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Design and feasibility of contaminated site clean-up technologies

Kirlenmiş saha temizleme yöntemlerinin dizayn ve fizibilitesi

Robert Raschman

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Contaminated Site Management

- Investigation
- Risk assessment
- Feasibility study
- Implementation design
- Remediation activities
- Supervision
- Post-Remediation monitoring

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- **_Investigation_**
- **_Risk Assessment_**
- **_Feasibility Study_**
- **_Implementation Design_**
- **_Remediation & Supervision_**
- **_Post-Remediation Monitoring_**

Investigation

- Site reconnaissance (history, operations, ownership, approach, surrounding areas etc.)
- Documentation review (maps, reports, authority decisions etc.)
- Geological and hydrogeological survey
- Identification of soil / groundwater contamination (priority contaminants, extend and level of contamination, source / plum zones)

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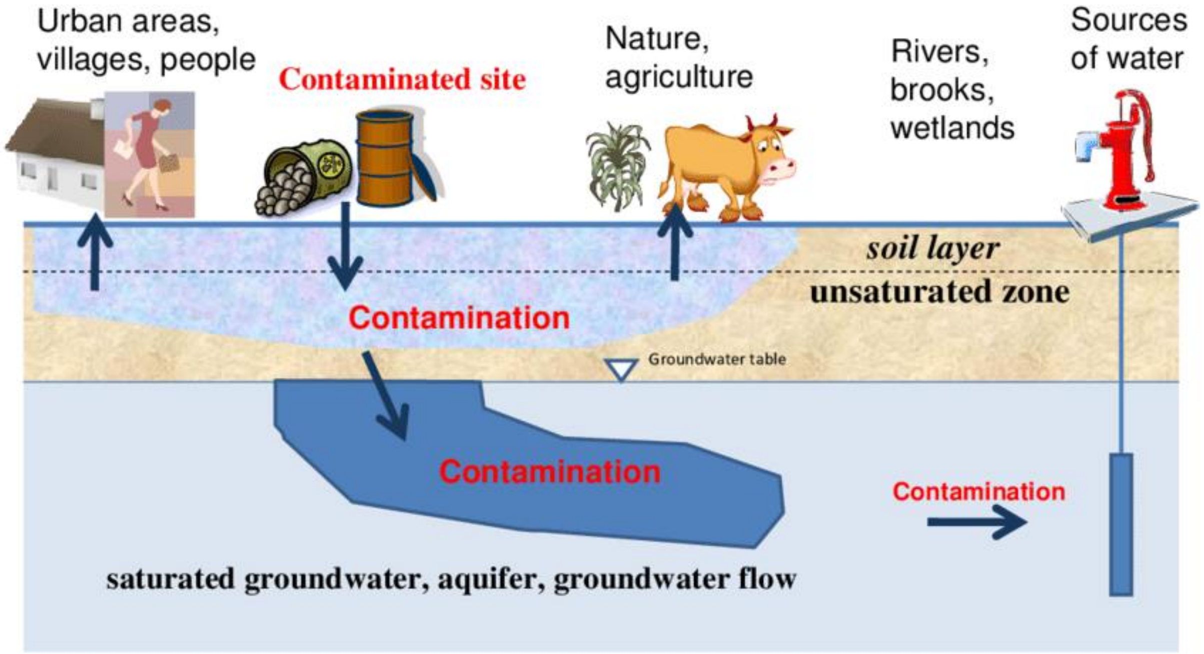
- *Investigation*
- *Risk Assessment*
- *Feasibility Study*
- *Implementation Design*
- *Remediation & Supervision*
- *Post-Remediation Monitoring*

Risk Assessment

- Identification of risk scenarios resulting from the real or potential negative impact of contamination on public health or on the environment
- Determination of adequate risk management measures (e,g, maximum acceptable soil and groundwater contamination levels „Target limits“, „Threshold values“, „Intervention limits“)



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- *Investigation*
- *Risk Assessment*
- *Feasibility Study*
- *Implementation Design*
- *Remediation & Supervision*
- *Post-Remediation Monitoring*

Feasibility Study & Implementation Design

Feasibility study on the site remediation

- Selection of the most suitable remediation approach
- Selection of the most suitable remediation method (technology)

