Nanoremediation and other *in-situ* remediation technologies

University of Stuttgart, USTUTT – VEGAS
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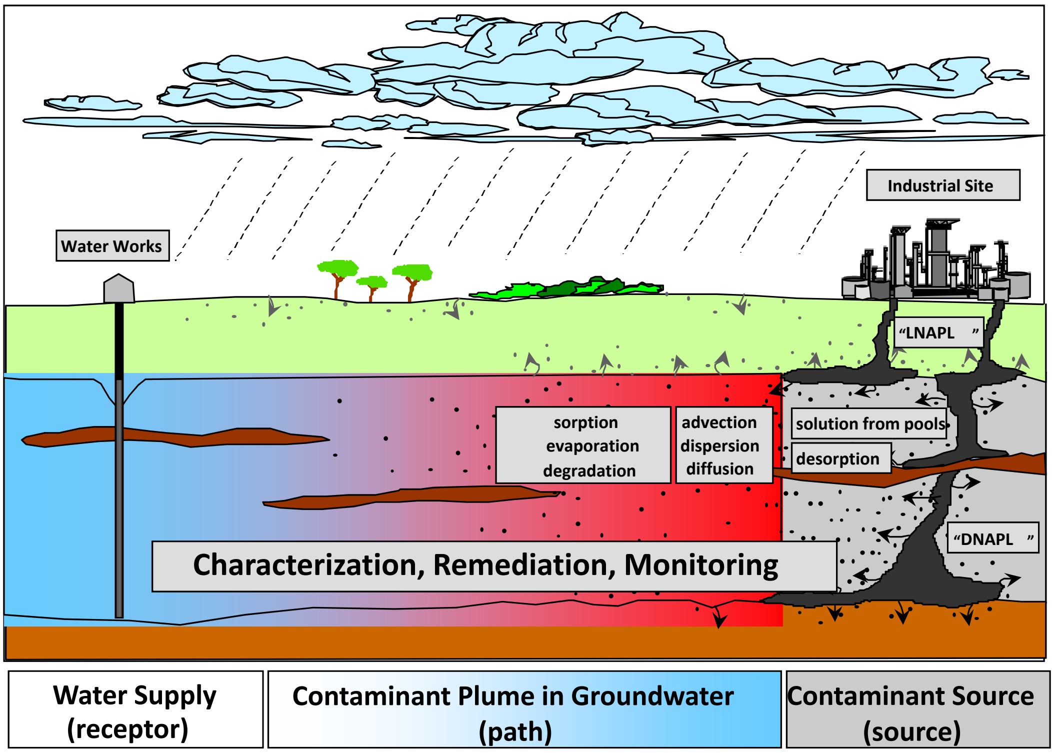
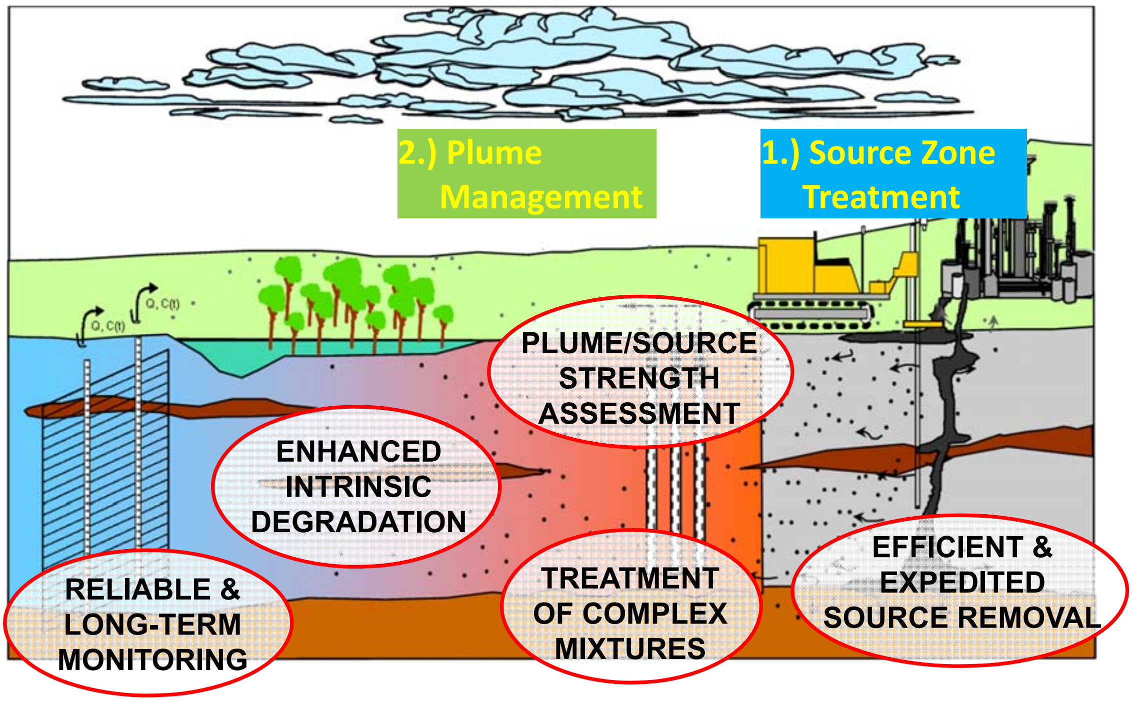
What can you expect ? ➔ flash lights

- The problem: Soil and groundwater contamination
- Source – plume
- Remediation methods ➔ *in-situ* technologies
  - Physical
  - thermal
  - chemical
  - biological
- Nanoremediation
- Contribution NanoRem

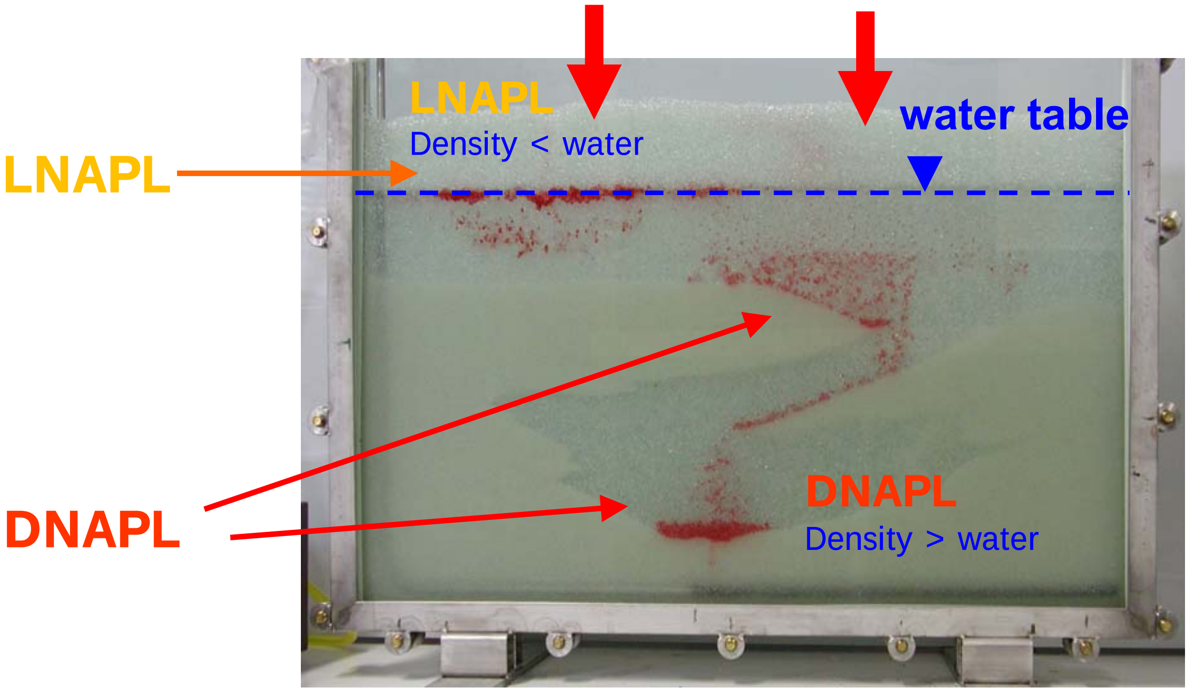
Industrial heritage: soil and groundwater contamination



