0.132 mg/L

↑ **S** : Increased solubilization
Increased potential for surface runoff
Increased leaching potential
May facilitate biodegradation

The soil pollutants

Properties

- Volatility

Definition: Tendency of a pollutant to pass into the vapor state

Parameters: **Pv** (Vapor pressure) (pure substance);

K_H (Henry's constant) (dissolved substance)

$\uparrow$ **Pv,** $\uparrow$ $K_H \Rightarrow \uparrow$ Volatility

$$K_H = C_G / C_A$$

C_G = pollutant concentration in gas phase

C_A = pollutant concentration dissolved in aqueous phase

E.g. Benzene K_H= 5.59 E-03 atm-m^3/mol

Pyrene K_H= 1.32 E-06 atm-m^3/mol

The soil pollutants
Properties

- Tendency to sorb to solids

Definition: Atraction by a solid surface. Depends on:

- the pollutant
- the solid properties
- the liquid medium (in general, water)

Parameters: K_{ow}: octanol-water partition coefficient

K_{oc}: partitioning coefficient onto organic carbon

K_d: soil distribution (or partitioning) coefficient

$\uparrow K_{ow} \uparrow K_{oc} \uparrow K_d \Rightarrow \uparrow$ Adsorption

The soil pollutants
Properties

- **Octanol-water partitioning coefficient**

Measures pollutant hydrophobicity (low solubility)

$$K_{ow} = C_{octanol}/C_A$$

K_{ow} = Octanol-water partitioning coefficient. (-)
$C_{octanol}$ = Pollutant concentation in octanol (mg/L)
C_A = Pollutant concentation in aqueous phase (mg/L)

E.g. Benzene log K_{ow}= 2.12 K_{ow}= 132
Pyrene log K_{ow}= 4.88 K_{ow}= 75858

BCF = Concentration in organisms / Concentration in the environment

↑ **Kow** => in general, ↑ Bioconcentration Factor (BCF)

potentially ↑ K_{oc} ↑K_d ↓S ↓K_H

The soil pollutants
Properties

- Partitioning coefficient onto organic carbon

$$K_{oc} = C_{oc} / C_A$$

K_{oc}= partitioning coefficient onto organic carbon (mL/g)
C_{oc} = mass of pollutant adsorbed in the soil organic carbon (mg/g)
C_A = pollutant concentration dissolved in aquaeous phase (mg/mL)

Ej. Benzene K_{oc}= 83 mL/g
Pyrene K_{oc}= 38000 mL/g

If organic carbon is responsable for most of the soil adsorption, then:

$$K_d = K_{oc} \cdot f_{oc}$$

f_{oc} = organic carbon fraction in soil (0-1)

↑ **Koc** : ↑ adsorption potential on soil organic matter

in general, ↓S ↓Kh ↑Kow ↑Kd

The soil pollutants
Properties

- **Soil distribution coefficient**

Describes how the contaminant is distributed between the adsorbed and dissolved phase.

$$K_d = C_S / C_A$$

K_d = soil distribution coefficient (mL/g)

C_S = mass of pollutant adsorbed per unit of dry soil matter (mg/g)

C_A = pollutant concentration dissolved in aqueous phase (mg/mL)

↑ **Kd** : higuer adsorption potential on soil
in general, ↓S y ↓Kh

The soil pollutants
Properties

- Chemical half-life

Definition: the amount of time required for a quantity to fall to half its value as measured at the beginning of the time period.

It can refer to any type of reaction (volatilization, photolysis, hydrolysis, biodegradation…)

Importance: gives an idea of pollution persistence in the environment

Parameter: $t_{½}$ (days)

The soil pollutants

Properties

- Density

Definition: Ratio of mass to volume of a compound

Importance: It will indicate the level (in elevation, not concentration) at which an insoluble residue will be balanced.

Units: liquid (g/ml or kg/m^3); solids (g/cm^3); gas (g/l o mg/m^3)

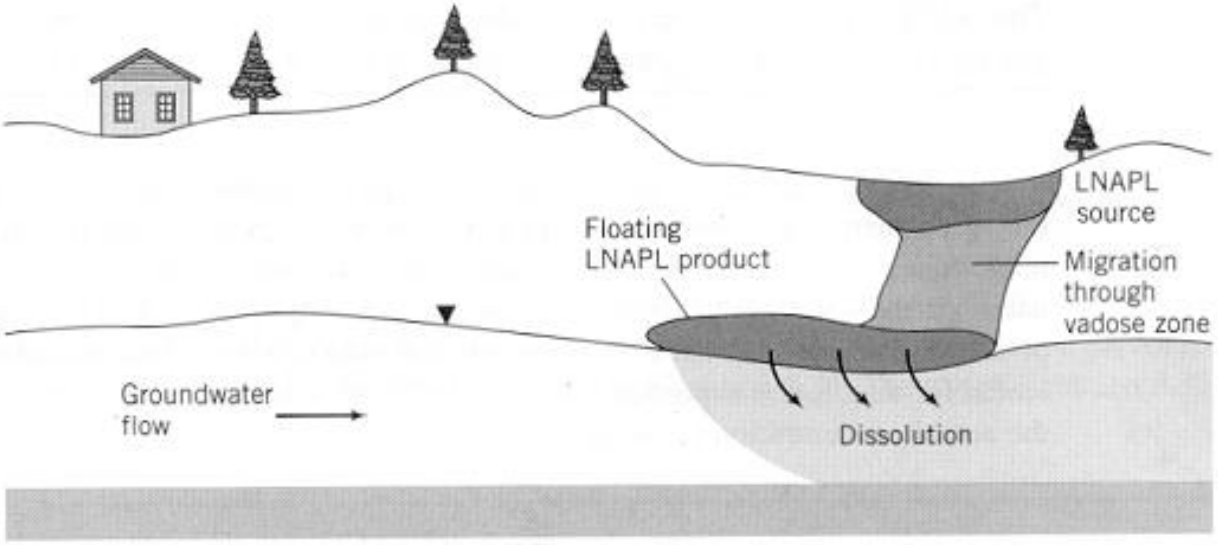
Relative density = compound density / water density at 4°C (1.0 g/mL)

Relative vapor density = vapor phase compound density / air density

The soil pollutants

Properties

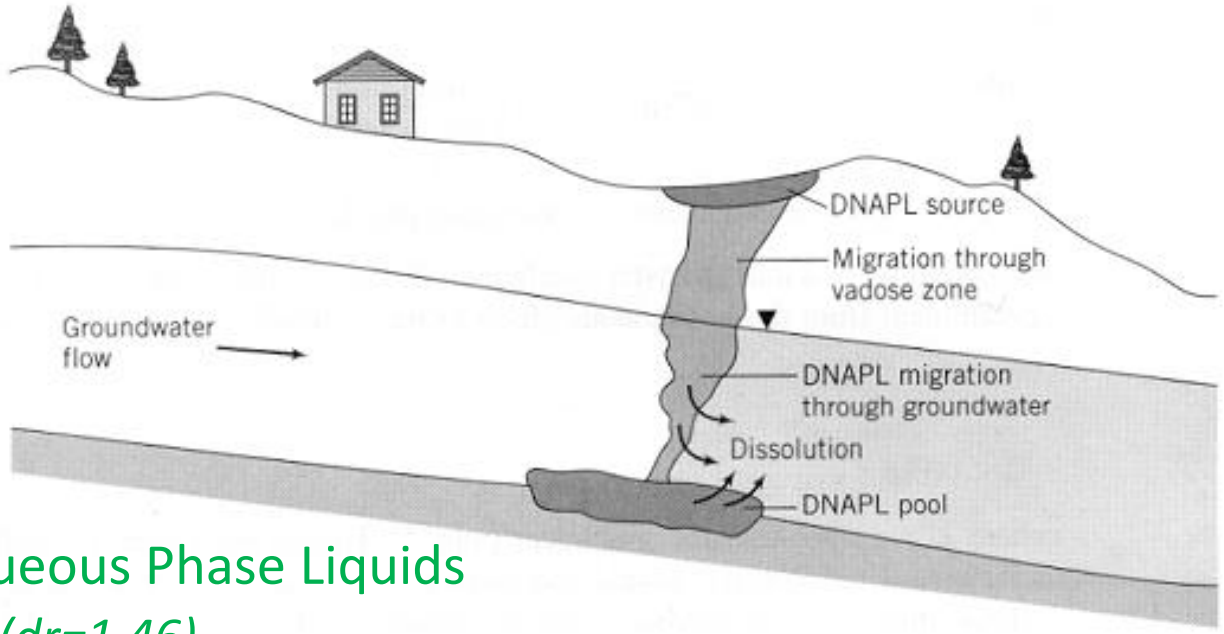
- Density



(a) LNAPL migration

LNAPL: Light Non Aqueous Phase Liquids

e.g. gasoline (dr=0.71)



(b) DNAPL migration

DNAPL: Dense Non Aqueous Phase Liquids

e.g. trichloroethylene (dr=1,46)

The soil pollutants (**organics**): fate in soils

Property	Range of parameters		
Solubility in water S (mg/L)	< 10	10-1 000	> 1 000
Octanol-water K_{ow}	>1 000	500-1 000	<500
Partition onto organic carbon K_{oc} (mL/g)	>10 000	1 000-10 000	<1 000
Hydrolysis $t_{½}$ (days)	> 90	30-90	<30
Photolysis $t_{½}$ (days)	> 90	30-90	<30
Volatility K_H (atm· m^3/mol)	$<10^{-7}$	10^{-7}-10^{-3}	$>10^{-3}$
Fate and transport of organic pollutant			
Solubilization	Negligible	Variable	Yes
Hydrolysis	Negligible	Variable	Yes
Photolysis	Negligible	Variable	Yes
Volatilization	Negligible	Variable	Yes
Sorption potential	High	Intermediate	Low
Persistence potential	High	Intermediate	Low
Leaching potential	Low	Intermediate	High
Surface runoff potential	Low	Intermediate	High
Bioaccumulation	Yes	Variable	Negligible
Biodegradation	Slow	Intermediate	Yes

THE SOIL POLLUTANTS

- Types:
  - Organic (heavy metals, cyanides)
  - Inorganic (hydrocarbons, pesticides)
- Processes in soil: depend on soil and pollutant properties
- Pollutants properties
  - Solubility (S)
  - Volatility (Pv, Kh)
  - Sorption:
    - Kd (Cs/Ca)
    - Koc (Coc/Ca)
    - Kow (Coct/Ca); ↑Kow → ↑BCF
  - Density (LNAPL floats, DNAPL sinks)
  - Half-life ($t_{1/2}$)

INDEX

http://mec-s1-p.mlstatic.com/soluciones-servicio-de-impresion-laser-11326-MEC20043116807_022014-F.jpg

SOLUTIONS

INDEX

SOLUTIONS: legislation

Legal framework in Spain

- ROYAL DECREE 9/2005 of 14 January which establishes a list of potentially soil contaminating activities and criteria and standards for declaring that sites are contaminated.

- LAW 7/2022 on waste and contaminated soils for a circular economy

- Others

Legal framework in Spain

- Definition of “contaminated soil”

soil whose characteristics have been:

- negatively altered
- by the presence of man-made chemical components
  - of a hazardous nature
  - in concentrations that imply an unacceptable risk for human health or the environment,

and that have been declared contaminated by express decision.

LAW 7/2022 on waste and contaminated soils for a circular economy

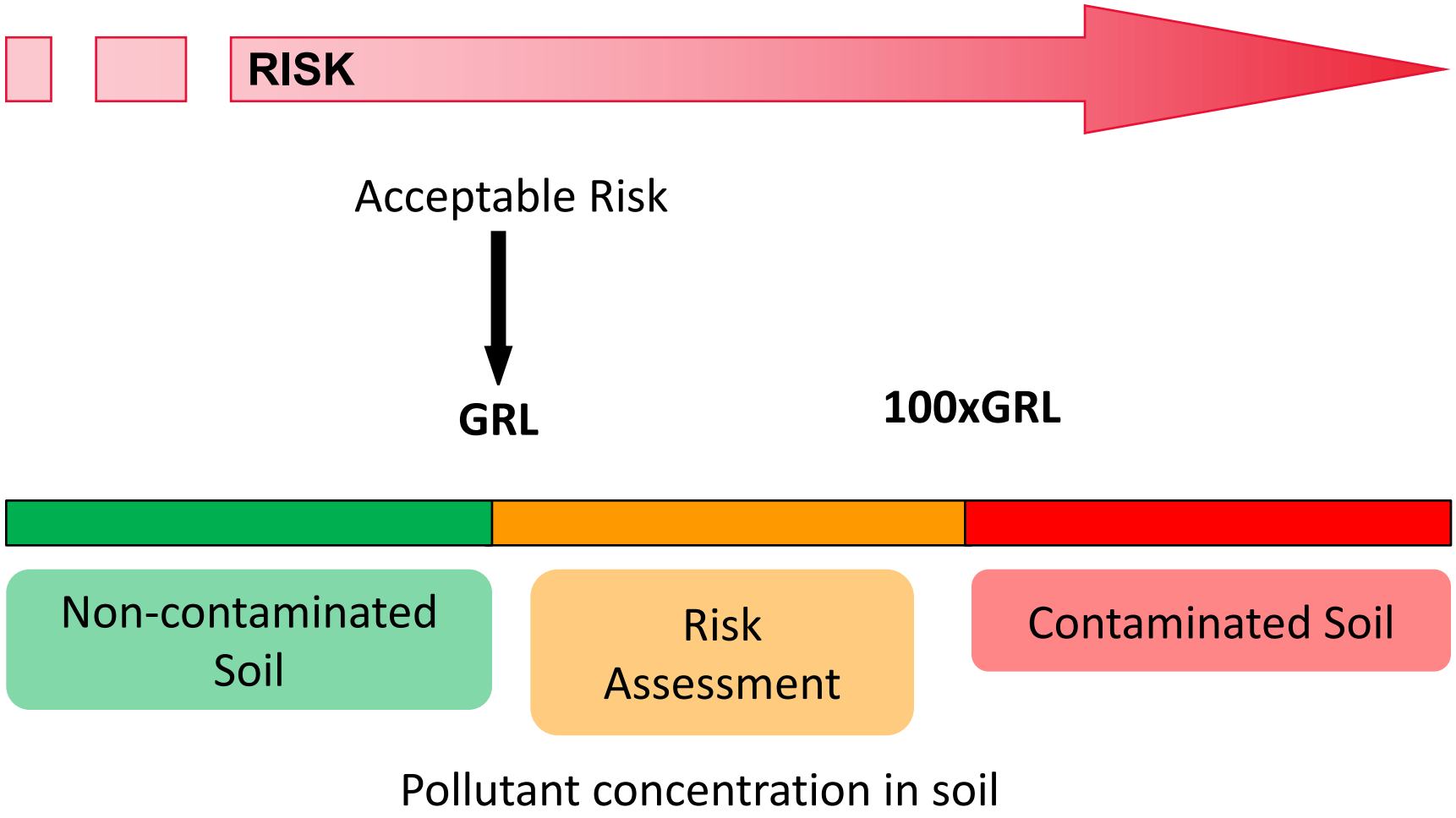
Legal framework in Spain

- Important statements
  - When a site is declared contaminated, this shall establish an obligation to carry out the actions necessary for its environmental remediation […].
  - The owners of potentially contaminating activities shall be obliged to submit regular situation reports to the competent body.
  - Generic reference level (GRL): the concentration of a contaminant in soil that does not result in a level of risk higher than the acceptable maximum for human health or ecosystems