Implementation design

- Detailed technical design of the selected remediation approach and method implementation (must respect the site-specific conditions, applicable legal requirements and technical standards, client´s requirements etc.)
- Approval of elaborated Implementation design
- Obtaining all permits, licences and approvals necessary for implementation of the designed activities in accordance with applicable legal requirements and decisions of local authorities

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- *Investigation*
- *Risk Assessment*
- *Feasibility Study*
- *Implementation Design*
- *Remediation & Supervision*
- *Post-Remediation Monitoring*

Remediation & Supervision

Remediation

↳ Acquiring and mobilization of equipment and machinery and personnel

↳ Installation and commissioning of technological equipment

↳ Implementation of remediation activities in accordance with the approved Implementation design

↳ Remediation monitoring (environmental, quality, hygiene etc.)

↳ Project management and reporting

↳ Verification (validation) sampling

↳ Handover of the remediated site to the client

Supervision

↳ Independent control of implemented remediation activities (material, time, financial performance)

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- *Investigation*
- *Risk Assessment*
- *Feasibility Study*
- *Implementation Design*
- *Remediation & Supervision*
- *Post-Remediation Monitoring*

Post-Remediation Monitoring

- Primarily concerned with residual contamination at a site
- Verification of long-term sustainability of implemented remediation measures
- Demonstrates that the objectives of the remedy are being met and that the risks to human health and the environment remain low and acceptable in the long term.
- Most often is associated with groundwater contamination ((because it is often impractical to completely remove contamination from groundwater)
- A separate presentation is devoted to this topic.

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Methodology of Feasibility Study

- Determination of the remediation objective(s)
- Evaluation of general response scenarios
- Set-up and evaluation of response approaches
- Identification and screening of remediation methods
- Assembly of remediation alternatives
- Evaluation of remediation alternatives
- Selection of the optimum remediation alternative

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- *Remediation objectives*
- *General response scenarios*
- *Evaluation of response approaches*
- *Screening of remediation methods*
- *Assembly of remediation alternatives*
- *Evaluation of remediation alternatives*
- *Selection of the optimum alternative*

Determination of Remediation Objectives

- Goals which have to be achieved by implementation of specific remediation measures.
- Clear definition of the objectives is necessary for subsequent evaluation of the possibility to achieve the objectives by application of pre-selected remediation alternatives
- Remedial action objectives aimed at protecting human health and the environment should specify:

  - Contaminants of concern

  - Exposure routes and receptors

  - Acceptable contaminant levels for each exposure route
- Recommended tool for determination of Remediation objectives: Risk Assessment (Risk Management Recommendations)