Dealing with soil and groundwater contamination

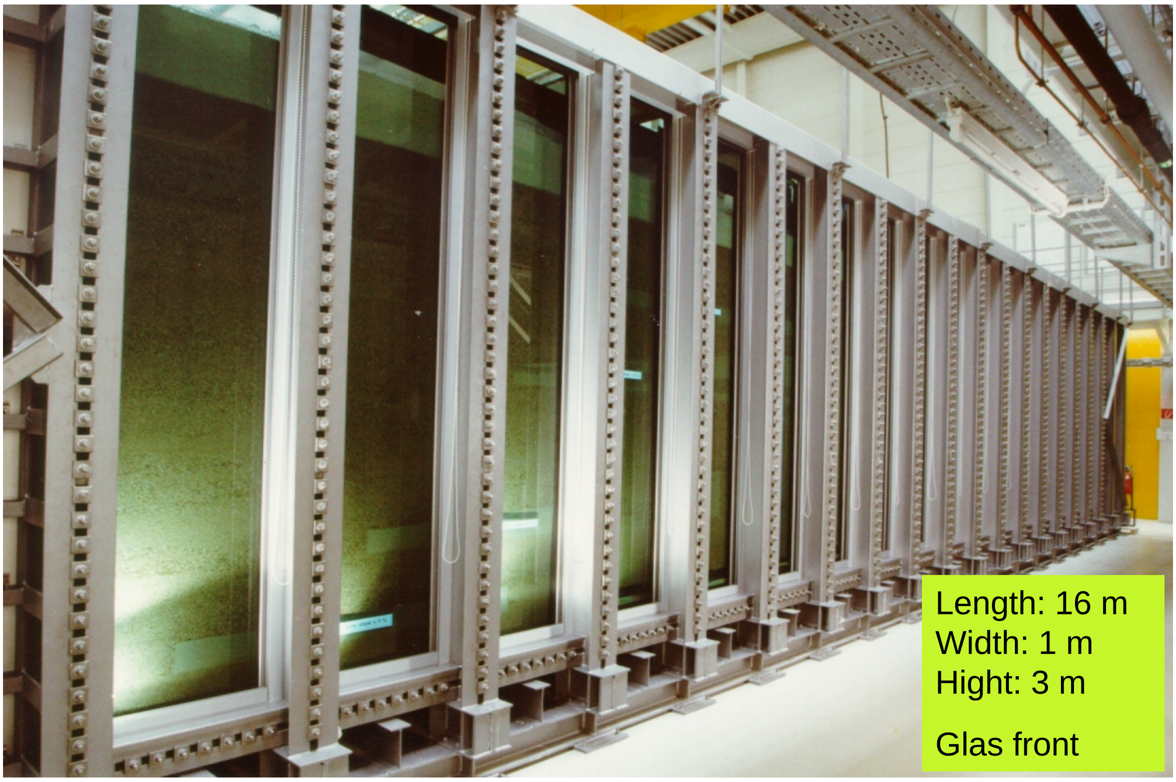


LNAPL / DNAPL problem



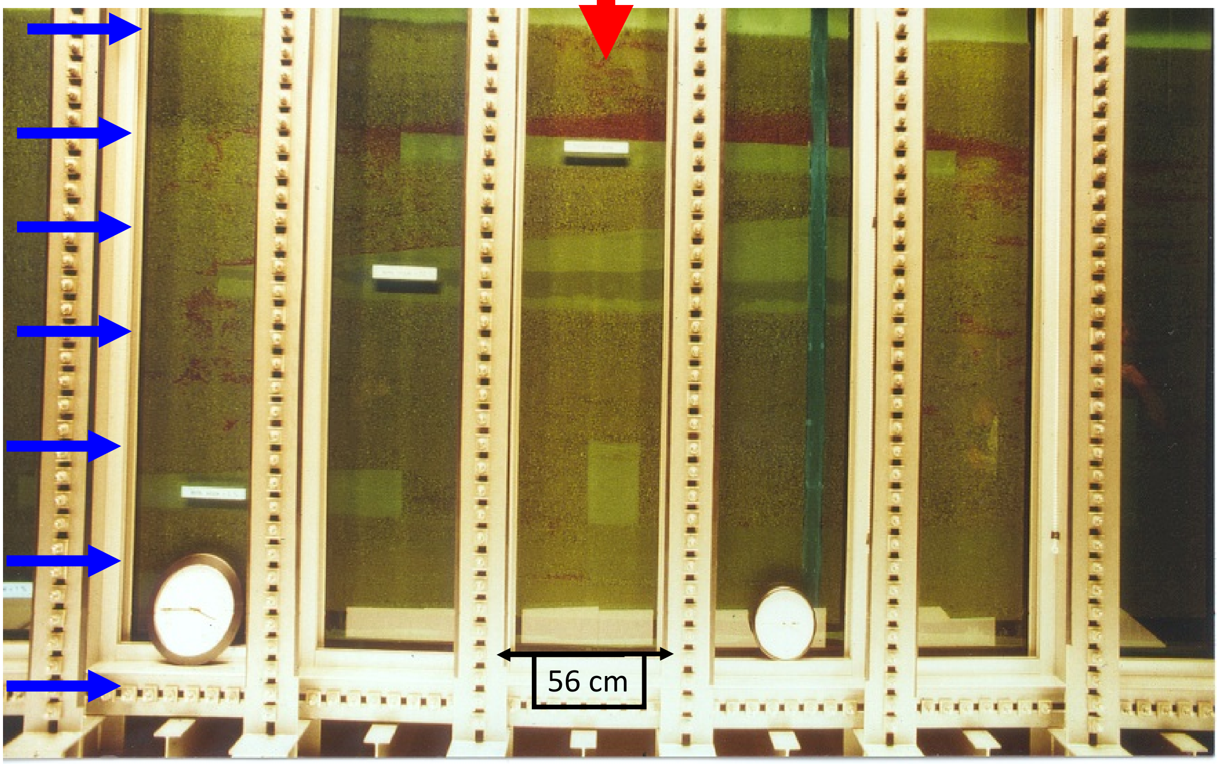
NAPL = Non-aqueous phase liquid (not miscible with water)