Legal framework in Spain

- Generic Reference Level (GRL)

  Depends on substance and land use



Legal framework in Spain

- Generic Reference Level

ANNEX V

List of contaminants and generic reference levels for the protection of human health based on land use

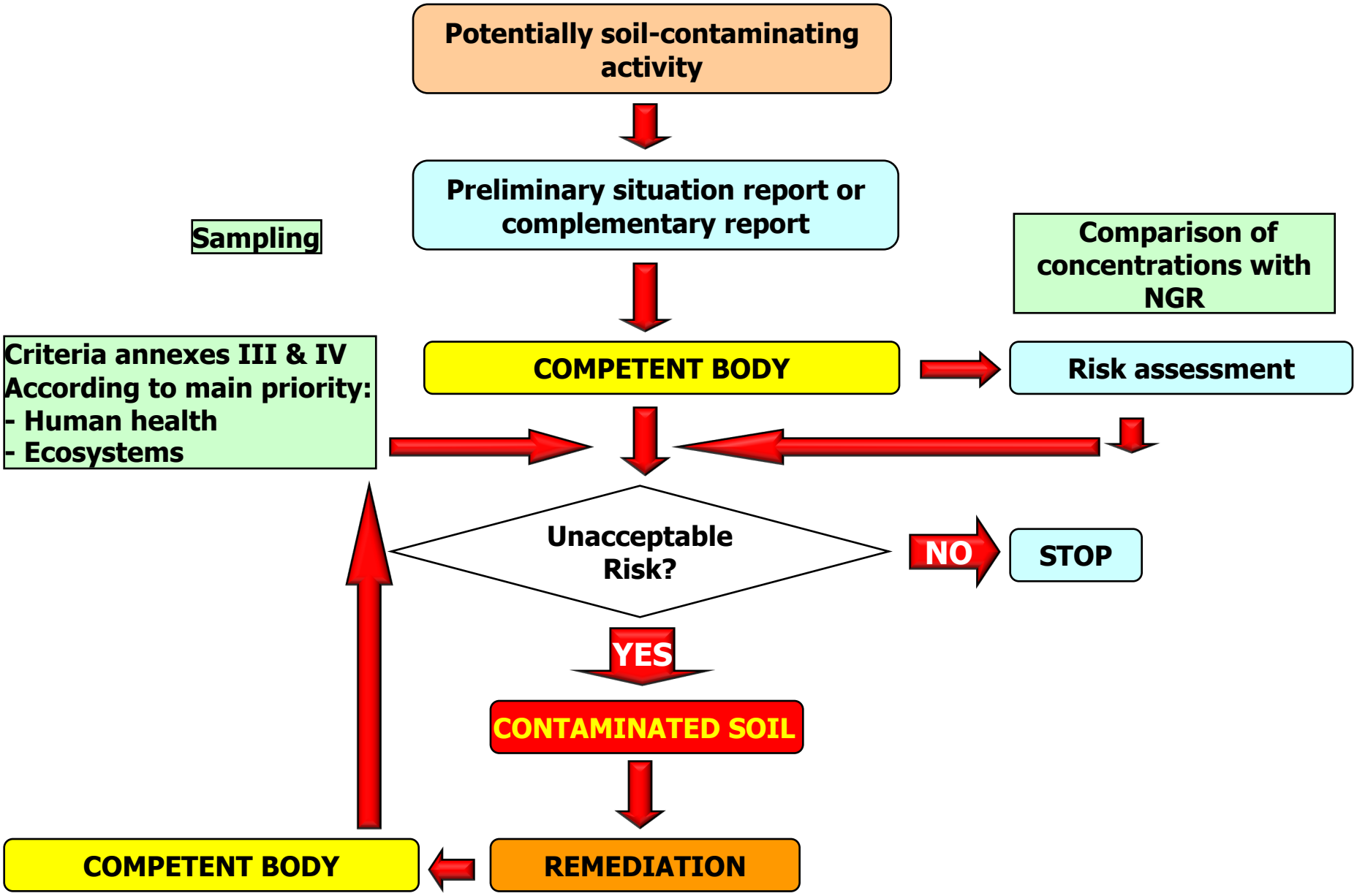
Protection of human health

Substance	CAS number	Industrial use	Urban use	Other uses
		(mg/kg dry weight)		
Benz[a]anthracene	56-55-3	20***	2***	0.2
Dibenz[a,h]anthracene	53-70-3	3***	0.3***	0.03
Benzene	71-43-2	10***	1***	0.1
Chlorobenzene	108-90-7	35	10***	1
1,2-Dichlorobenzene	95-50-1	100**	70**	7
1.4-Dichlorobenzene	106-46-7	40***	4***	0.4
1,2,4-Trichlorobenzene	120-82-1	90***	9***	0.9
p-Chloroaniline	106-47-8	30***	3***	0.3

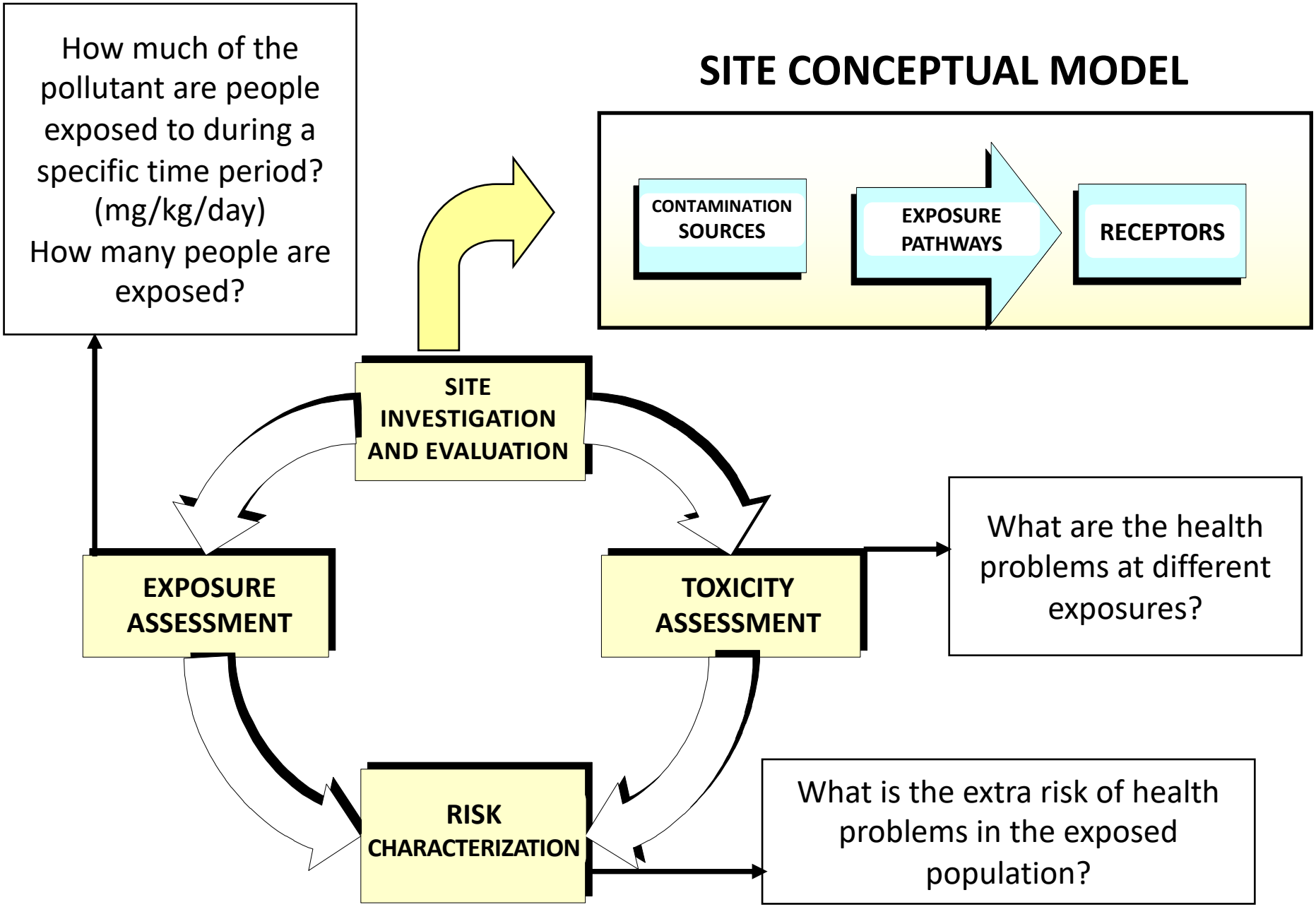
INDEX

SOLUTIONS: polluted soil management

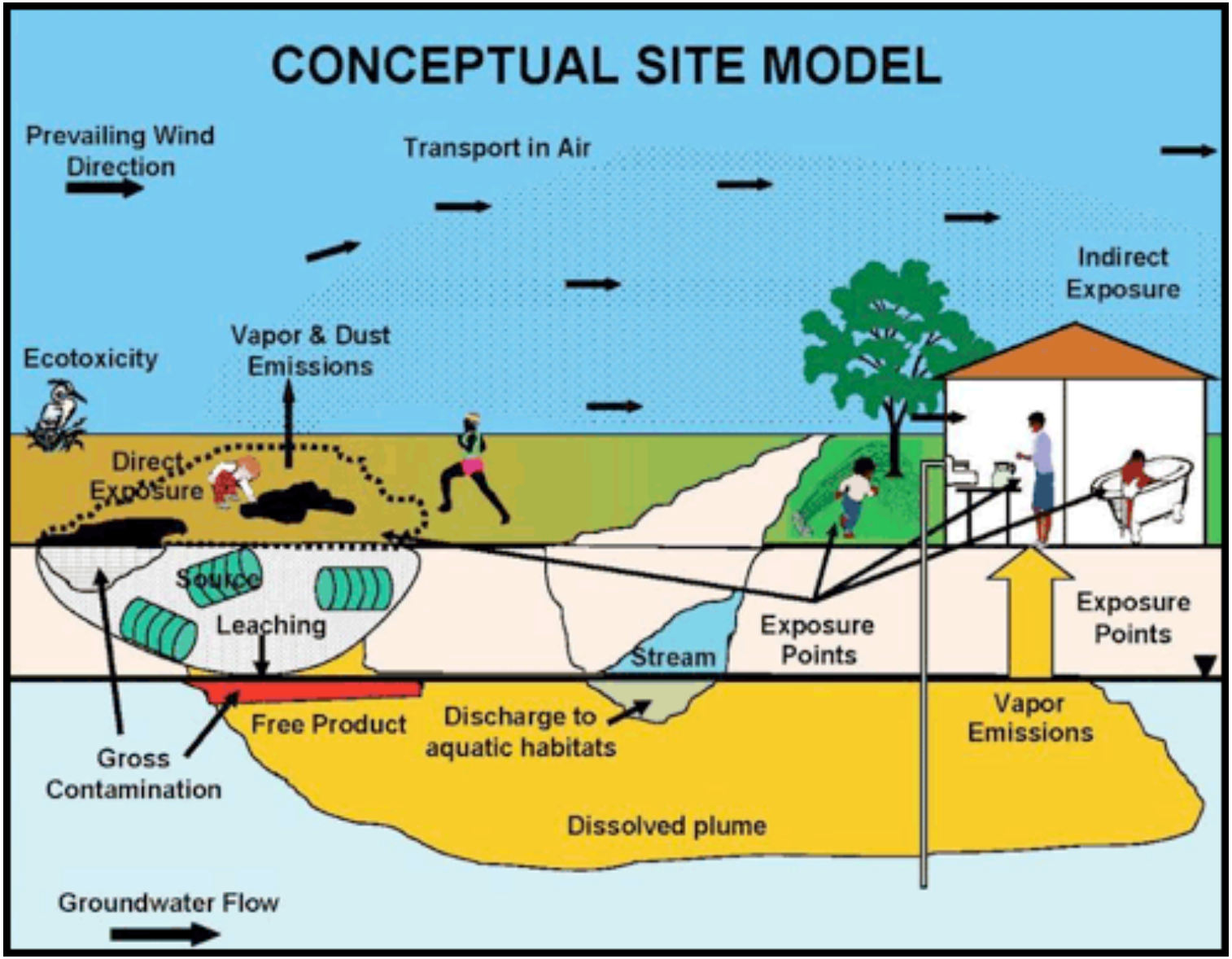
Legal framework in Spain: soil management process



Risk Assessment process



Conceptual site model_Example



http://www.itrcweb.org/ism-1/images/Figure_3_1.png

SOLUTIONS:
Site investigation

http://www.globalgreengroup.eu/wp-content/uploads/2016/05/83.jpg

Site investigation

- Research steps

Preliminary site investigation	Desktop study: site story, topography, hydrology, geology, hydrogeology, ...
Preliminary site inspection	Site walkover survey: visible signs of contamination, stockpiled material, wastes, former buildings,...
Detailed site investigation	Field investigation: soil sampling
Supplementary site investigation	Additional information. Example: establish if certain remediation technology is an appropriate method
Site validation investigation	Remediation validation investigation: after completing remediation.

Site investigation

- Soil sampling
  - Solid samples: boreholes (manual or mechanical) and trenchs
  - Liquid samples: by manual systems or by pumping systems.
  - Gaseous samples: gas collection in suitable devices
  - Other samples: microorganisms, flora and fauna.
- In situ measurements
  - Portable devices (X-ray fluorescence, gas chromatography, etc.)