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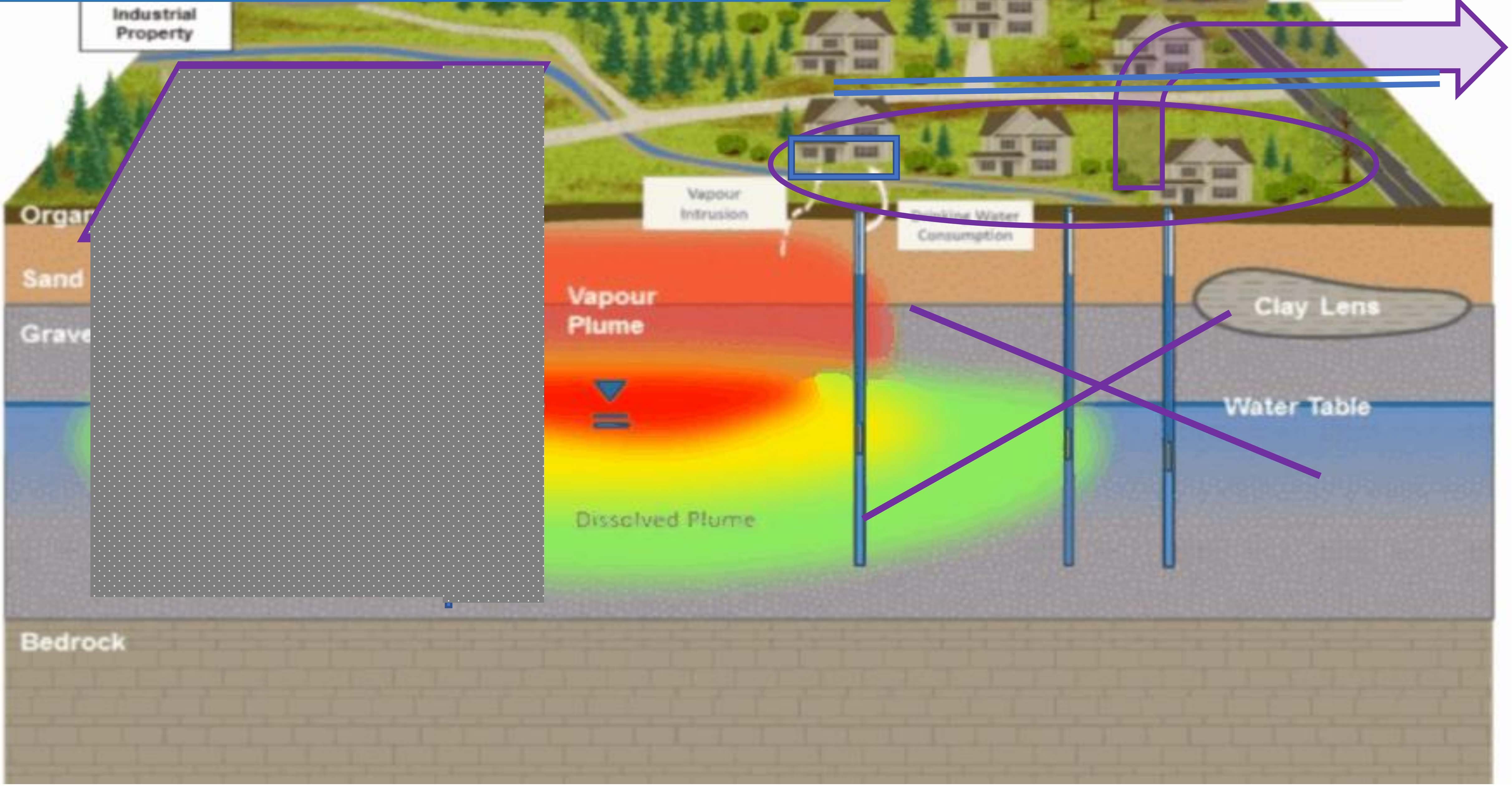
Evaluation of General Response Scenarios

- *"No action" scenario:* No active remediation measures are applied under this scenario. It is a baseline for comparison of other potential response scenarios.
- *Institutional control scenario:* Application of legal or administrative measures or actions to prevent exposure of public to existing contamination - such as administrative closure of the site for public, relocation of local inhabitants to another area etc.
- *Engineering control scenario* - Application of technical measures to minimize risks related to exposure of public to existing contamination - such as containment (capping), connection to a public drinking water network etc.
- *Treatment scenario* - Response scenario based on reduction of the site contamination by application of one or more soil and/or groundwater treatment methods.

Treatment Scenario



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Evaluation of Response Approaches

- Selection of the scenario(s) fulfilling the relevant remediation goals
- Combination of several response scenarios can be applied at a site
- Example: • Industrial and residential area • Soil and groundwater contaminated with POPs and other contaminants • Remediation goals: (i) Protection of groundwater resources and (ii) Reduction of public health risks to acceptable level • Exposure routes: (i) Contaminated groundwater
    - Response Approach 1: Treatment Scenario only (Soil and groundwater remediation)
    - Response Approach 2: Combination of Engineering Scenario (Containment of the source zone), Institutional Scenario (ban on groundwater use), Treatment Scenario: Groundwater pumping and treatment inside containment

skládka
smer prúdenia podzemnej vody
HOPV SLOVNAFT
Dunaj
vodárenský zdroj Jelka
vodárenský zdroj Kalinkovo
vodárenský zdroj Hamuliakovo
vodárenský zdroj Šamorín
Zdrž Hrušov
Zdrž Hrušov
Hydrogeologické (monitorovacie) vrty
Monirovací vrt Slovnaft
Sonda SHMÚ
Vrt HOPV Slovnaft
Hranica modelovaného územia
N
0m 2500m 5000m 7500m
Germany
Czechia
Slovakia
Austria
Hungary
Romania
Croatia
Vienna
Bratislava
Ohraničenie skládky
Plocha A
Plocha B
Trvalo obývané domy v záhradkárskej oblasti
Google

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Information Summary:

- Former blind arm of the river Maly Dunaj
- From 1966 till 1979 officially used as a landfill for disposal of waste from chemical plant CHZJD / Istrochem (pesticide production)
- Area: 46 500 m^2
- Thickness of deposited waste layer: 1,5 - 2,5 m.
- Quantity of deposited waste: 90 000 m^3
- Rehabilitation of the landfill: 1980 (just covering with 2-3 m of clean soil)
- Priority contaminants: Chlorinated pesticides (Hexachlorobenzene, Hexachlorocyclohexane isomers), Herbicides, Chlorinated benzenes (chlorobenzene, dichlorobenzenes), PCBs, PAHs, BTEX, TPHs, Heavy metals

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Potential risks:

- Workers in workshops and warehouses constructed on the landfill area (Northern part)
- Homeless people in an emergency accommodation facility (Northern part)
- Random visitors of freely accessible areas (dogs walking)
- Residents of several houses and garden owners in the area adjacent to the Southern part of the landfill
- Residents of the nearby Bratislava districts Vrakuňa and Podunajské Biskupice due to the use of contaminated groundwater
- Residents in villages downstream groundwater flow potentially at risk of pollution migrating from the landfill area
- Malý Dunaj river Southeast of the landfill

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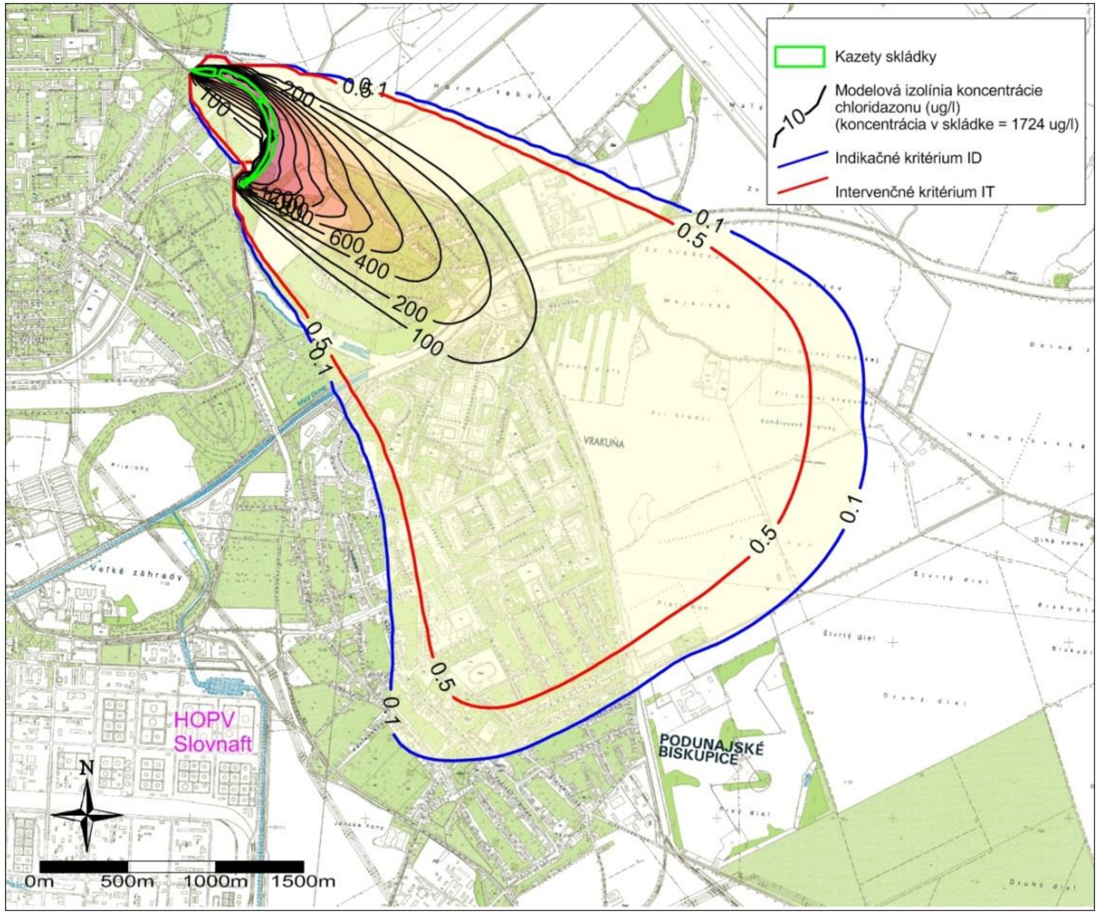
Mathematical Model:

- Contaminants from the landfill can migrate deep into the central area of the Žitný ostrov area, which is an important groundwater reservoir.