VEGAS Large Flume



WP1, University of Stuttgart
USTUTT – VEGAS

CHC spill in an aquifer



Source aquifer

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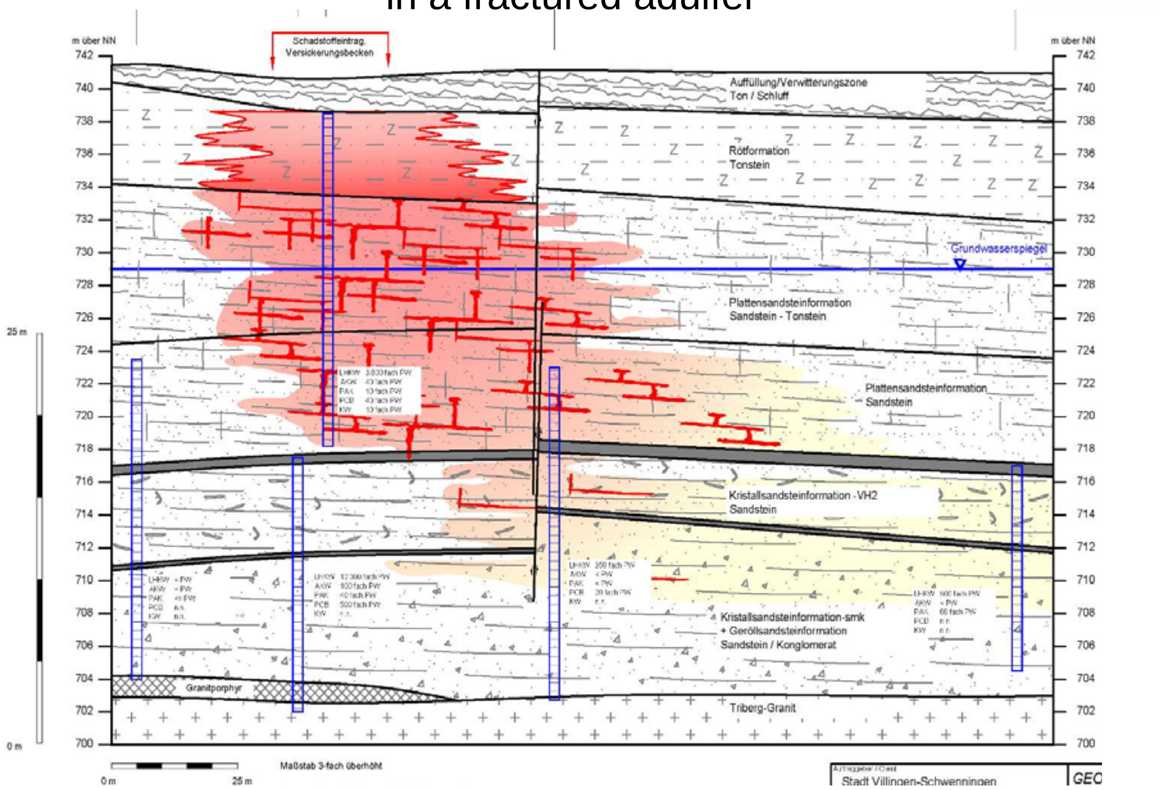
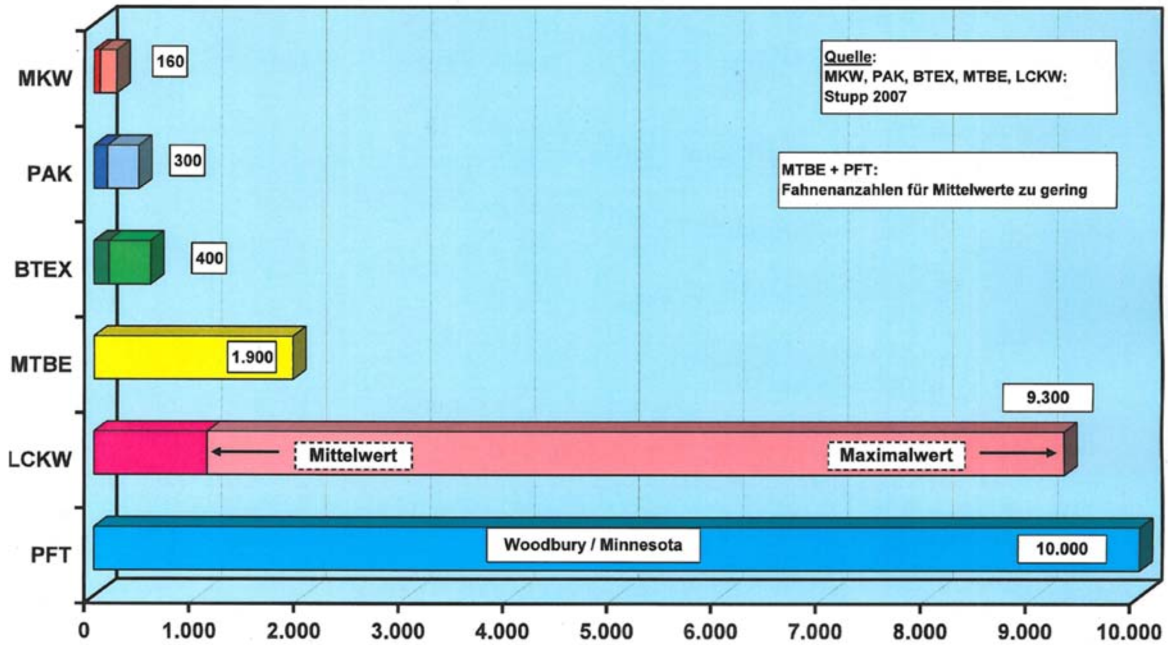
Geology and „image“ of a source zone in a fractured aquifer