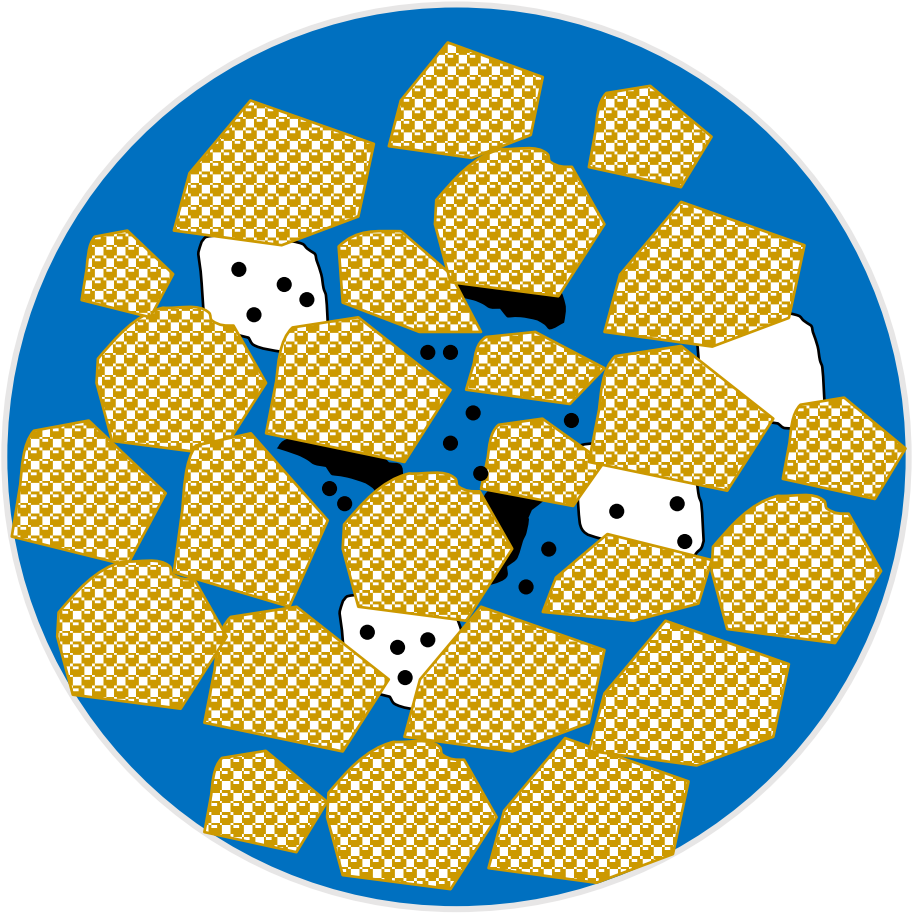
INDEX

SOLUTIONS: remediation

http://dec.alaska.gov/spar/csp/images/ksalmon/ksbiocell3f.jpg

Contaminated soil remediation

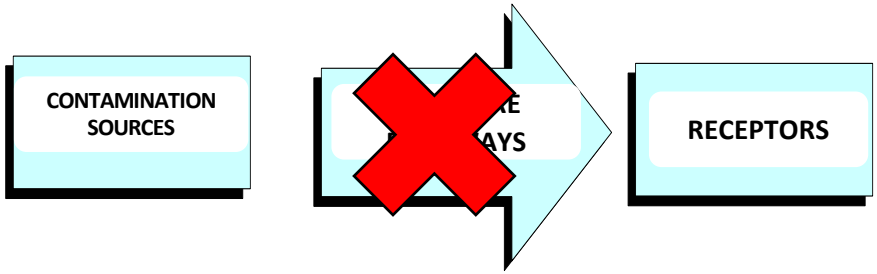
- Remediation of soil, water and gas



Contaminated soil remediation strategies

- Access restriction

- Containment or confinement (isolation or inmovilization)



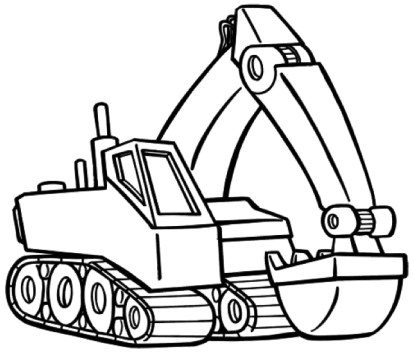
- Eliminate sources and reduce contamination (treatment)

Contaminated soil remediation

- Techniques
  - *In situ:* no excavation of the soil
  - *Ex situ:* excavation of the soil
    - On-site: the soil is excavated but treated in the site.

      NO TRANSPORT
    - Off-site: the soil is excavated and transported to a remote site for cleaning

      TRANSPORT



Contaminated soil remediation

- Techniques
  - Containment techniques
    - Isolate the contaminant in the soil without acting on it, generally through the use of physical barriers to the soil itself.
  - Confinement techniques
    - Reduce the mobility of the contaminants in the soil to keep them from migrating, acting directly on the physical-chemical conditions
  - Decontamination techniques
    - Reduce the concentration of the contaminants in the soil

Contaminated soil remediation

- Containment (Isolate contaminants)
  - Physical barrier (slurry wall)
  - Landfill and soil capping

- Confinement (Reduce mobility of contaminants)
  - Stabilization (pH increase)
  - Solidification (addition of cement, asphalt..)
  - Vitrification (high temperatures => glass structure)

- Decontamination (Reduce concentration of contaminants)
  - Types:
    - Biological
    - Physical/Chemical
    - Thermal

Contaminated soil remediation

- Containment (Isolate contaminants)
  - Physical barrier (slurry wall)
  - Landfill and soil capping
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  - Types:
    - Biological
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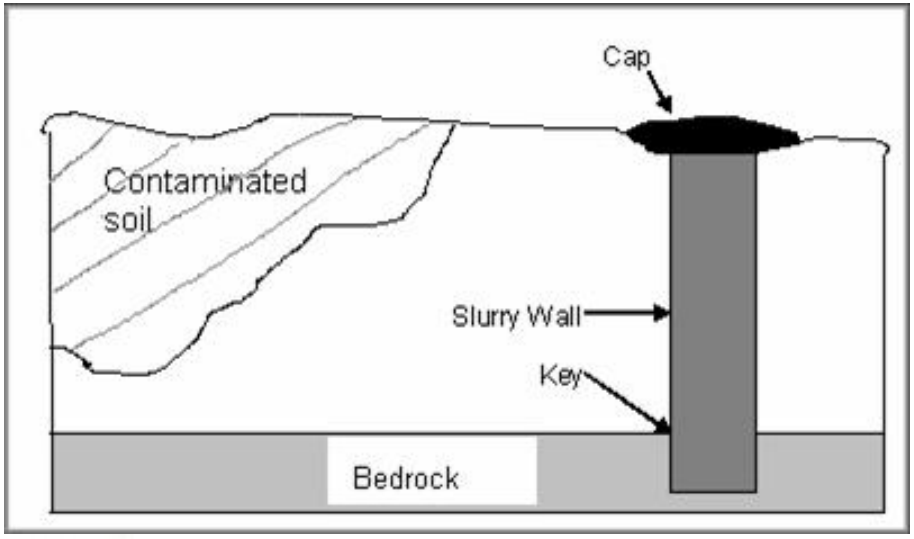
    - Thermal

Techniques for soil remediation

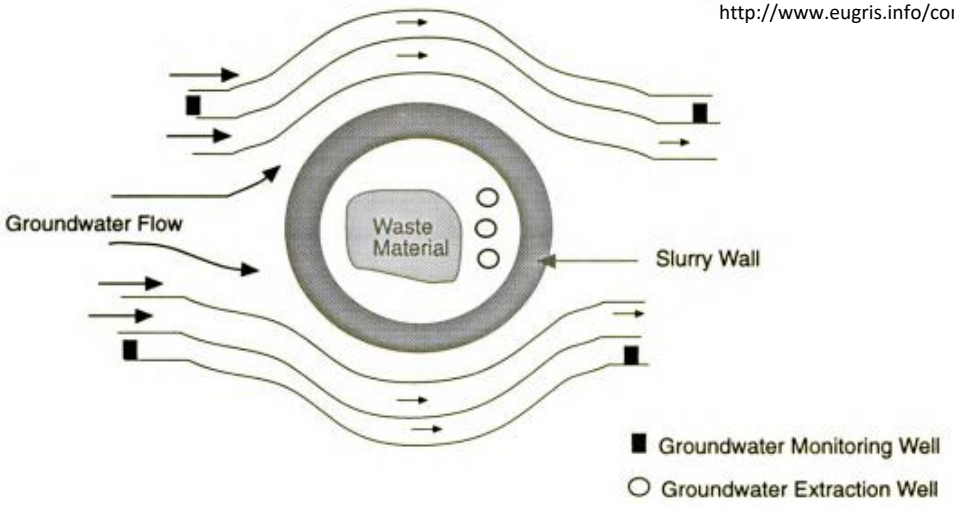
Slurry wall

(Groundwater / in situ)

(all pollutants)



http://www.eugris.info/content/Content_Digests/ContainmentFD_files213/IMAGE002.JPG



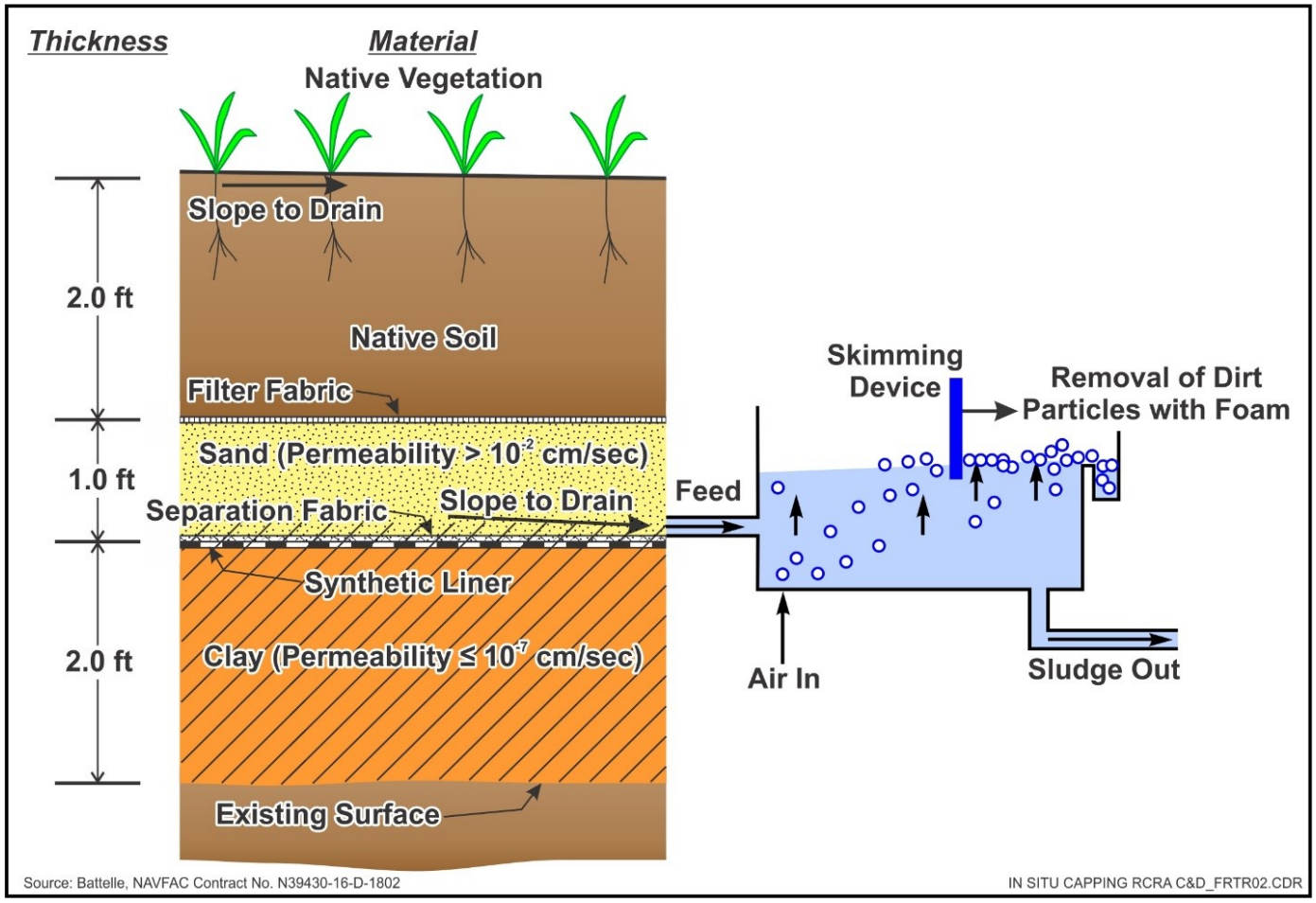
http://www.geoengineer.org/images/students/davidq/figure_2.jpg

Physical barriers are used to contain and divert ground water.

Consist of vertically excavated trench filled with a slurry.

Techniques for soil remediation

Landfill and soil capping (Soil / ex situ) (all pollutants)



Barriers between a waste body or contamination source and the groundwater and/or ground surface

Techniques for soil remediation

Landfill (Soil / ex situ) (all pollutants)

http://ec.europa.eu/regional_policy/projects/stories/image.cfm?id=1071

Contaminated soil remediation: decontamination

In situ

- Biological (VOCs, fuels)
  - Bioventing
  - Enhanced biorremediation
  - Fitoremediation
  - Biowall
  - Monitoring natural attenuation
- Physico-chemical
  - Electromigration (inorg.)
  - Soil flushing (VOCs, inorg.)
  - Air sparging and vapour extraction (VOCs)
- Thermal
  - Enhanced vapour extraction (sVOCs, fuels)

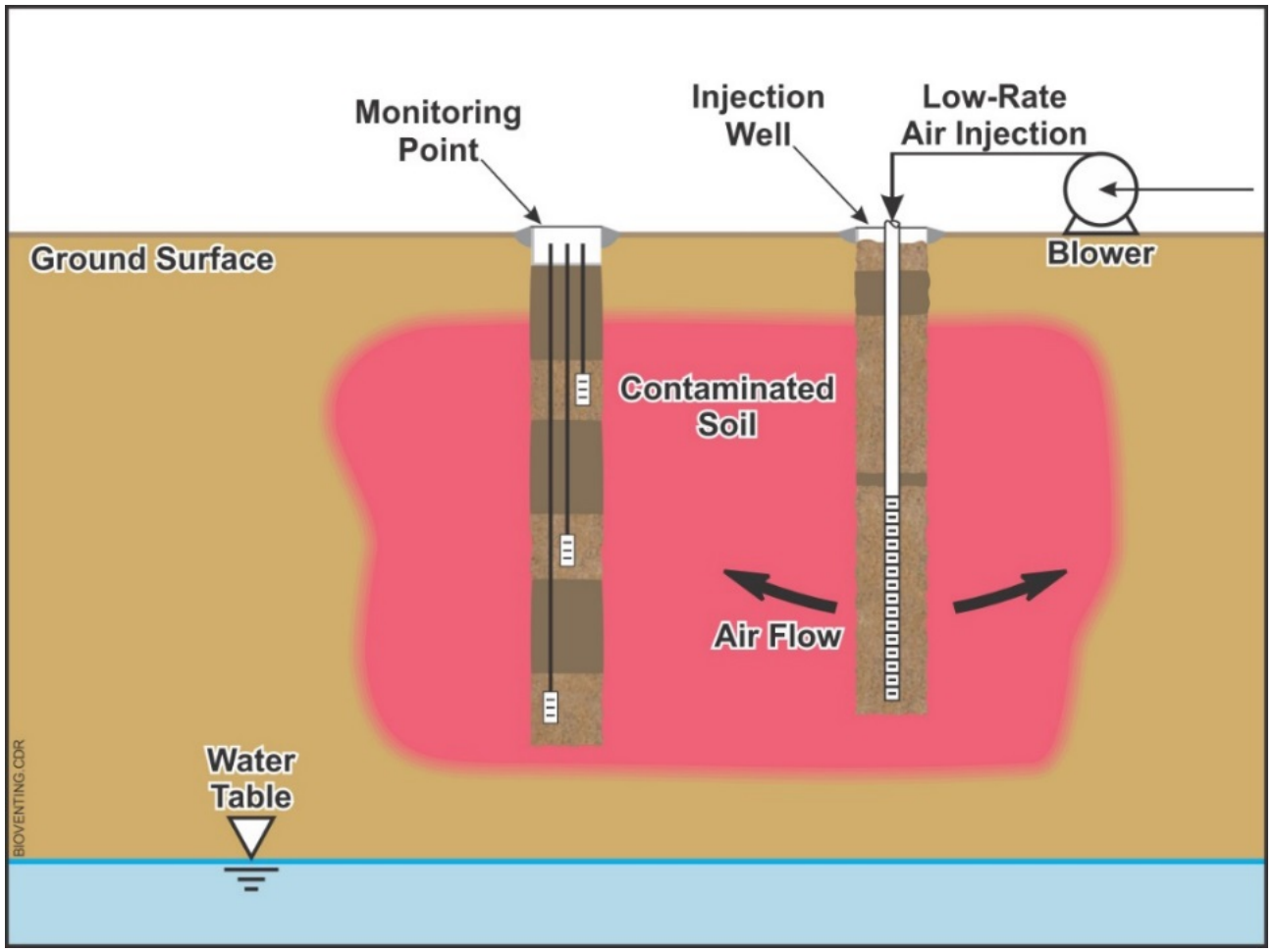
Contaminated soil remediation: decontamination