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Risk Management Measures:

- Reduce the concentration of priority contaminants in the unsaturated zone or take adequate protective measures to prevent possible contact of persons with contaminated soil and further deterioration of groundwater quality.
- Reduce the level of groundwater contamination or take adequate protective measures so that pollution does not migrate to the residential areas of Bratislava Vrakuňa and Podunajské Biskupce and further to the Žitný ostrov area.
- Do not use water from wells in Vrakuna for drinking, bathing (pools), washing and garden watering.
- Prevent new construction activities at the landfill area.
- Restrict free access to the landfill area (eg by its fencing).

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- Do not increase groundwater pumping downstream groundwater flow.
- Monitor development of groundwater pollution both at the landfill area and downstream groundwater flow and further at Žitný ostrov reservoir.

Threshold limmits:

- For soi in zones A and B
- For groundwater in zones A and B.

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Remediation Approaches:

- *“No action” scenario:* All the identified risks will endanger public health and the environment for a very long time.
- *Institutional control scenario:* The main identified risks will endanger public health and the environment for a very long time.
- *Engineering control scenario* - Application of technical measures aimed at minimizing the contact with the contaminated environment and elimination of further migration of pollution. It does not remove or reduce the level of contamination in the area of interest.

Technical solution:

- Construction of an underground slurry wall around the entire landfill area (total length 2,050 m)
- Capping of the landfill area with impermeable surfaces
- Pumping and treatment groundwater from the area surrounded by an underground slurry wall

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- Implementation time: 18 months
- Estimated investment costs: EUR 14 600 000
- Estimated operational costs (groundwater pumping, maintenance, monitoring: EUR 240 000 / year

- *Treatment scenario* - Technical solution:
  - Ex situ remediation of source area
  - Enhanced attenuation of plume zone
  - Implementation time: 59 months
  - Estimated costs: EUR 113 130 000

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Screening of Remediation Methods

- Once the preferred response approaches have been selected, engineering and/or treatment methods potentially suitable for technical implementation of the approaches should be identified and screened.
- Those remediation methods that are clearly not feasible (e.g. not effective or implementable or are substantially more costly than other technologies for a selected response approach) should be eliminated from further consideration.
- Following aspect should be considered when screening the remediation methods: (i) Efficiency in removing existing contamination, (ii) Technical feasibility under the project conditions, (iii) Duration of remediation, (iv) Legislative aspects and permitting, (iv) Limitations and risks, (vi) Costs

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- *Remediation objectives*
- *General response scenarios*
- *Evaluation of response approaches*
- *Screening of remediation methods*
- *Assembly of remediation alternatives*
- *Evaluation of remediation alternatives*
- *Selection of the optimum alternative*

Classification of Remediation Methods

a) According to principle of applied technology:

- Physical
- Chemical
- Biotechnological
- Other

PHYSICAL	CHEMICAL	BIOLOGICAL	OTHER
Soil (waste)	**Soil (waste)**	**Soil (waste)**	**Soil (waste)**
mechanical treatment and sorting	chemical oxidation	bioventing	landfilling
solidification/stabilisation	chemical reduction	phyto-remediation	isolation of contamination by underground sealing and by covering
venting	neutralisation	biodegradation	
washing			
incineration			
thermal desorption			
Groundwater	**Groundwater**	**Groundwater**	**Groundwater**
air sparging	chemical oxidation	biological reductive dechloration	hydraulic barriers
pumping and subsequent treatment:	chemical reduction	biological reduction	reactive barriers
separation by gravity	neutralisation	bio-slurping	monitored / assisted attenuation
stripping (by air or steam)		biodegradation	isolation of contamination by underground sealing and by covering
sorption			
coagulation			
flocculation			

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Classification of Remediation Methods

b) According to applied strategy:

- Extraction of contaminants (pump&treat etc.)
- Destruction or transformation of contaminants (bioremediation etc.)
- Immobilization of contaminants (insulation etc.)
- Monitoring of existing contamination
- Institutional measures (e.g. closure of the site for public)

c) According to the location where decontamination process takes place:

- In Situ
- Ex Situ (On-site, Off-site)

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- *Remediation objectives*
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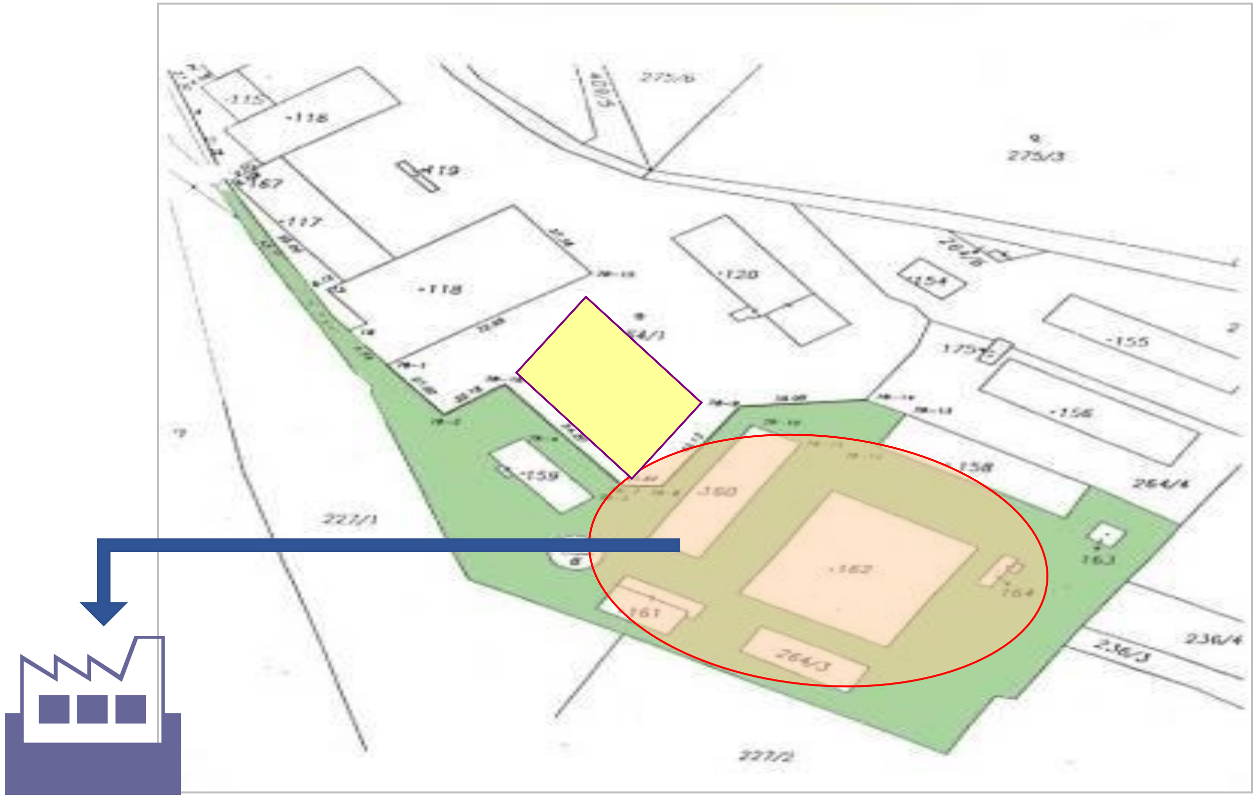
c) According to location where decontamination process takes place:

- „In situ“ - directly inside contaminated saturated zone
- „Ex situ“ - after extraction of contaminated groundwater
    - „On-site“ - treatment at the remediated site
    - „Off-site“ - treatment outside the cleaned-up area, in a permitted facility (landfill etc.)