Source fractured

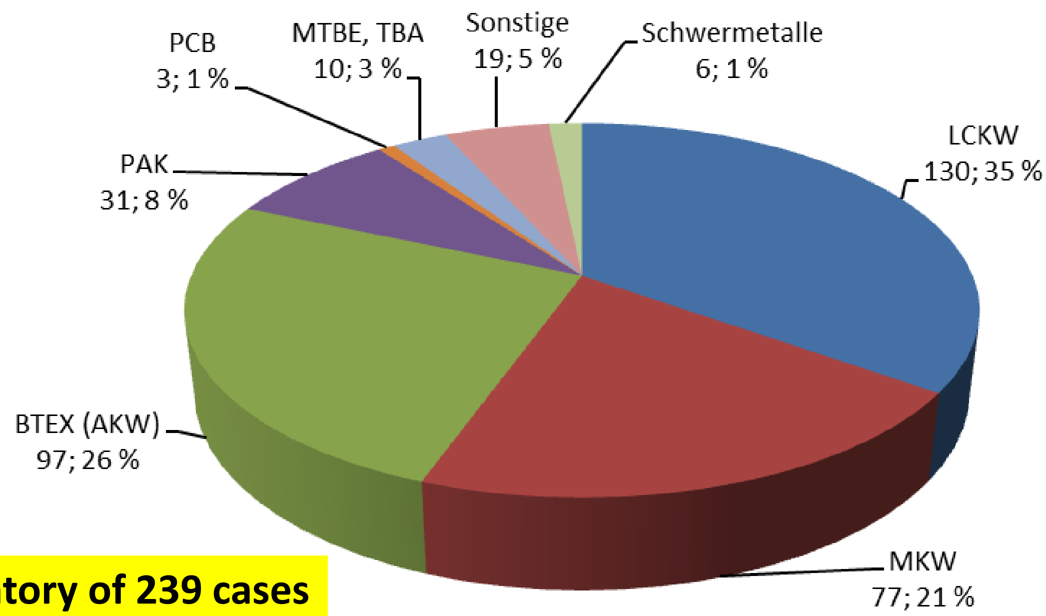
Plume lengths



Source: Dr. D. Stupp, 2011

Contamination treated *in-situ*

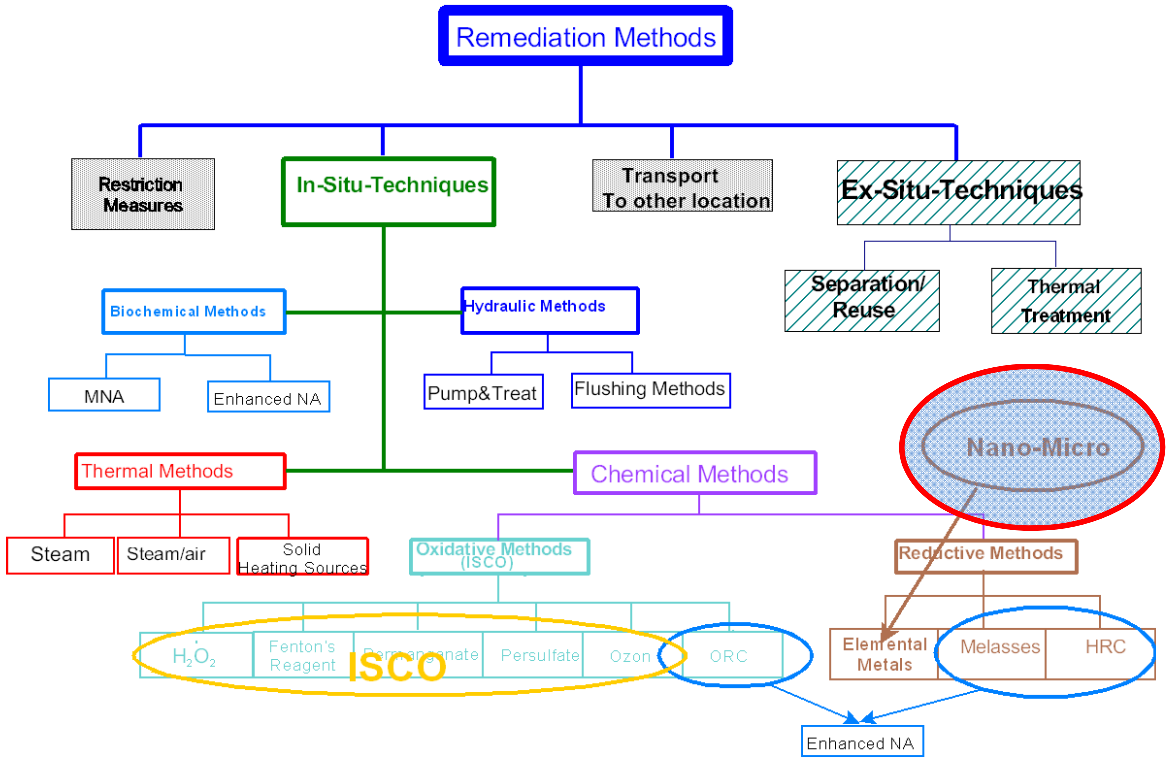
n = 373



Inventory of 239 cases

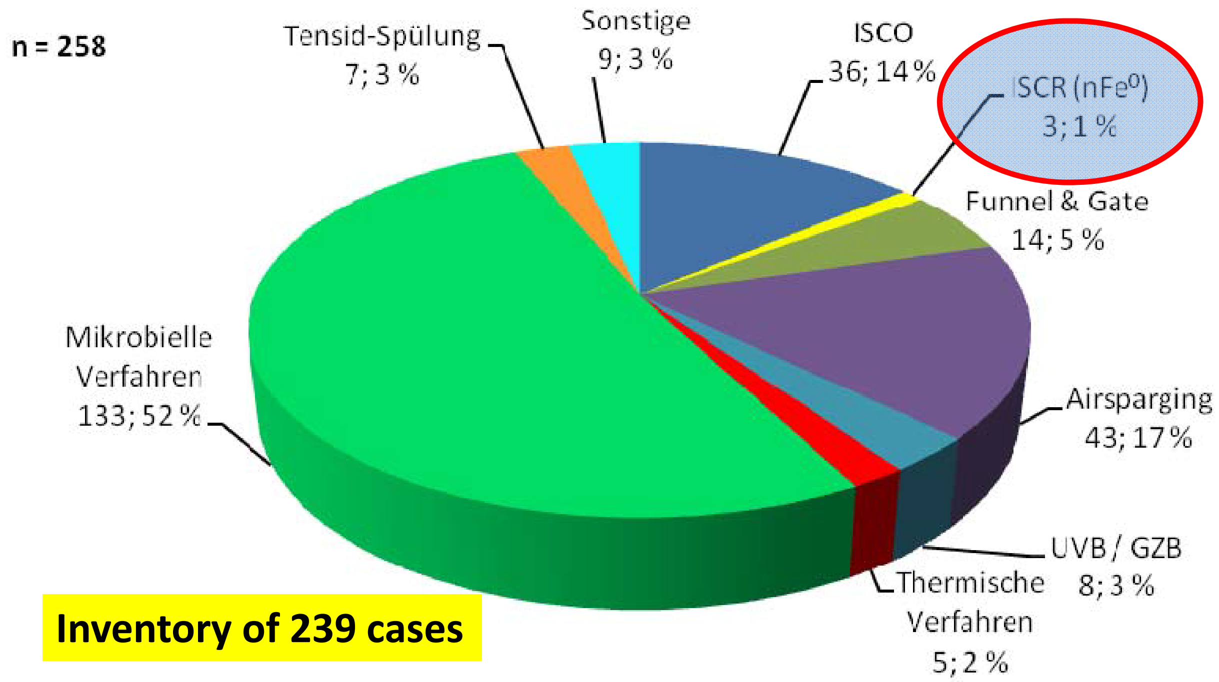
Held, Th., Schroers, St.; 2012, Länderfinanzierungsprogramm „Wasser, Boden und Abfall“ 2010, „Auswertung von Fällen mit In-situ-Anwendungen in der gesättigten Zone bei der Altlastenbearbeitung (Projekt B 3.10)
http://www.laenderfinanzierungsprogramm.de/cms/WaBoAb_prod/WaBoAb/Vorhaben/LABO/B_3.10/index.jsp