In situ

- Biological (VOCs, fuels)
  - Bioventing
  - Enhanced biorremediation
  - Fitoremediation
  - Biowall
  - Monitoring natural attenuation
- Physico-chemical
  - Electromigration (inorg.)
  - Soil flushing (VOCs, inorg.)
  - Air sparging and vapour extraction (VOCs)
- Thermal
  - Enhanced vapour extraction (sVOCs, fuels)

Techniques for soil remediation

Bioventing (Soil / in situ / biological)

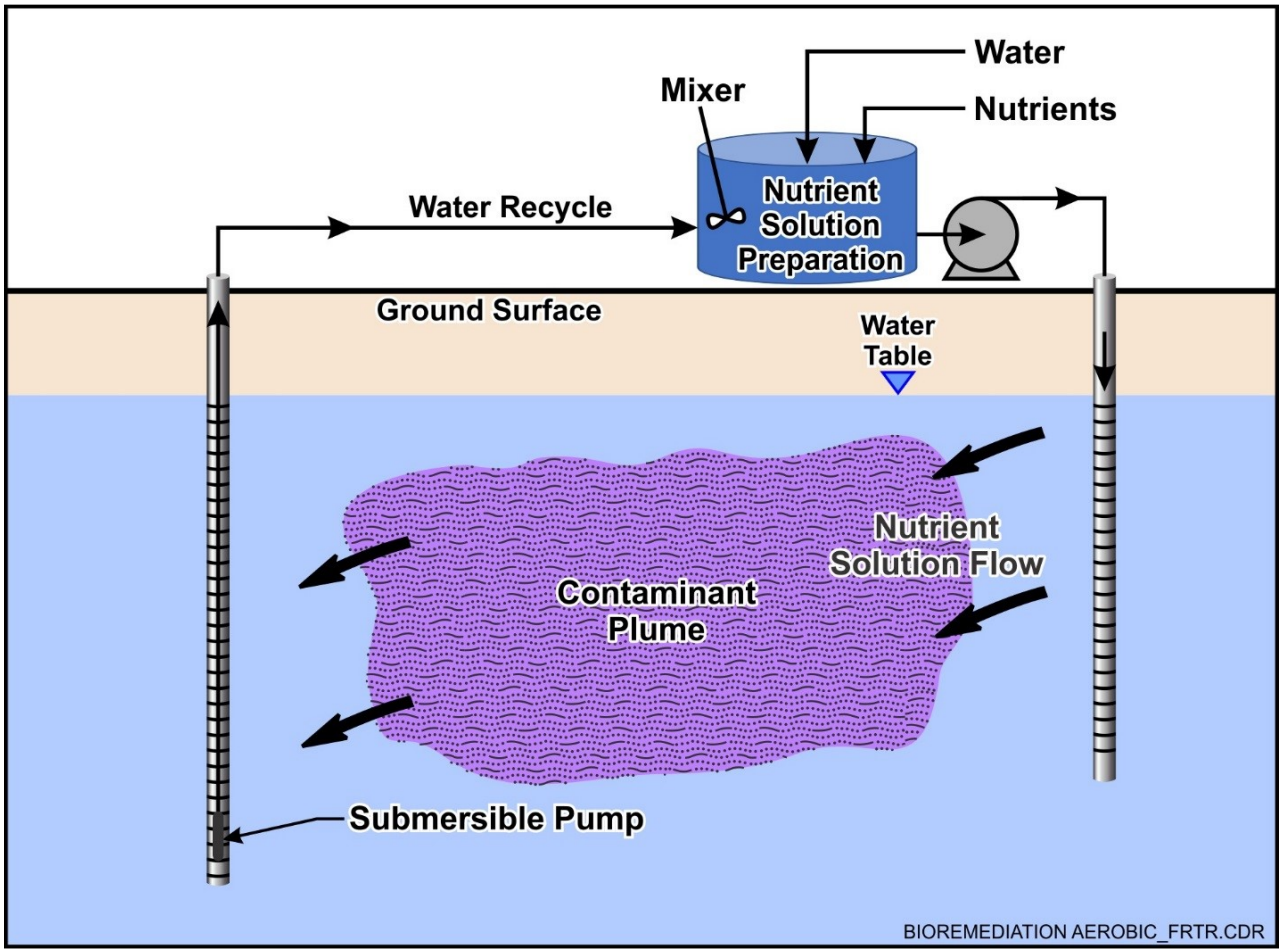


https://www.frtr.gov/matrix/

Air movement is forced to increase oxygen concentrations and stimulate biodegradation

Techniques for soil remediation

Enhanced bioremediation (Soil / in situ / biological)

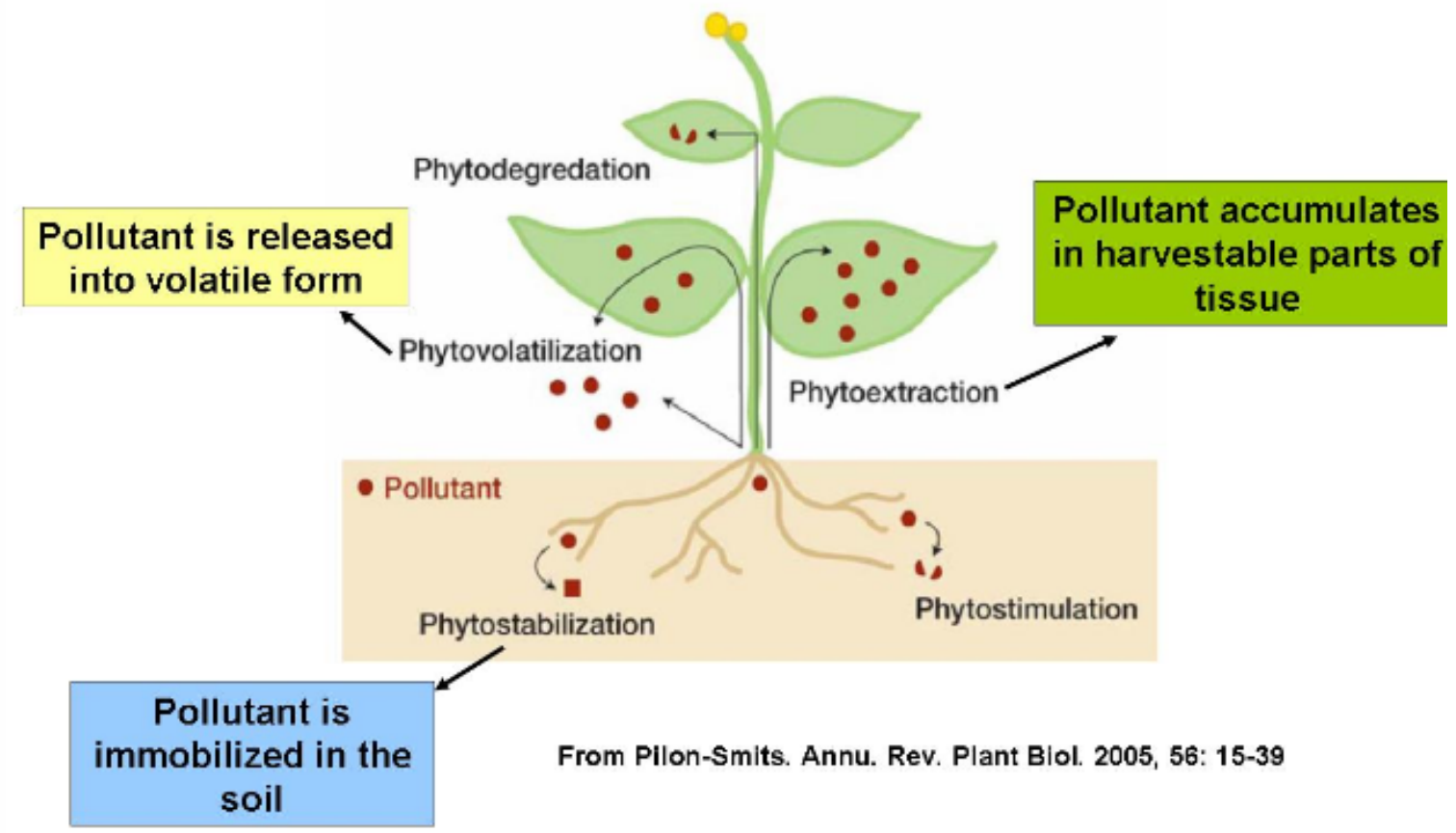


https://frtr.gov/matrix/Enhanced-Aerobic-Bioremediation/

Addition of water with nutrients, or other amendments to stimulate microorganisms

Techniques for soil remediation

Phytoremediation (Soil or groundwater/ in situ / biological)

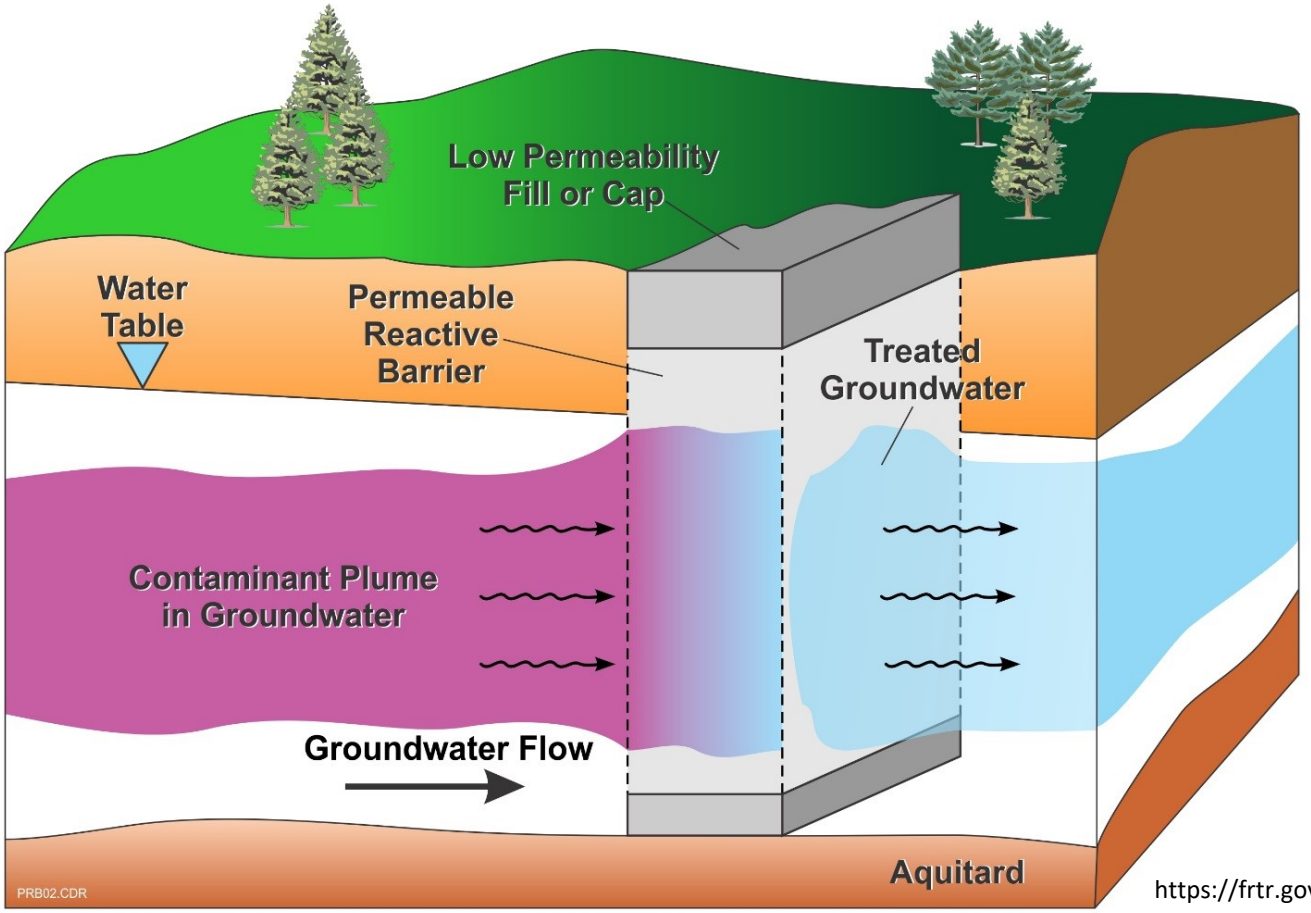


Plants are used to remove, transfer or stabilize contaminants

Techniques for soil remediation

Biowall

(Groundwater / in situ) (VOC, sVOC, fuels

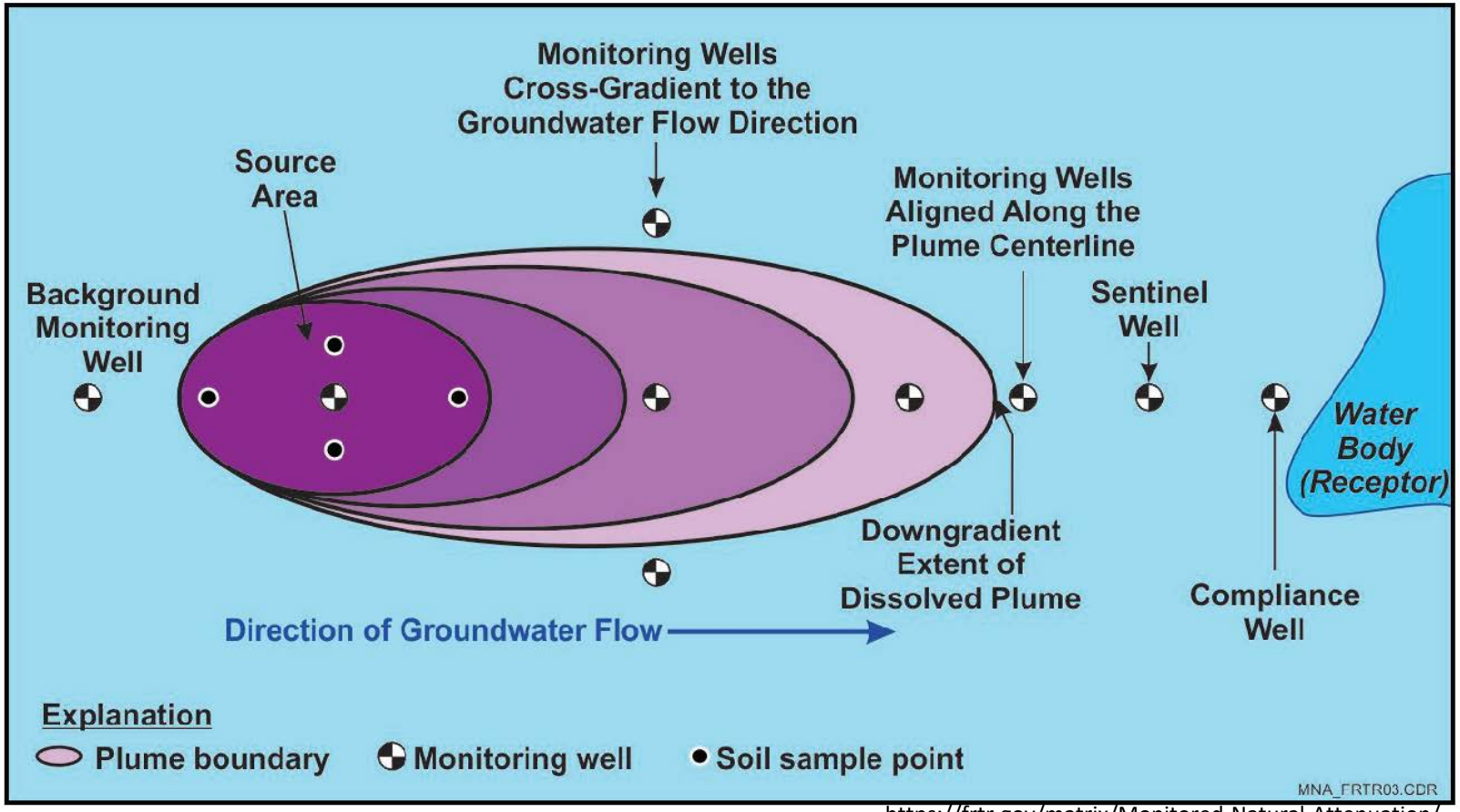


https://frtr.gov/matrix/Biowalls/

Permeable barrier to treat groundwater as it passes through the wall.