Soil and groundwater remediation



Applied *in-situ* methods

n = 258



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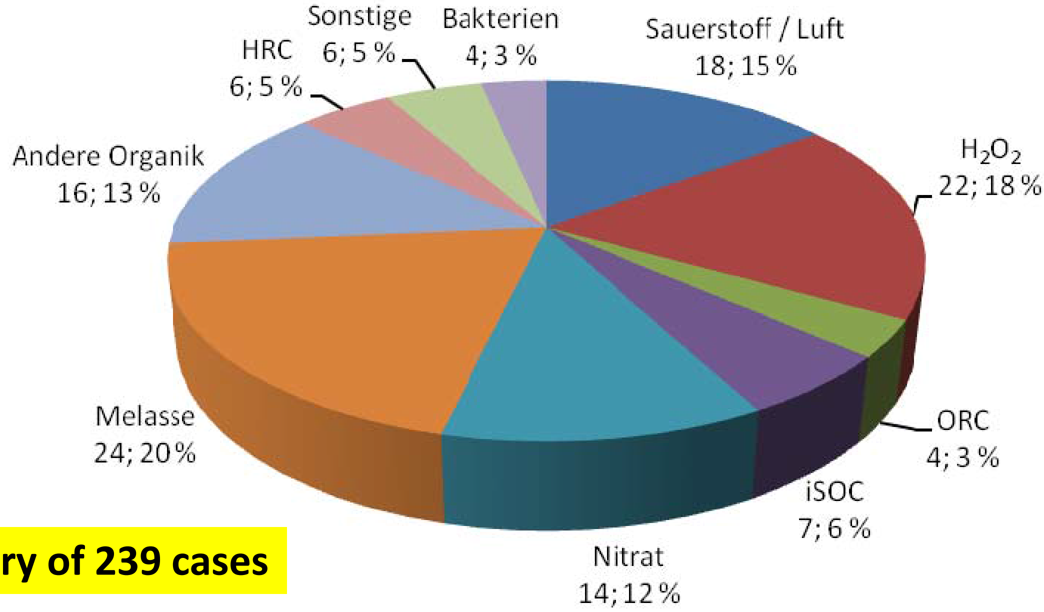
Microbiological methods

n = 121



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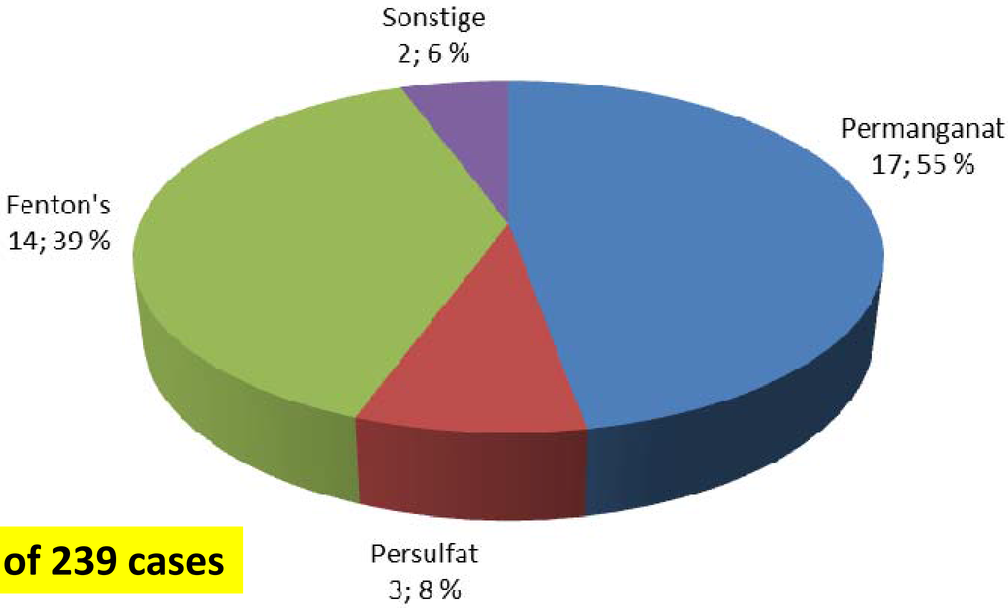
Applied ISCO techniques

n = 36



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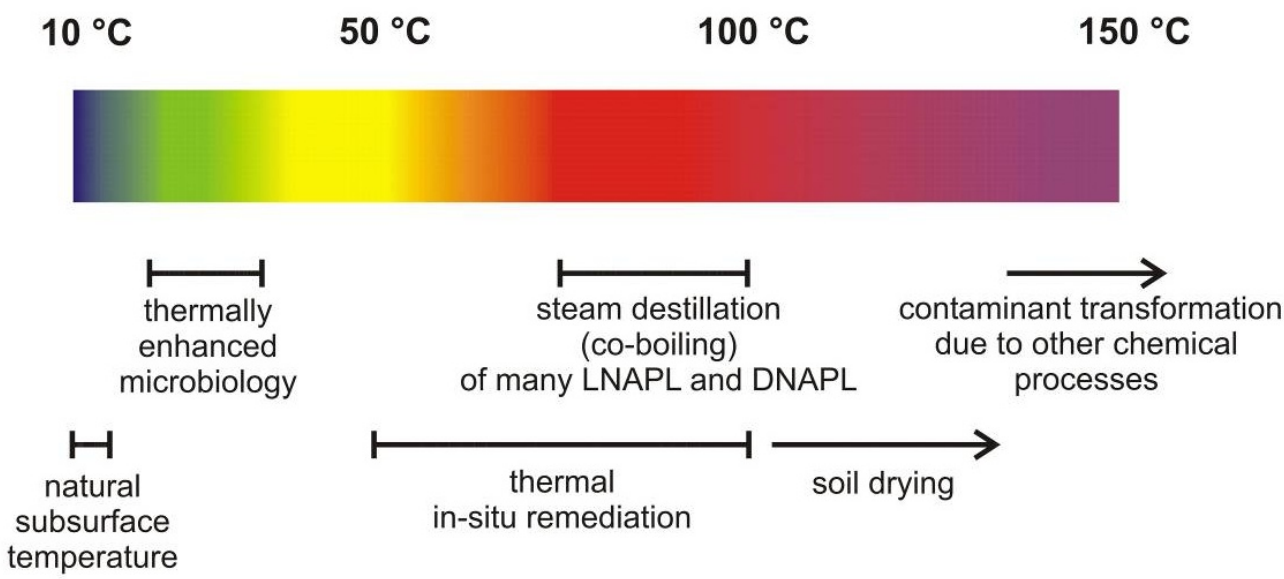
Thermal In-situ Technologies