Techniques for soil remediation

Monitoring natural attenuation (Groundwater / in situ / biological)



https://frtr.gov/matrix/Monitored-Natural-Attenuation/

Natural subsurface process, such as dilution, volatilization, biodegradation and chemical reactions, are allowed to reduce contaminant concentrations to acceptable levels

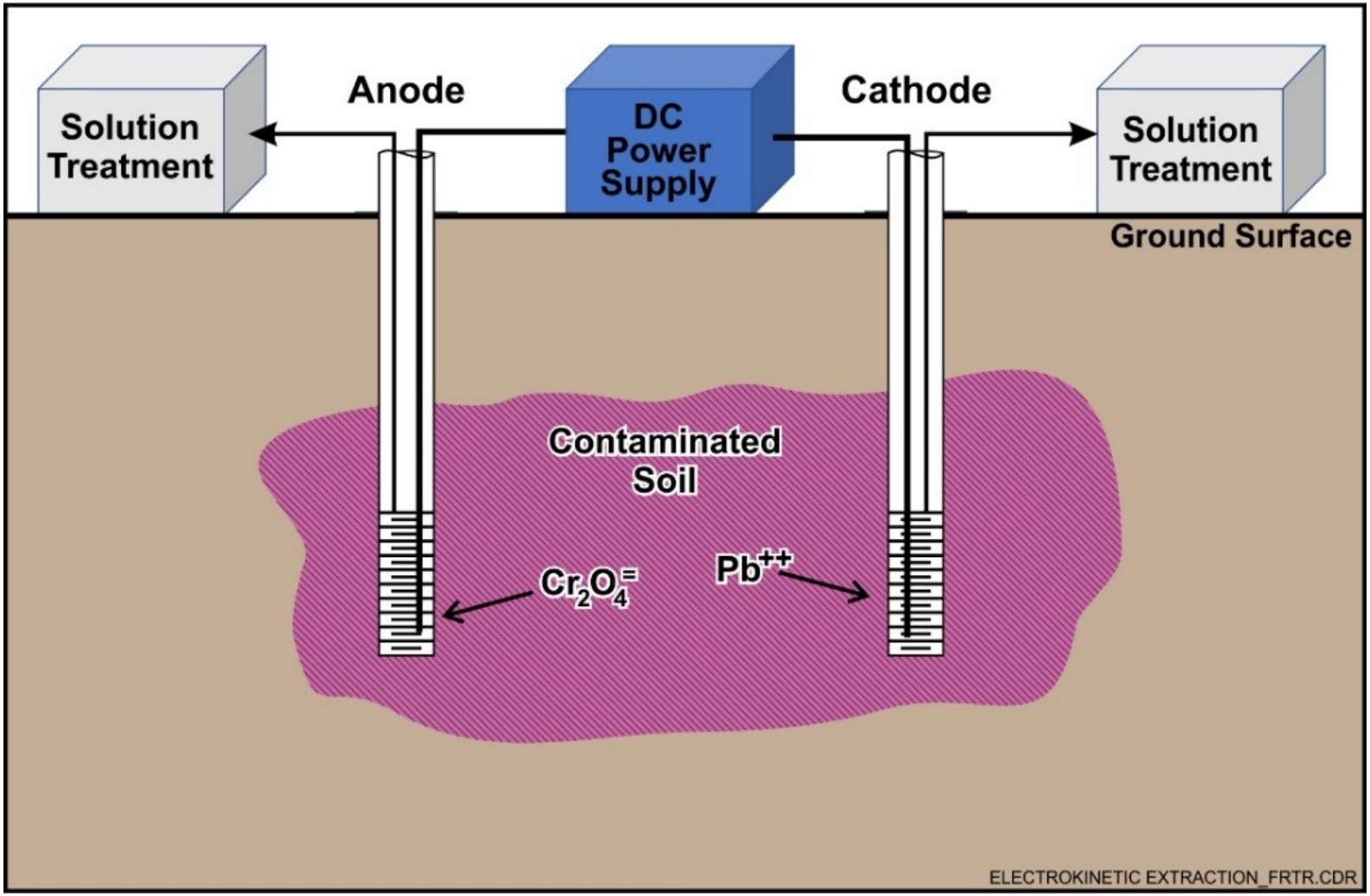
Contaminated soil remediation: decontamination

In situ

- Biological (VOCs, fuels)
  - Bioventing
  - Enhanced biorremediation
  - Fitoremediation
  - Biowall
  - Monitoring natural attenuation
- Physico-chemical
  - Electromigration (inorg.)
  - Soil flushing (VOCs, inorg.)
  - Air sparging and vapour extraction (VOCs)
- Thermal
  - Enhanced vapour extraction (sVOCs, fuels)

Techniques for soil remediation

Electromigration (Soil / in situ / physical)

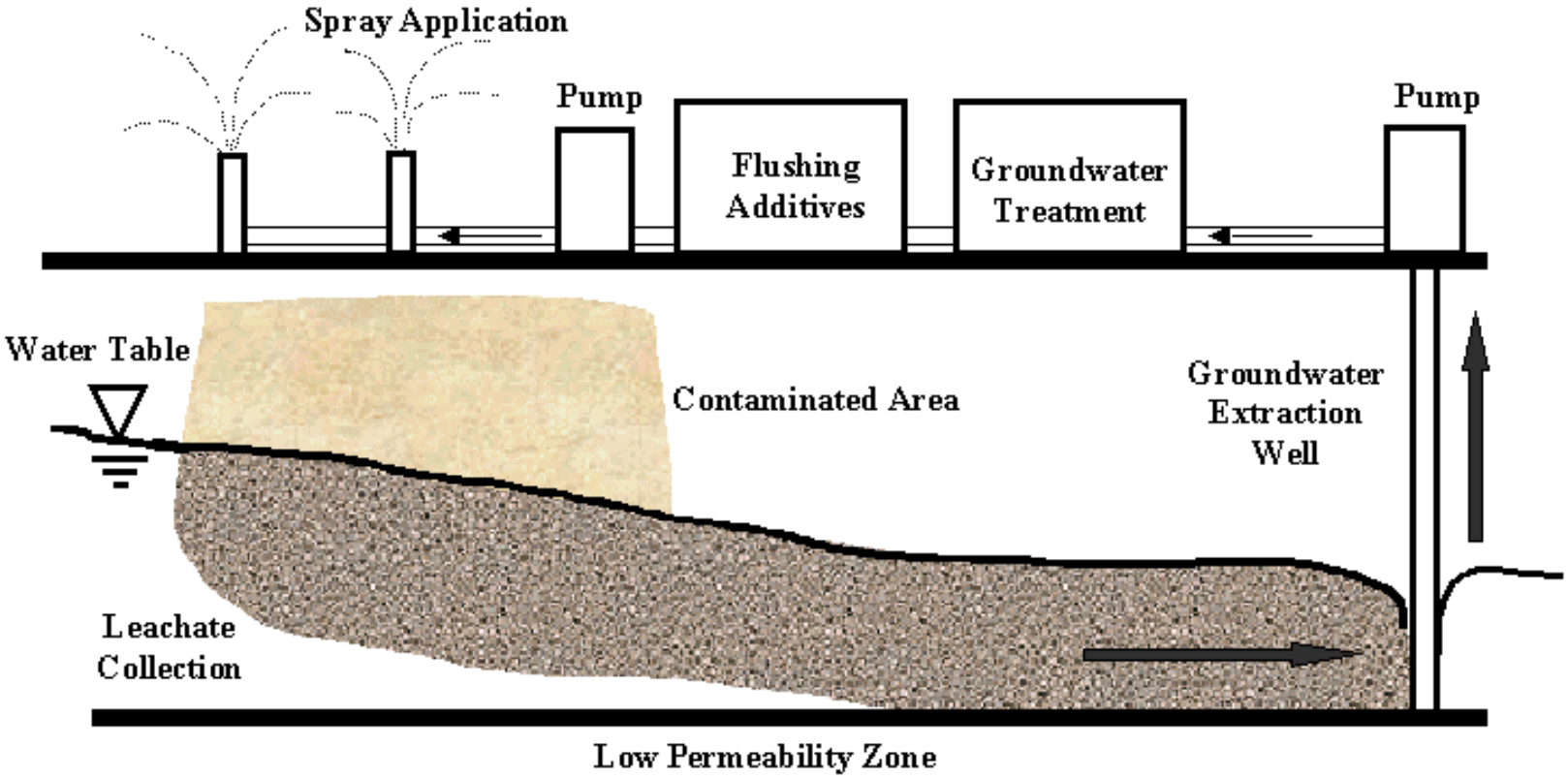


Electric current is applied to mobilize metals

https://www.frtr.gov/matrix/

Techniques for soil remediation

Soil flushing (Soil / in situ / physical)

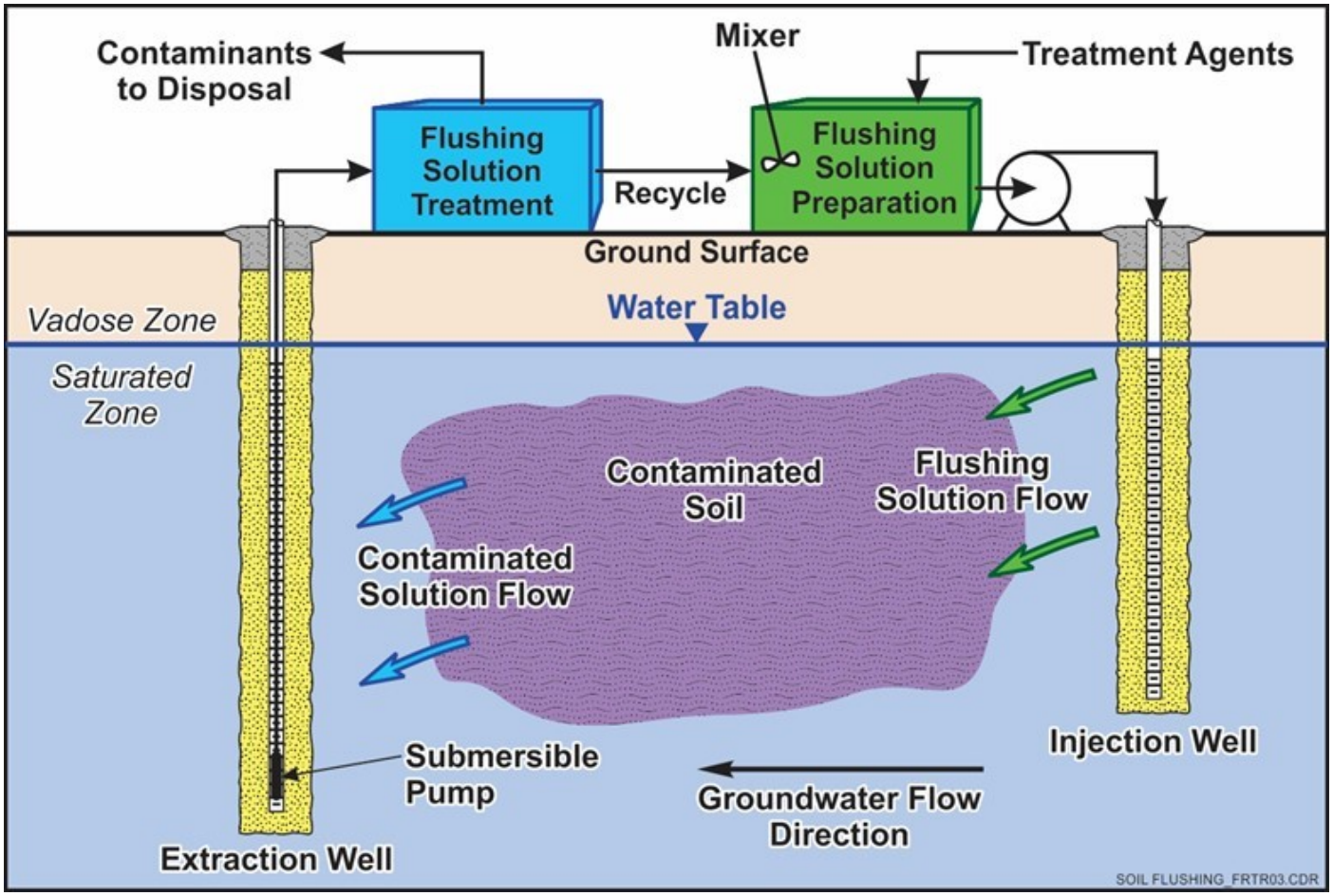


https://www.frtr.gov/matrix/

Water is applied to the soil through spray. Contaminants are leached into the groundwater which is extracted and treated

Techniques for soil remediation

Soil flushing (Soil / in situ / physical)

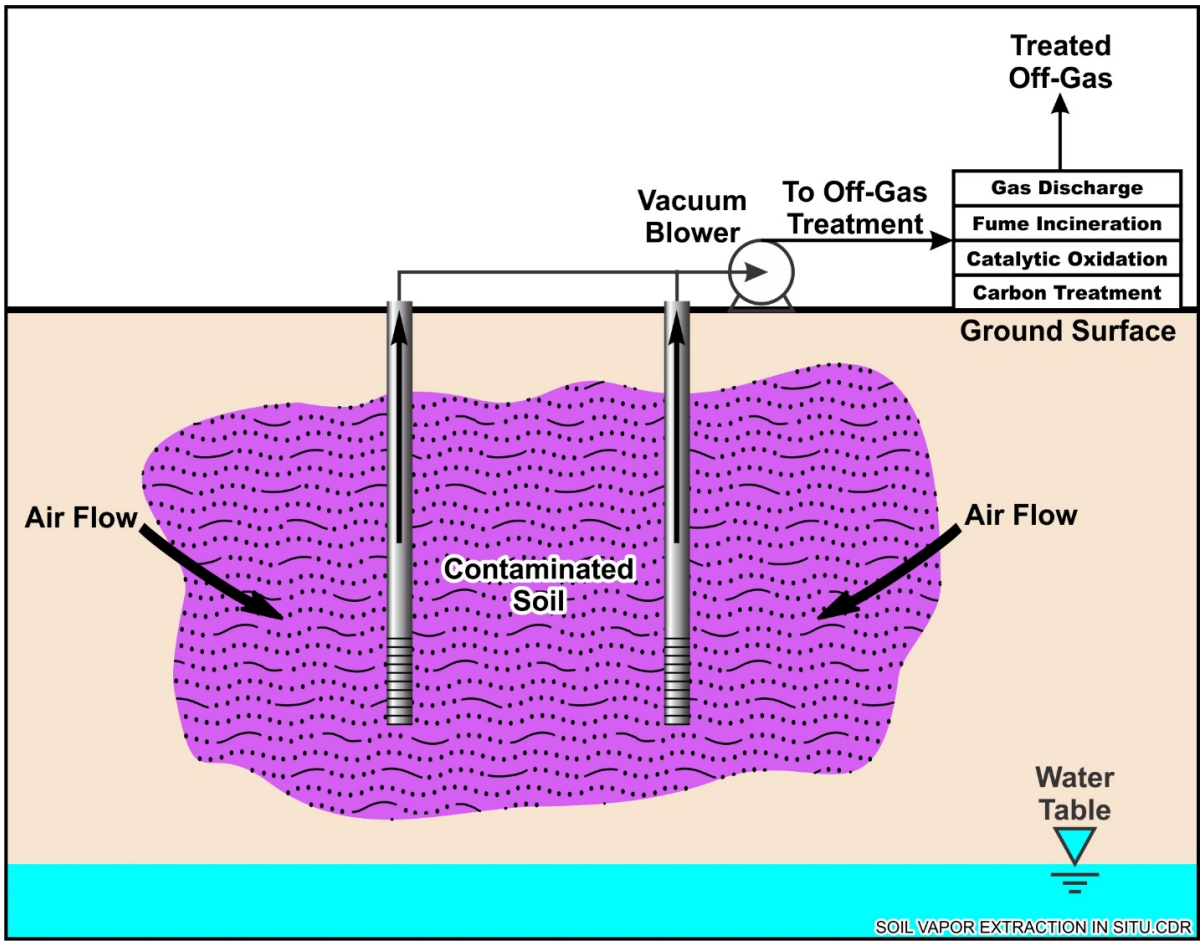


https://frtr.gov/matrix/Soil-Flushing/

Water is injected to the soil. Contaminants are leached into the groundwater which is extracted and treated