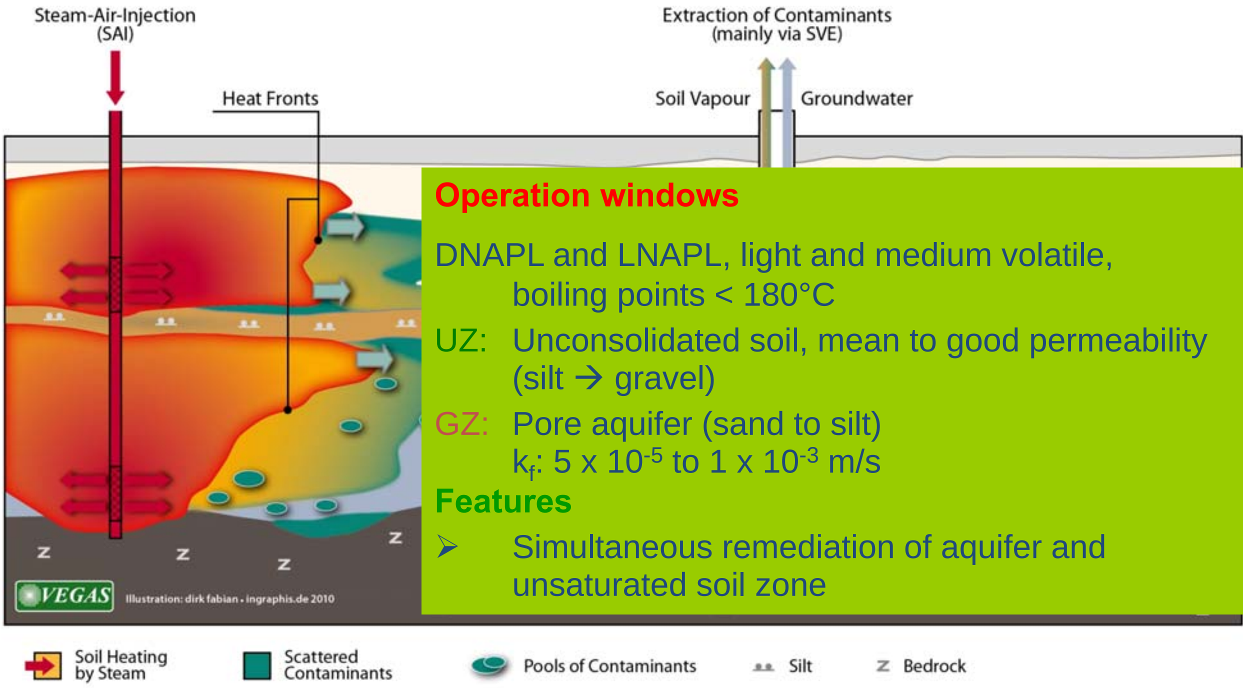
Convection →	Conduction	Ohm	di-electric
Steam- / Steam-Air - Injection	Conductive Heating, Thermal Wells (electric or hot gas)	Electric Resistance Heating	RF- / Radio-frequency Heating

- organic compounds (LNAPL & DNAPL)
- increase of vapor pressure of contaminant by heating of subsurface / steam distillation
  ➔ by factors enhanced extraction rates
- **Extraction of contaminants as gas** (SVE Soil Vapour Extraction)
- fast and reliable (and controllable) remediation process
  ➔ selection of technique dependent on site conditions and “composition“ of contaminants (mixtures)
  ➔ expert knowledge required

Operating Windows



Steam–Air–Injection (SAI)



Operation windows

DNAPL and LNAPL, light and medium volatile, boiling points < 180°C

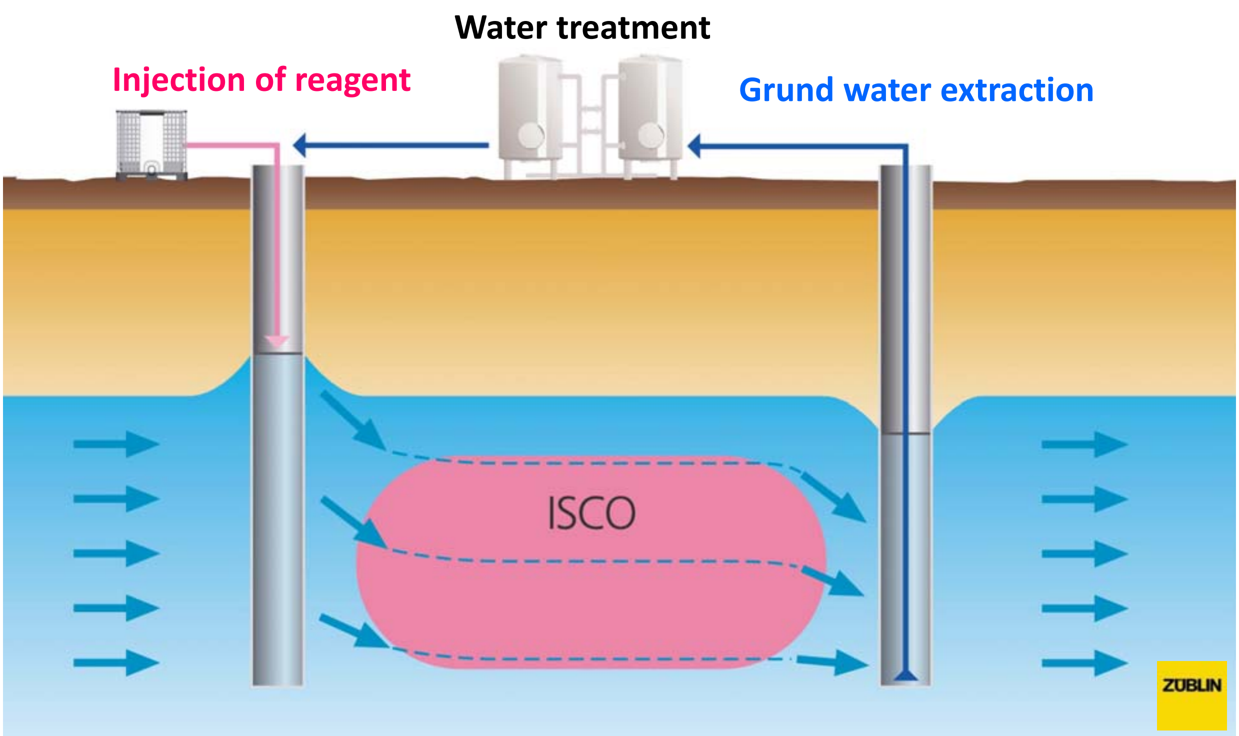
UZ: Unconsolidated soil, mean to good permeability (silt → gravel)