Techniques for soil remediation

Soil vapor extraction (Soil / in situ / physical)



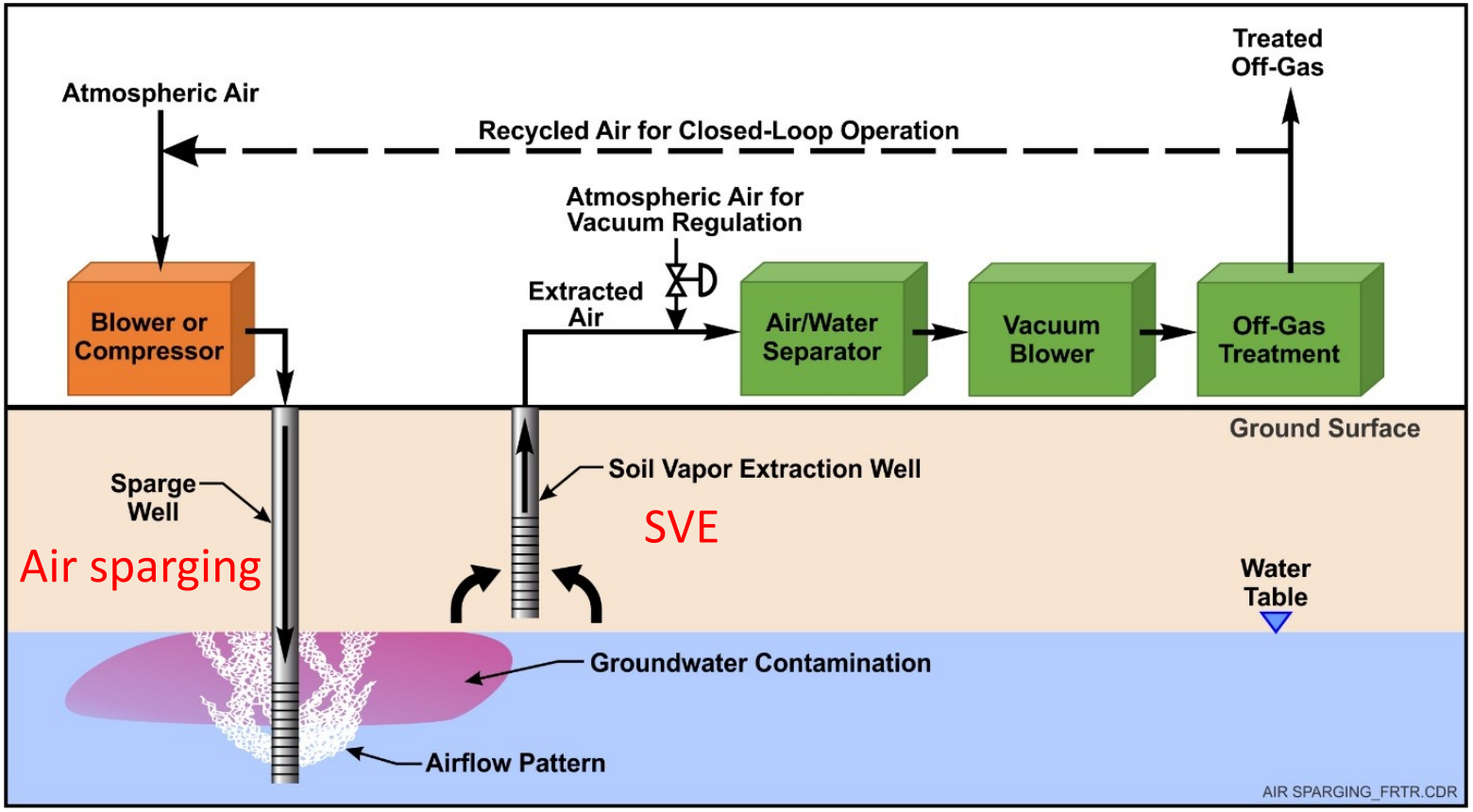
https://frtr.gov/matrix/Soil-Vapor-Extraction/

Application of vacuum in the vadose zone to induce flow air and removal of VOC's and some sVOC's

Techniques for soil remediation

Air sparging (Groundwater / in situ / physical) +

Soil vapor extraction (Soil / in situ / physical)

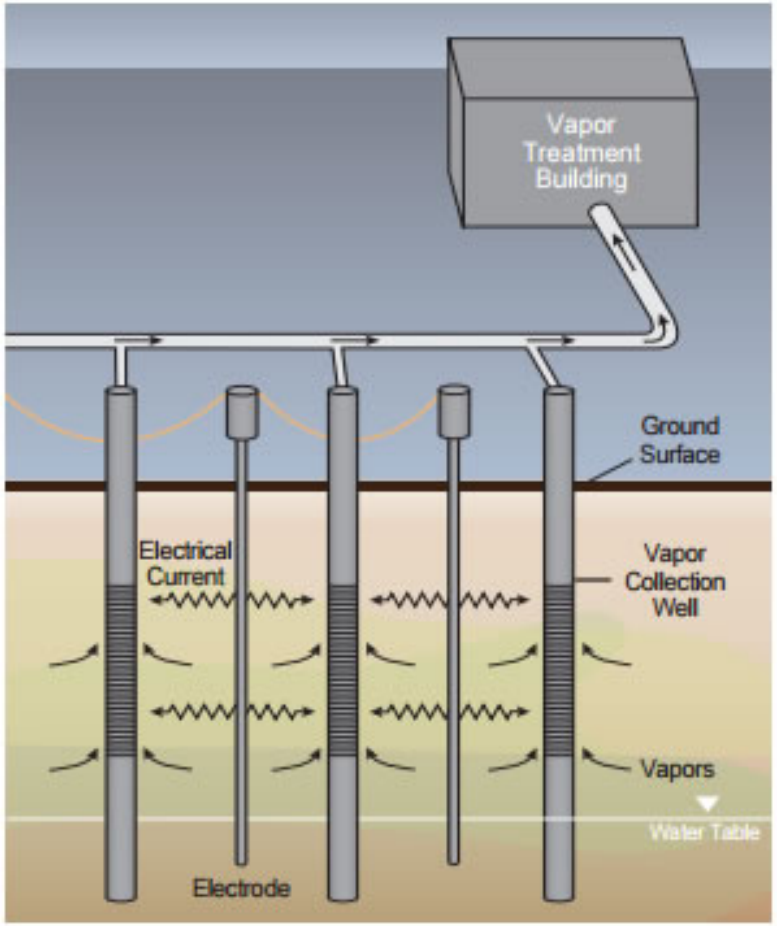


https://www.frtr.gov/matrix/

Air is injected to the aquifer, bubbling the pollutants up into the unsaturated soil where they are extracted

Techniques for soil remediation

Enhanced soil vapor extraction (Soil / in situ / physical)

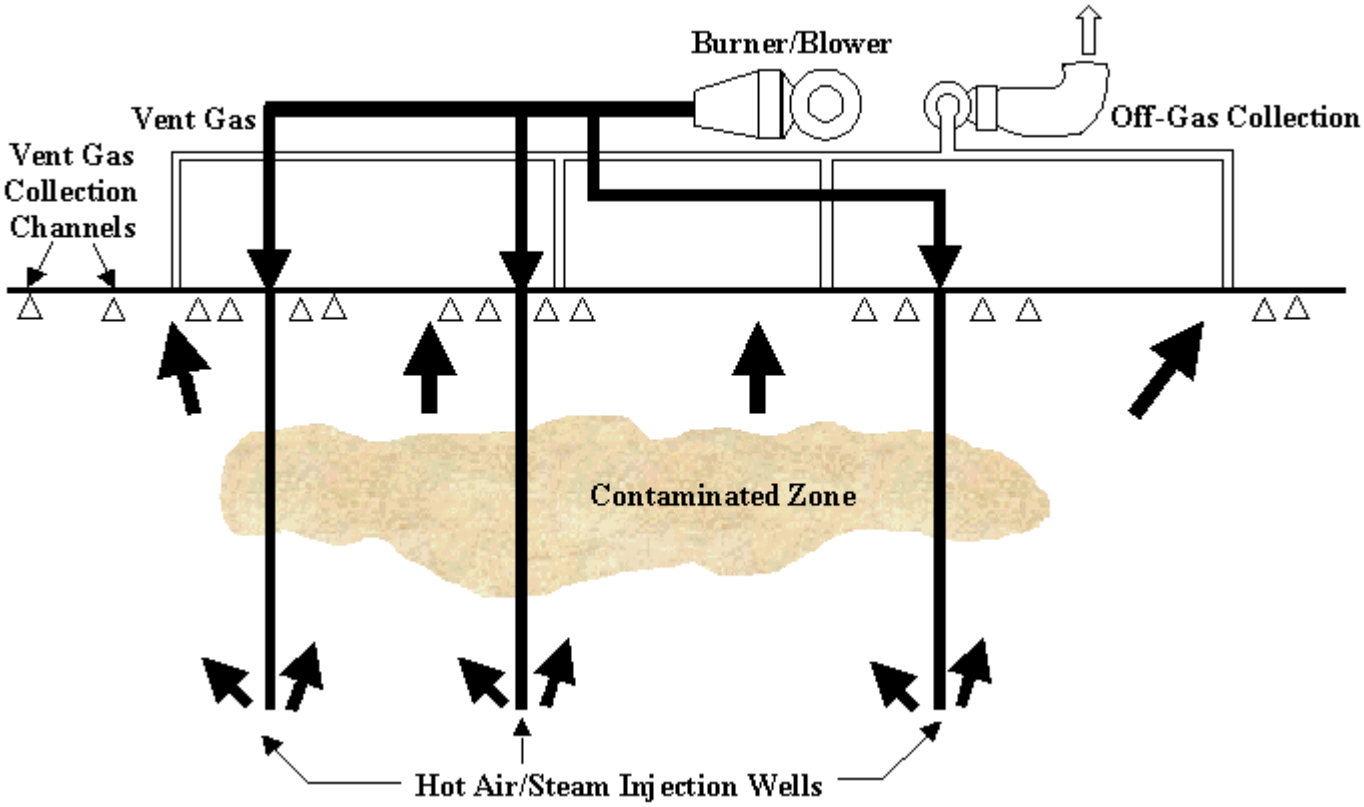


https://www.xdd-llc.com/situ-thermal-treatment-technology/attachment/in-situ-thermal-treatment/

Uses electrical resistance to increase the volatilization of sVOC's and facilitate extraction

Techniques for soil remediation

Enhanced soil vapor extraction (Soil / in situ / physical)



https://frtr.gov/matrix2/section4/D01-4-9b.html

Uses electrical hot-air/stream injection to increase the volatilization of sVOC's and facilitate extraction

Contaminated soil remediation: techniques

Ex situ

- Biological (VOCs, fuels)
  - Biopiles
  - Landfarming
- Physico-chemical
  - Soil washing (VOCs, inorganics)
  - Chemical extraction (sVOCs, inorganics)
- Thermal (organics)
  - Incineration
  - Thermal desorption

Contaminated soil remediation: techniques

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- Biological (VOCs, fuels)
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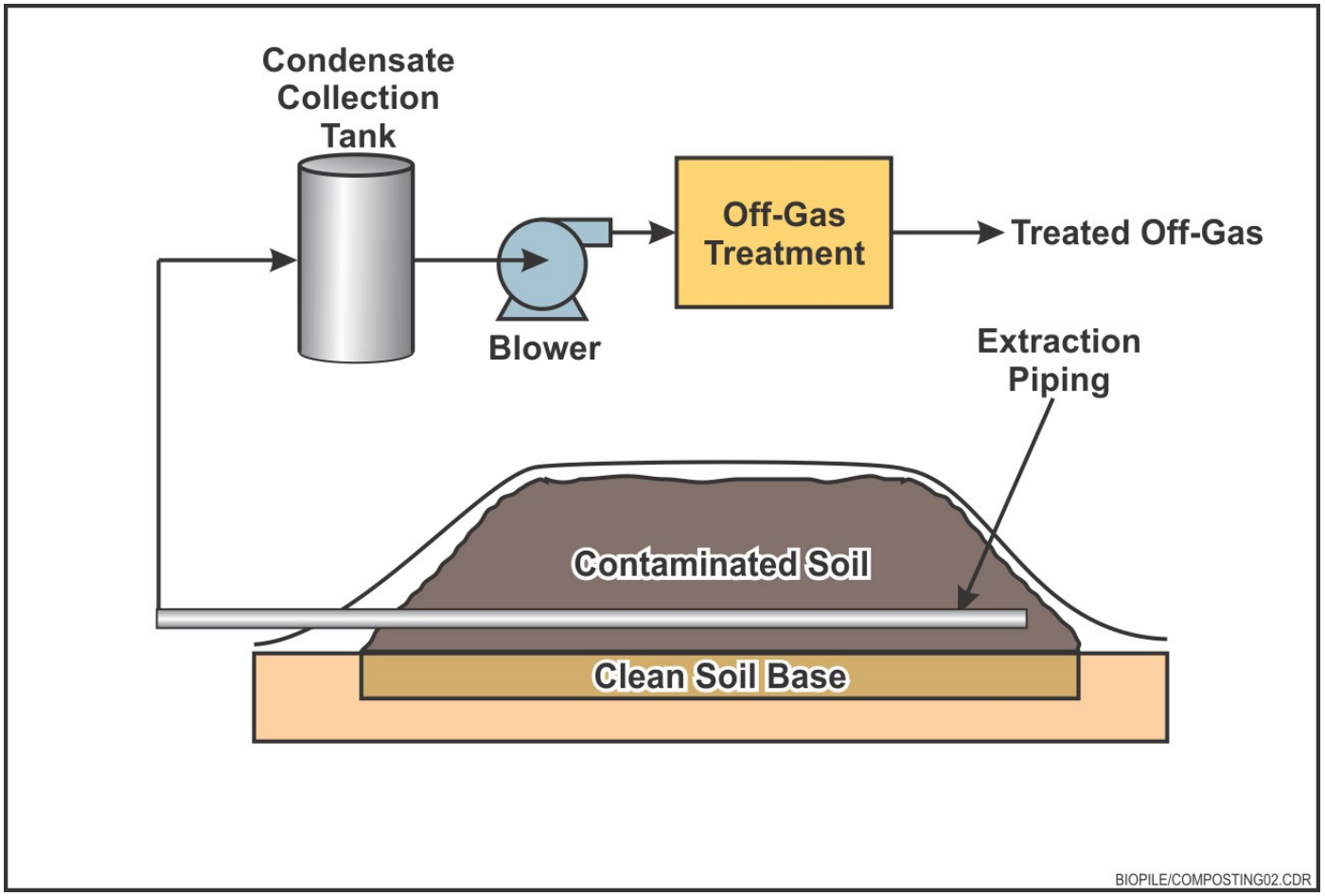
- Thermal (organics)
  - Incineration
  - Thermal desorption

Techniques for soil remediation

Biopiles (Soil / ex situ / biological)



https://www.frtr.gov/matrix/

Soil is excavated, and air, nutrients and moisture are controled to enhance biodegradation

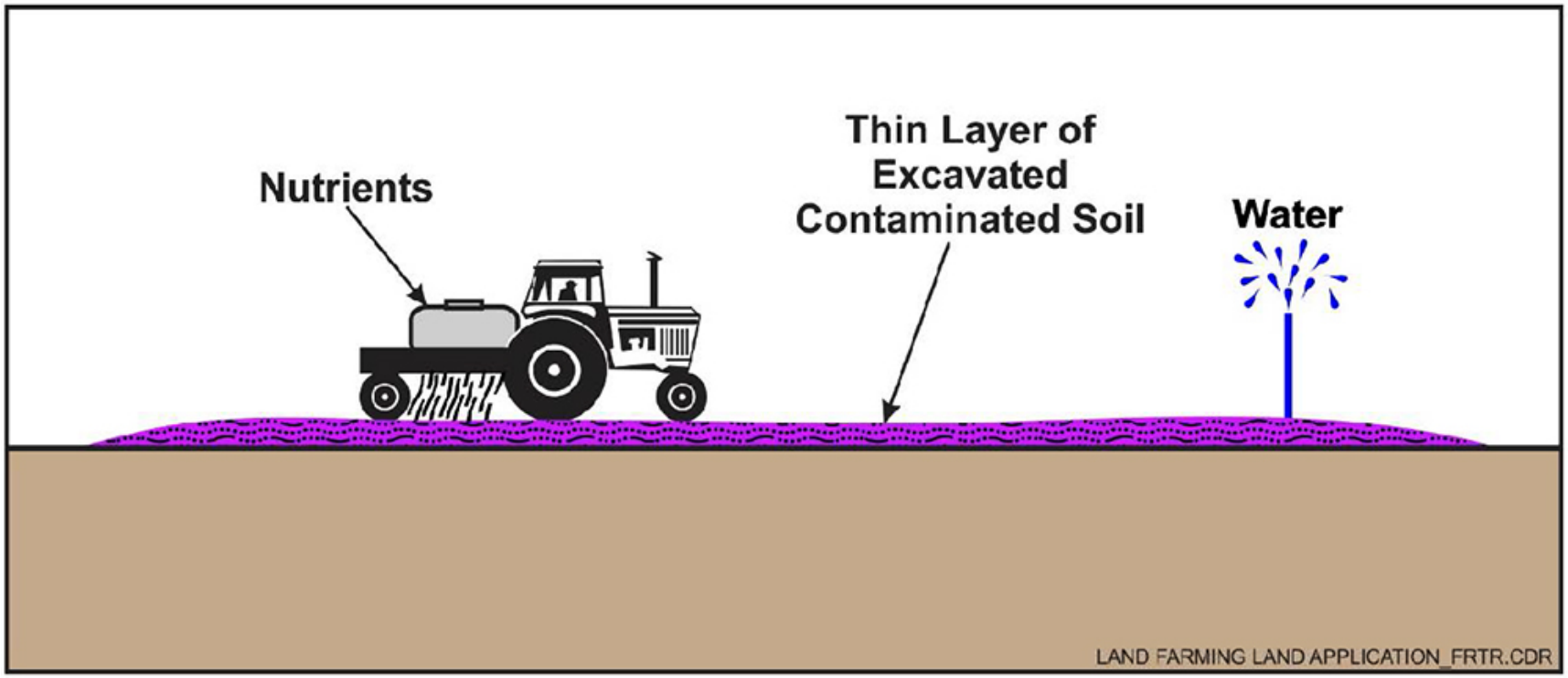
Techniques for soil remediation

Biopiles (Soil / ex situ / biological)

http://media.dma.mil/2012/Dec/17/2000756699/-1/-1/0/121129-A-ZZ999-123.JPG

Techniques for soil remediation

Landfarming (Soil / ex situ / biological)



https://frtr.gov/matrix/Landfarming/

Soil is excavated and tilled for aeration to enhance biodegradation

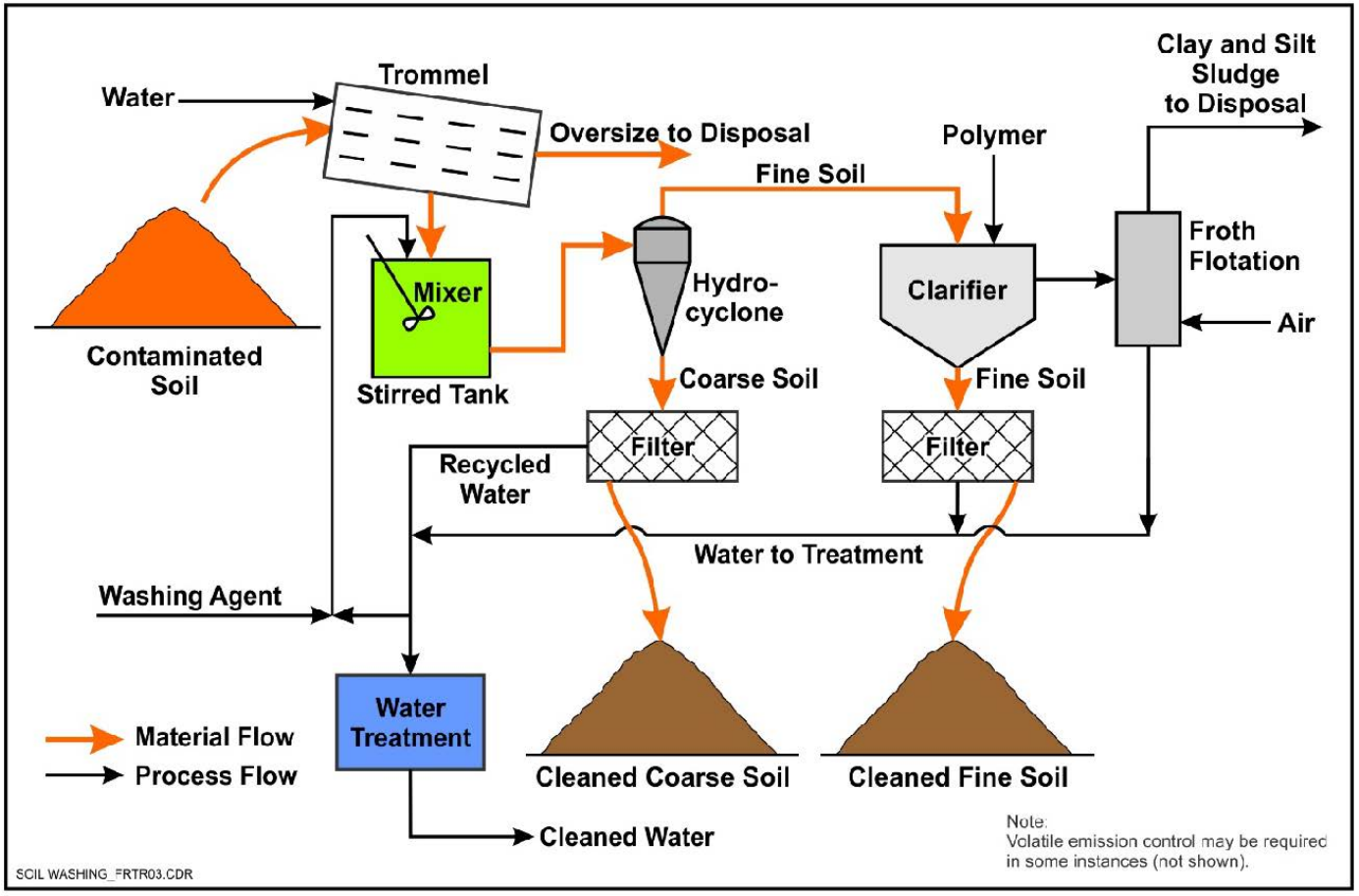
Contaminated soil remediation: techniques

Ex situ

- Biological (VOCs, fuels)
  - Biopiles
  - Landfarming
- Physico-chemical
  - Soil washing (VOCs, inorganics)
  - Chemical extraction (sVOCs, inorganics)
- Thermal (organics)
  - Incineration
  - Thermal desorption

Techniques for soil remediation

Soil washing (Soil / ex situ / physical)

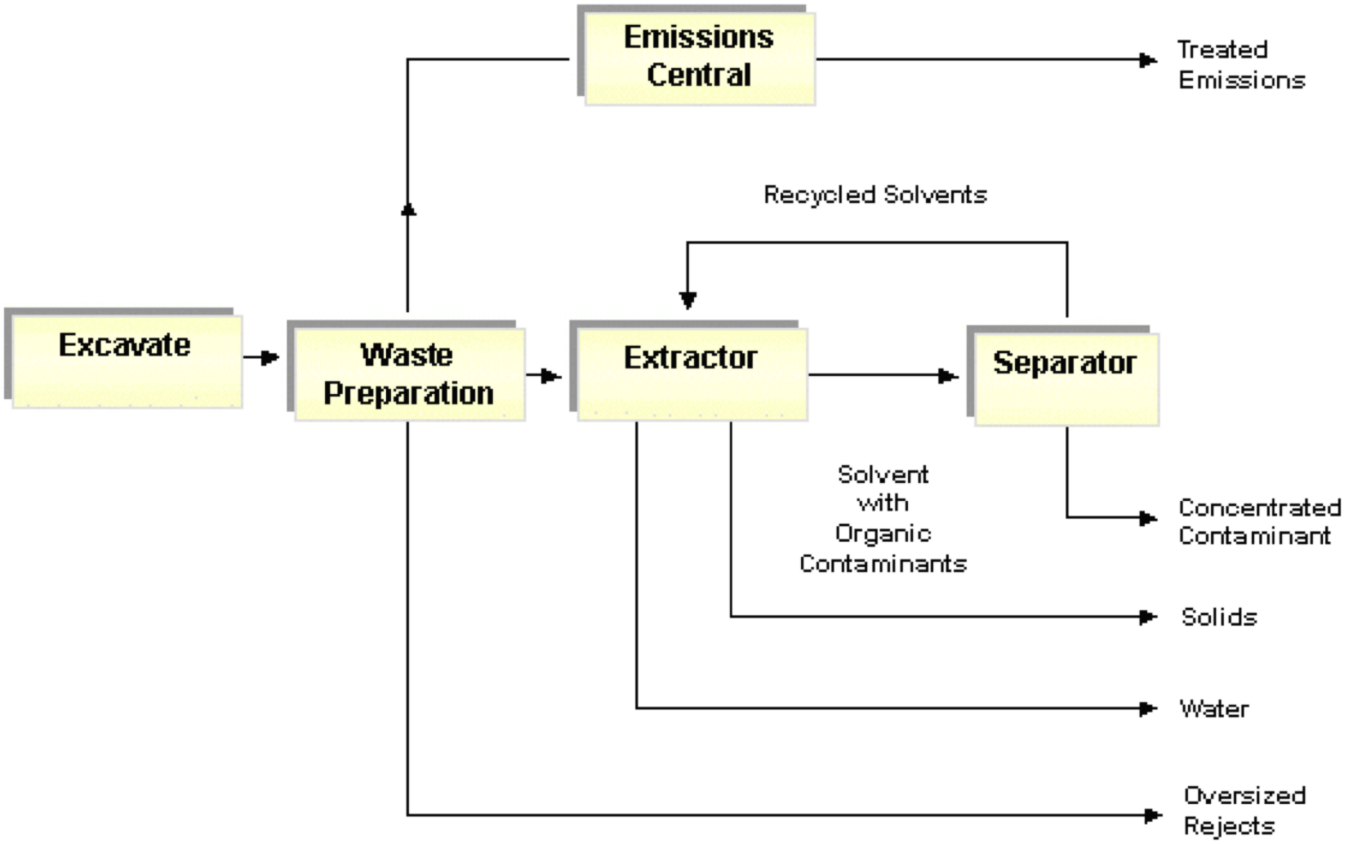


https://frtr.gov/matrix/Soil-Washing/

Contaminants are removed from soils by dissolving or suspending them in a wash solution

Techniques for soil remediation

Chemical extraction (Soil / ex situ / physical)



https://www.frtr.gov/matrix/

Contaminants are removed from soils by the use of an extracting chemical (acid, organic solvent, …)

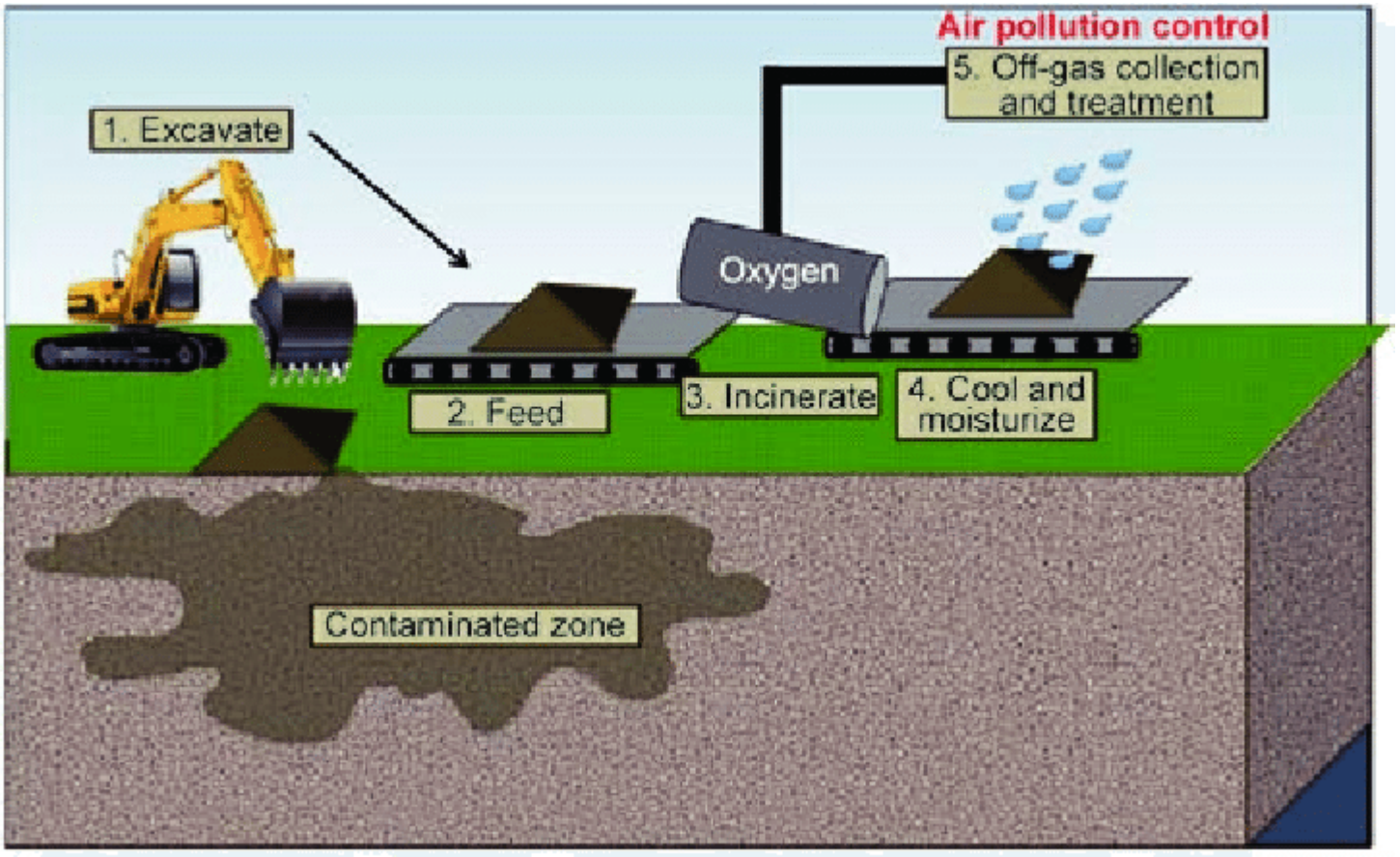
Contaminated soil remediation: techniques