GZ: Pore aquifer (sand to silt) k_f: 5 x 10^{-5} to 1 x 10^{-3} m/s

Features

- Simultaneous remediation of aquifer and unsaturated soil zone

ISCO *in-situ* chemical oxidation



Oxidable or reducible contaminants

VEGAS

Oxidable contaminants

- hydrocarbons
- PAH
- BTEX
- CHC
- (ammonium → nitrate)

→end products:
CO_2, water

Reducible contaminants

- CHC
- (nitrate → N_2)
- (chromium (VI) → chromium (III))

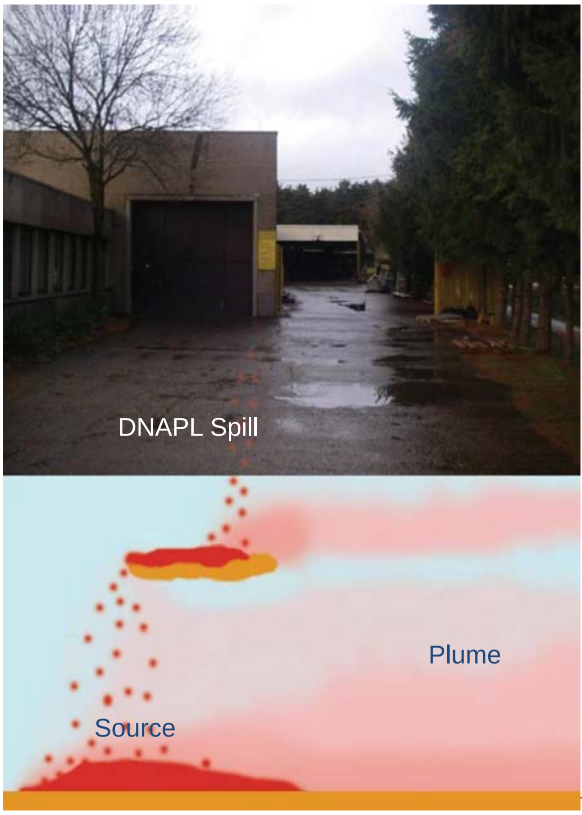
→end products:
hydrocarbons, chloride

ISCO and ISCR reagents

Oxidating agents	active agents	E_0 [V]	remarks
Permanganate	MnO_4^-	1,7	MnO_2 formed
Fenton's reagent	H_2O_2	1,8	complex chemism, difficult to handle reaction (pH)
	$OH^{\$}$	2,8	
	$HO_2^{\$}$	1,7	
	$O_2^{-\$}$	-2,4	
	HO_2^-	-0,88	
Ozone			
Persulfate			

Reduction agents	active Reagent	E_0 [V]	remarks
Iron	Fe	-0,4	well investigated, high density (transport?)
Non-Iron metals	Al	-1,66	little investigated, corrosion problems?
	Mg	-2,36	
"H_2": HRC, molasses, soy oil...	"H_2"	<-0.2	microbial reaction

Nano particles for *in-situ* remediation



- Small size
  ➔ higher surface area
  ➔ more reactive
- NPs (in a carrier fluid) injected into saturated zone via wells
- Focus on source treatment
- Applicable below buildings
- “independent” of application depth
- „semi-passive“ technology
- particles e.g. nZVI
- innovative technology

Carbo-Iron as In-situ reagent

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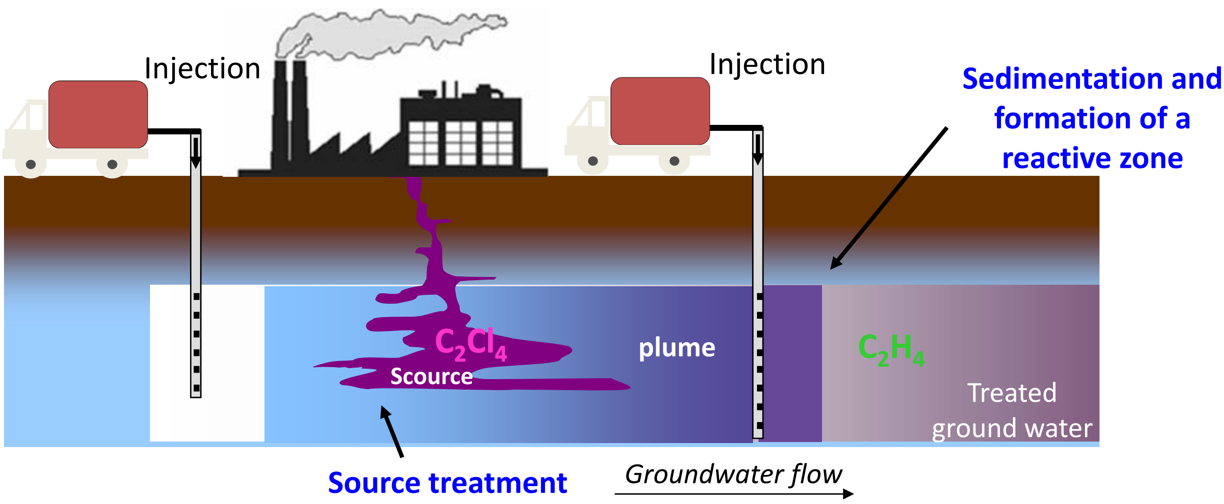
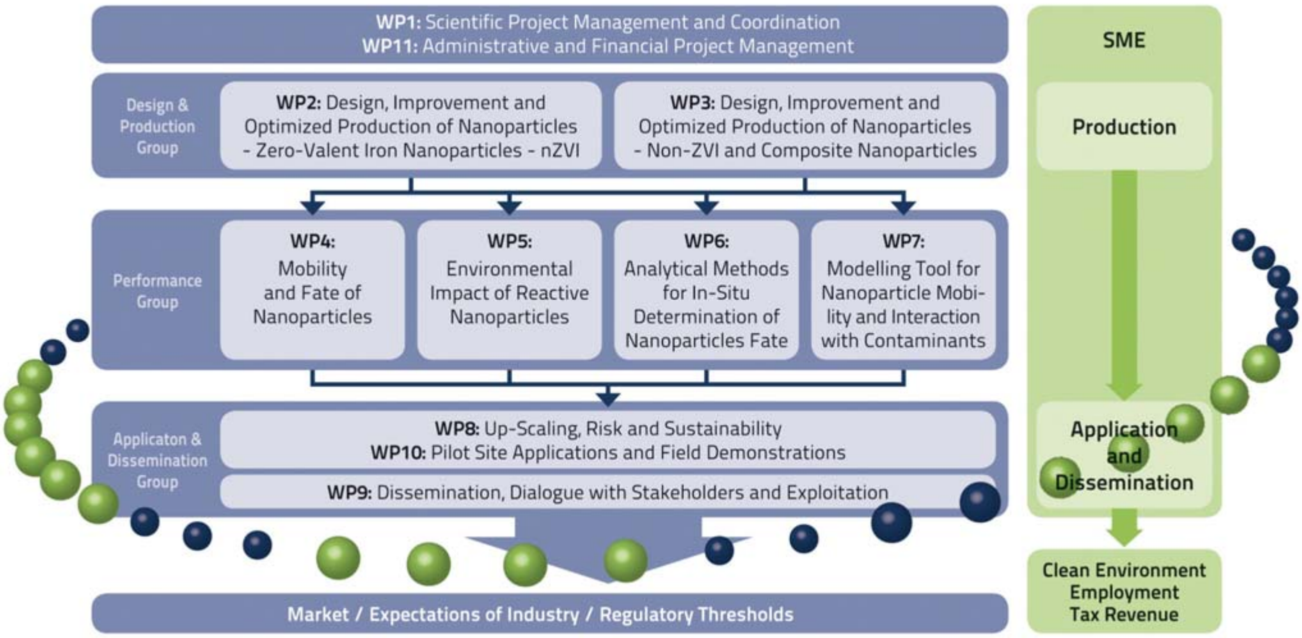


Composite Material ➔ Carbo-Iron:
→ Surface properties optimized for max. transport
→ Reactivity supported by sorption at Carbon particles

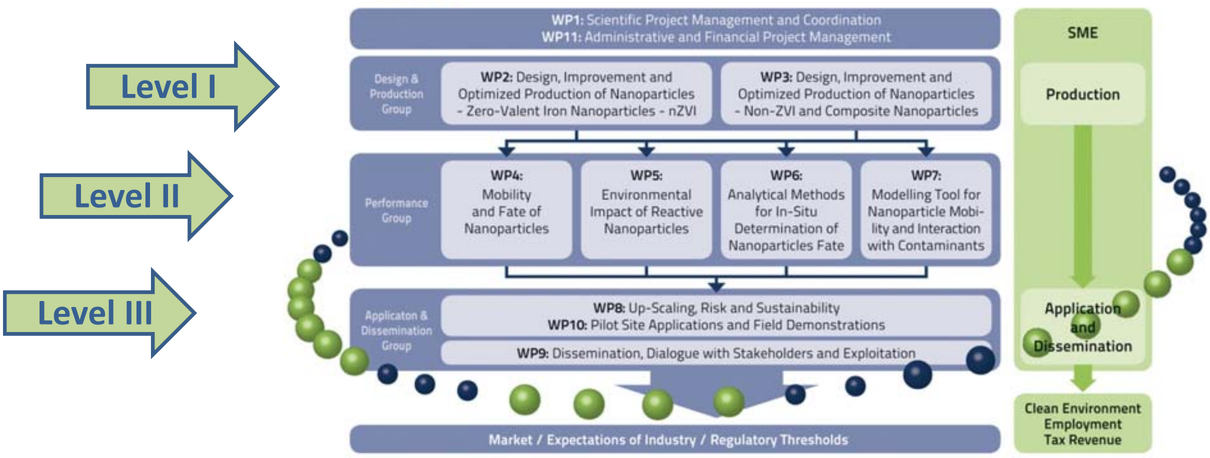
NanoRem Structure

Taking **Nano**technological **Rem**ediation Processes from Lab Scale to End User Applications for the Restoration of a Clean Environment



NanoRem´s three level approach

Taking **Nano**technological **Rem**ediation Processes from Lab Scale to End User Applications for the Restoration of a Clean Environment



I Development and production: **WP2** and **WP3**

II Properties and behavior in the environment: **WP4** to **WP7**

III Application, permission (approval) and promotion

- Large scale experiments and pilot sites: **WP8** and **WP10**
- Dissemination, communication and exploitation: **WP9**

NanoRem´s Overall Goals

- Identification of the most **appropriate nanoremediation technological approaches** that could achieve a **step-change** in practical remediation performance.
- Development of **lower cost production techniques** and production at **commercially relevant scales**, also for large-scale applications.
- Determination of the **mobility and migration potential** of nanoparticles in the subsurface, and their **potential to cause harm**, focusing on the NP types most likely to be adopted into practical use in the EU.
- **Development of a comprehensive toolbox** for the design of nanoremediation operations, field scale nanoremediation performance and determination of **the fate of NPs in the subsurface.**
- **Dissemination and stakeholder dialog** to ensure that research, development and demonstration meets end-user and regulatory requirements.
- Pre-deployment **risk assessment,** - regulatory requirement, **sustainability, market niche**
- Provision **of tests at representative scales** to validate cost, performance, and fate and transport findings.

NanoRem

NanoRem aims to

- unlock the true potential of nanoremediation
- support appropriate use of nanotechnology in restoring land and aquifer resources
- develop knowledge-based and economical remediation technology at a world leading level for the benefit of a wide range of users in the EU environmental sector
- enhance the development of nanoremediation markets and its applications in the EU and beyond

Production

Particle name	Manufacturer	Comment / used in NanoRem
NANOFER 25s	NanoIron	Reference particle, WP10: Large Scale Flume , Pilot sites CZ (DNAPL)
NANOFER STAR (air stable)	NanoIron	WP4: Cannot be transported To be optimized
NANOFER STAR* (air stable)	NanoIron	Modified NANOFER STAR Needed in WP 10: Large Scale Flume Pilot site IS
Milled Fe(0)	UVR-FIA	Needed in WP 10, Pilot site Zurzach, CH
Carbo-Iron (lab)	UFZ	Needed in WP10: Large Scale Flume
Carbo-Iron (industry)	SciDre Dresden	Pilot site HU
Fe-Oxide	HMGU	Needed in WP 10 : Large Scale Container, Pilot Site CZ (LNAPL), PO, ES
Bio-Fe-oxides	UMAN	Research status
Fe-Zeolites	UFZ	Research status
Nano-Metals (Mg, Al)	USTUTT	No final product available yet
Ferrates	USTUTT	No final product available yet

WP2 and WP3

NanoRem Pilot Sites

Site	Country	Site Primary Investigator	Target Cont.	NP-Type	Reaction Principle	Aquifer
Zurzach	CH	Solvay	CHC	milled nZVI	Reduction/ Sorption	porous / unconfined
Spolchemie 1	CZ	Aquatest	CHC	NANOFER 25s	Reduction	porous / unconfined
Spolchemie 2	CZ	Aquatest	BTEX	Iron-Oxide	Oxidation/ microbial Enhancement	porous / unconfined
Barreiro	PO	GeoPlano	HM	Iron-Oxide	Immobilisation	porous / unconfined
Besor-Secher Neot Hovar	IS	Negev, BGU	CHC	air-stable nZVI NANOFER STAR*	Reduction	fractured
Balassagyarmat	H	Golder	CHC	Carbo-Iron	Reduction / Soption	porous / unconfined
Bizkaia	ES	Tecnalia	HM	Iron-Oxide	Reduction/ Immobilisation	porous / unconfined

WP10 sites

Potential benefits

- Faster reaction
- Increased range of treatable contaminants
- Complete degradation / transformation
- Capacity for source term treatment
- Compatibility with *in situ* bio
- Limited environmental persistence
- More sustainable; no excavation, transport nor disposal is necessary

Thank **you for your interest**
and
the **EU for the funding**

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