Ex situ

- Biological (VOCs, fuels)
  - Biopiles
  - Landfarming
- Physico-chemical
  - Soil washing (VOCs, inorganics)
  - Chemical extraction (sVOCs, inorganics)
- Thermal (organics)
  - Incineration
  - Thermal desorption

Techniques for soil remediation

Incineration (Soil / ex situ / thermal)

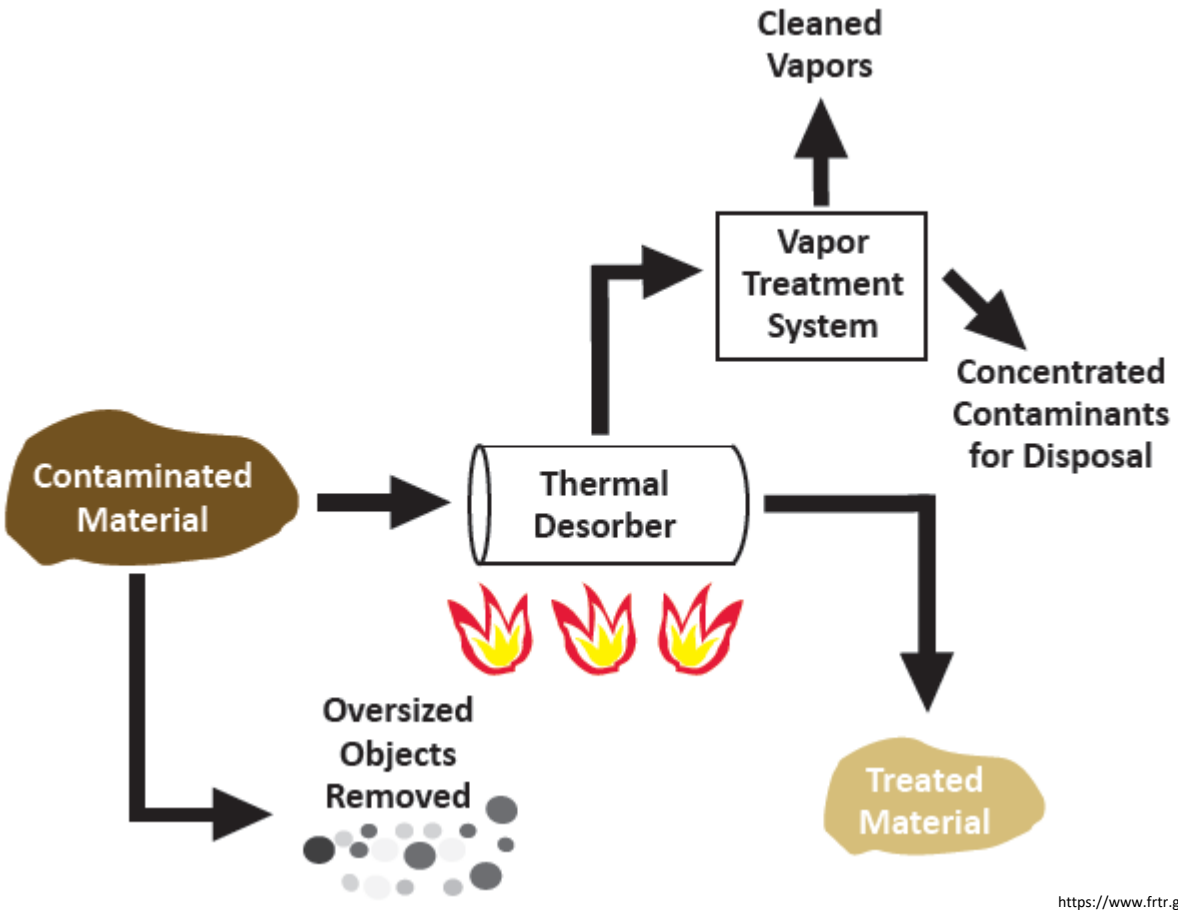


https://www.frtr.gov/matrix/

High temperatures (870 to 1200 ºC) are used to volatilize and combust organic pollutants

Techniques for soil remediation

Thermal desorption (Soil / ex situ / thermal)



https://www.frtr.gov/matrix/

Contaminated soil is excavated and heated to evaporate contaminants

Techniques for soil remediation

Thermal desorption (Soil / ex situ / thermal)

http://www.ecotrade.org/homepage/oikos454/catalog.asp?DirectoryID=817&CatalogID=658

Contaminated soil is excavated and heated to evaporate contaminants

Techniques for soil remediation

Thermal desorption (Soil / ex situ / thermal)

http://www.bauerenvironment.com/export/sites/www.bauerumweltgruppe.com/images/sanierungstechnik/Campina_2.png

Contaminated soil remediation

Remediation Technologies Screening Matrix (USA)

https://frtr.gov/matrix2/top_page.html

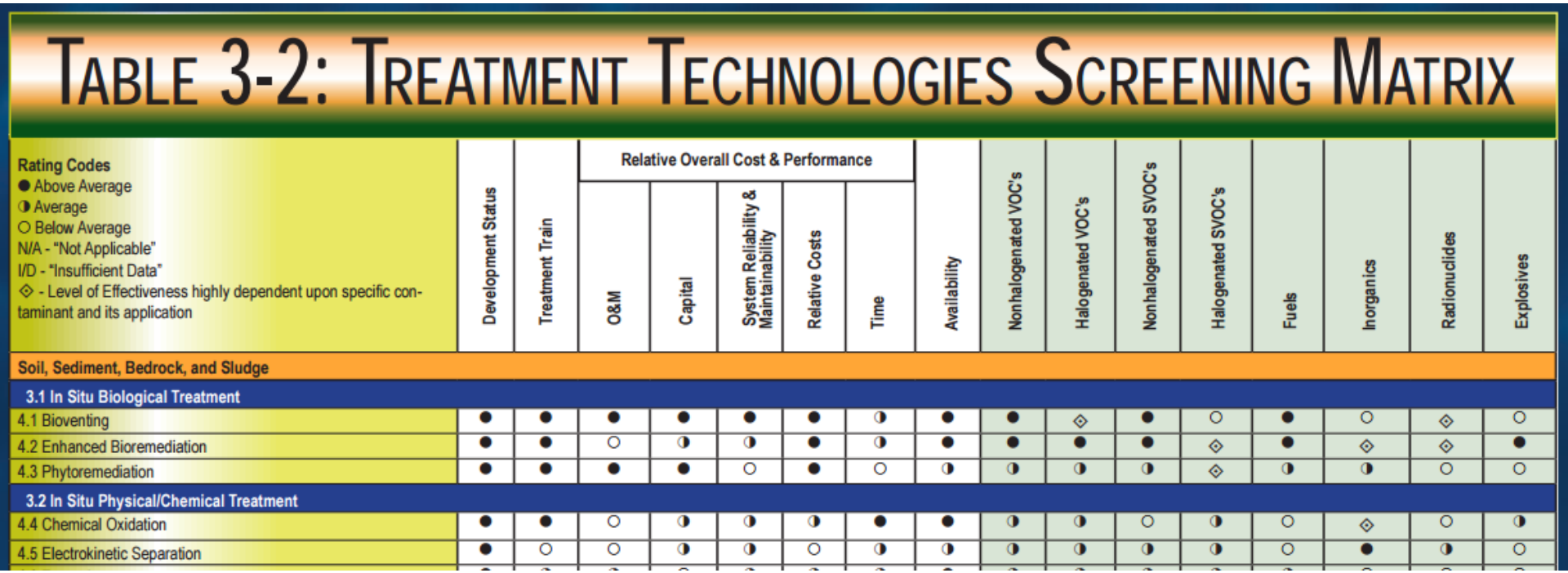
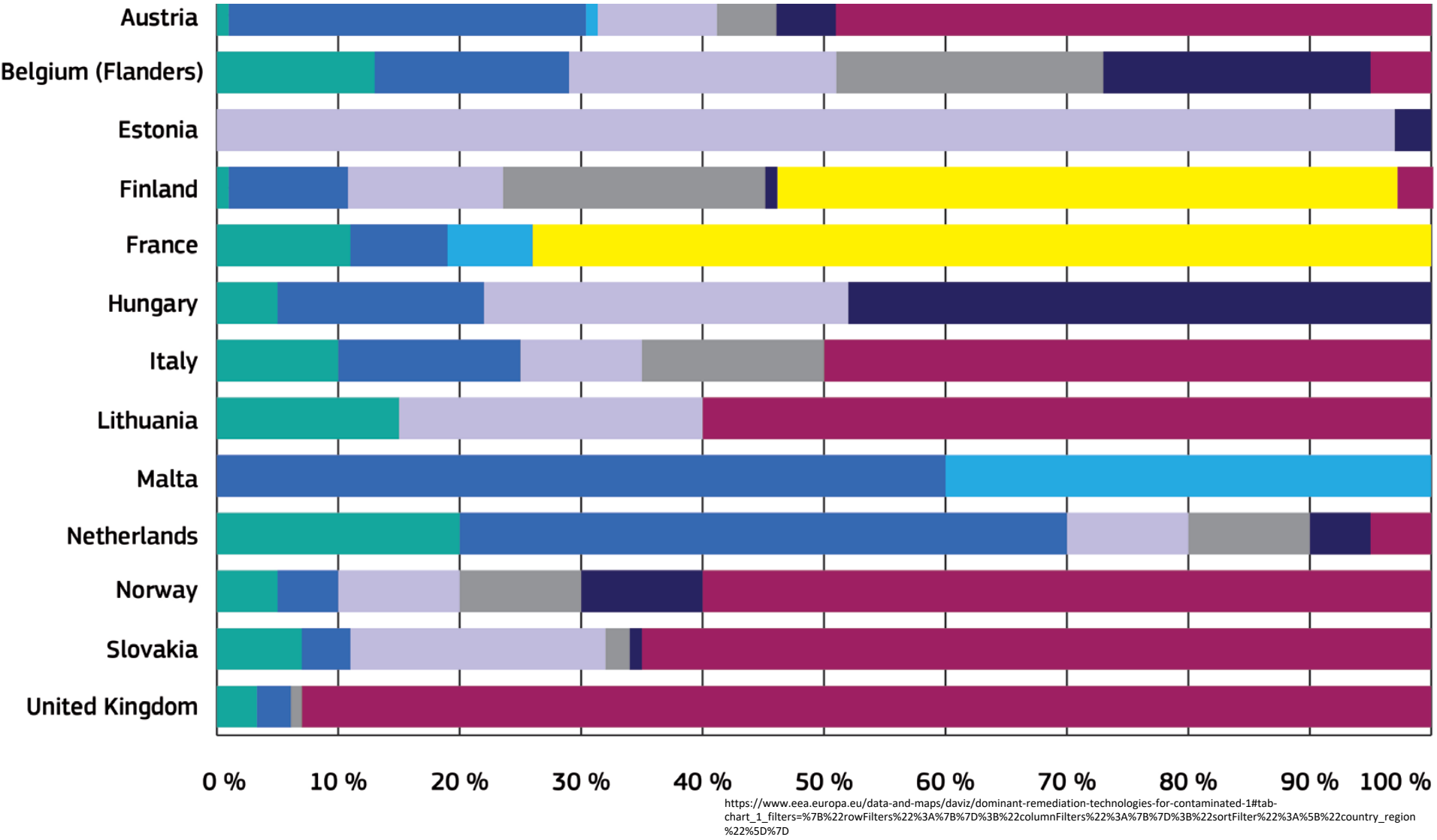


TABLE 3-2: TREATMENT TECHNOLOGIES SCREENING MATRIX

Rating Codes
● Above Average
◑ Average
○ Below Average
N/A - "Not Applicable"
I/D - "Insufficient Data"
◈ - Level of Effectiveness highly dependent upon specific contaminant and its application

	Development Status	Treatment Train	Relative Overall Cost & Performance					Availability	Nonhalogenated VOC's	Halogenated VOC's	Nonhalogenated SVOC's	Halogenated SVOC's	Fuels	Inorganics	Radionuclides	Explosives
			O&M	Capital	System Reliability & Maintainability	Relative Costs	Time									
Soil, Sediment, Bedrock, and Sludge																
3.1 In Situ Biological Treatment																
4.1 Bioventing	●	●	●	●	●	●	◑	●	●	◈	●	○	●	○	◈	○
4.2 Enhanced Bioremediation	●	●	○	◑	◑	●	◑	●	●	●	●	◈	●	◈	◈	●
4.3 Phytoremediation	●	●	●	●	○	●	○	◑	◑	◑	◑	◈	◑	◑	○	○
3.2 In Situ Physical/Chemical Treatment																
4.4 Chemical Oxidation	●	●	○	◑	◑	◑	●	●	◑	◑	○	◑	○	◈	○	◑
4.5 Electrokinetic Separation	●	○	○	◑	◑	○	◑	◑	◑	◑	◑	◑	○	●	◑	○

Most frequent techniques for soil remediation in EU



https://www.eea.europa.eu/data-and-maps/daviz/dominant-remediation-technologies-for-contaminated-1#tab-chart_1_filters=%7B%22rowFilters%22%3A%7B%7D%3B%22columnFilters%22%3A%7B%7D%3B%22sortFilter%22%3A%5B%22country_region%22%5D%7D

Chapter review (1/2)

- Soil pollution as a suitable Mining Engineering work field
- Soil degradation: recent concern
- Multiple sources and consequences of soil pollution
- The fate of contaminants in soil depends on:
  - Soil properties
    - Grain size, texture, estructure, ...
    - Cation Exchange Capacity, pH, redox potential
  - Contaminant properties
    - Solubility (S), volatility (K_H), tendency to sorb to soils (K_{ow}, K_{oc}, K_d), density (d), chemical half life ($t_{1/2}$), [...]

Chapter review (2/2)

- Types of pollutants: organic and inorganic
- Solutions
  - Legal framework
    - Generic reference level
    - Risk Assessment
  - Soil investigation
  - Remediation
    - Many options: the proper one for the specific site should be selected