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- *Remediation objectives*
- *General response scenarios*
- *Evaluation of response approaches*
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- *Evaluation of remediation alternatives*
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Overview of Remediation Methods

Complex overview of today applied methods for soil and groundwater remediation:

- see US EPA: Remediation Technologies Screening Matrix and Reference Guide
- Content:

1 Introduction
2 Contaminant perspectives
3 Treatment perspectives
4 Treatment technology profiles (59 methods)
5 References

http://www.frtr.gov/matrix2/

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FRTR

Remediation Technologies Screening Matrix and Reference Guide, Version 4.0

Section 2 Introduction: Contaminant Perspectives

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Information on classes and concentrations of chemical contaminants, how they are distributed through out the site, and in what media they appear is essential to begin the preselection of treatment technologies. In this document, contaminants have been separated into eight contaminant groups as follows:

- Nonhalogenated volatile organic compounds (VOCs).
- Halogenated volatile organic compounds.
- Nonhalogenated semivolatile organic compounds (SVOCs).
- Halogenated semivolatile organic compounds
- Fuels.
- Inorganics.
- Radionuclides.
- Explosives.

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Remediation Technologies Screening Matrix and Reference Guide, Version 4.0

2.6 HALOGENATED SEMIVOLATILE ORGANIC COMPOUNDS (SVOCs)

Sites where halogenated SVOCs may be found include burn pits, chemical manufacturing plants and disposal areas, contaminated marine sediments, disposal wells and leach fields, electroplating/metal finishing shops, firefighting training areas, hangars/aircraft maintenance areas, landfills and burial pits, leaking collection and system sanitary lines, leaking storage tanks, radiologic/mixed waste disposal areas, oxidation ponds/lagoons, pesticide/herbicide mixing areas, solvent degreasing areas, surface impoundments, and vehicle maintenance areas and wood preserving sites. Potentially applicable remediation technologies are presented in Table 2-4. Typical halogenated SVOCs, excluding fuels and explosives, which are presented in subsection 2.7 and subsection 2.10, encountered at many sites include the following:

1,2,4-Trichlorobenzene	4-Chloroaniline	Hexachlorobenzene
1,2-Bis(2-chloroethoxy) ethane	4-Chlorophenyl phenylether	Hexachlorobutadiene
1,2-Dichlorobenzene	Bis(2-chloroethoxy) ether	Hexachlorocyclopentadiene
1,3-Dichlorobenzene	Bis(2-chloroethoxy) methane	o-dichlorobenzene
1,4-Dichlorobenzene	Bis(2-chloroethoxy) phthalate	p-Chloro-m-cresol
2,4,5-Trichlorophenol	Bis(2-chloroethyl) ether	p-dichlorobenzene
2,4,6-Trichlorophenol	Bis(2-chloroisopropyl) ether	Pentachlorobenzene
2,4-Dichlorophenol	Chlordane	Pentachlorophenol (PCP)
2-Chloronaphthalene	Chlorobenzene	Polychlorinated biphenyls (PCBs)
2-Chlorophenol	Chlorobenzilate	Quintozene
3,3-Dichlorobenzidine	Chlorphenothane	Tetrachlorophenol
4-Bromophenyl phenyl ether	Hexachlorobenzene	Unsym-trichlorobenzene

- Pesticides:

Aldrin	4,4´-DDT	Ethyl parathion
BHC-alpha	Dieldrin	Heptachlor
BHC-beta	Endosulfan I	Heptachlor epoxide
BHC-delta	Endosulfan II	Malathion
BHC-gamma	Endosulfan sulfate	Methylparathion
Chlordane	Endrin	Parathion
4,4´-DDD	Endrin aldehyde	Toxaphene
4,4´-DDE	Ethion	

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2.5 NONHALOGENATED SEMIVOLATILE ORGANIC COMPOUNDS (SVOCs)

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Sites where nonhalogenated SVOCs may be found include burn pits, chemical manufacturing plants and disposal areas, contaminated marine sediments, disposal wells and leach fields, electroplating/metal finishing shops, firefighting training areas, hangars/aircraft maintenance areas, landfills and burial pits, leaking collection and system sanitary lines, leaking storage tanks, radiologic/mixed waste disposal areas, oxidation ponds/lagoons, pesticide/herbicide mixing areas, solvent degreasing areas, surface impoundments, and vehicle maintenance areas and wood preserving sites. Potentially applicable remediation technologies are presented in Table 2-3. Typical nonhalogenated SVOCs (excluding fuels and explosives, which are presented in Subsection 2.7 and subsection 2.10) encountered at many sites include the following:

1,2-benzacenaphthene	Benzidine	Ethyl parathion
1,2-Diphenylhydrazine	Benzo(a)anthracene	Fluorene
1-aminonaphathalene	Benzo(a)pyrene	Indeno(1,2,3-cd)pyrene
2,3-phenylenepyrene	Benzo(b)fluoranthene	Isophorone
2,4,-Dinitrophenol	Benzo(k)fluoranthene	Malathion
2-aminonaphthalene	Benzoic Acid	Methylparathion
2-Methylnaphthalene	Benzyl alcohol	Naphthalene
2-Nitroaniline	Bis(2-ethylhexyl)phthalate	n-Nitrosodimethylamine
2-Nitrophenol	Butyl benzyl phthalate	n-Nitrosodi-n-propylamine
3-Nitroaniline	Chrysene	n-Nitrosodiphenylamine
4,6-Dinitro-2-methylphenol	Dibenzofuran	Parathion
4-Nitroaniline	Diethyl phthalate	Phenanthrene
4-Nitrophenol	Dimethyl phthalate	Phenyl naphthalene
Acenaphthene	Di-n-butyl phthalate	Pyrene
Acenaphthylene	Di-n-octyl phthalate	tetraphene
Allyldioxybenzene methylene ether	Diphenylenemethane	
Anthracene	Ethion	

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4 TREATMENT TECHNOLOGY PROFILES

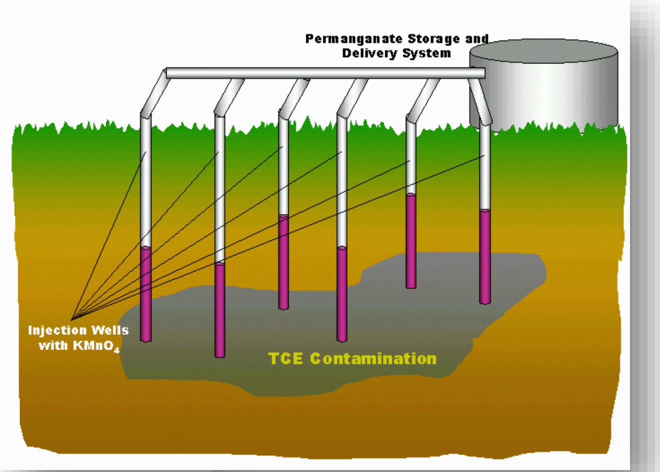
Soil, Sediment, Bedrock and Sludge Treatment Technologies

In Situ Biological Treatment

In Situ Physical/Chemical Treatment

In Situ Thermal Treatment

Ex Situ Biological Treatment



Technology>> Soil, Sediment, Bedrock and Sludge

>>3.10 In Situ Physical/Chemical Treatment

>>4.4 Chemical Oxidation

Introduction>> Oxidation chemically converts hazardous contaminants to non-hazardous or less toxic compounds that are more stable, less mobile, and/or inert. The oxidizing agents most commonly used are ozone, hydrogen peroxide, hypochlorites, chlorine, and chlorine dioxide.

Description:

Figure 4-4: Typical Chemical Oxidation System

The Chemical oxidants most commonly employed to date include peroxide, ozone, and permangan
organic chemicals; other organics are amenable to partial degradation as an aid to subsequent bior
percent) for unsaturated aliphatic (*e.g.*, trichloroethylene [TCE]) and aromatic compounds (*e.g.*, ben
affirmed that matching the oxidant and *in situ* delivery system to the contaminants of concern (COC

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Applicability:

The rate and extent of degradation of a target COC are dictated by the propert
temperature, the concentration of oxidant, and the concentration of other oxida
scavengers. Given the relatively indiscriminate and rapid rate of reaction of the
importance. Oxidant delivery systems often employ vertical or horizontal inject

Permanganate is relatively more stable and relatively more persistent in the su
system. All three oxidation reactions can decrease the pH if the system is not l
of redox-sensitive and exchangeable sorbed metals; possible formation of toxi

Limitations:

The following factors may limit the applicability and effectiveness of chemcial c

- Requirement for handling large quantities of hazardous oxidizing chem
- Some COCs are resistant to oxidation.
- There is a potential for process-induced detrimental effects. Further res
cost effectivenes.

Data Needs:

Engineering of *in situ* chemical oxidation must be done with due attention paid
process chemicals as well as proper management of remediation wastes. The
reaction transport modeling, combined with treatability studies at the lab and fi

Performance Data:

In situ chemical oxidation is a viable remediation technology for mass reduction in source areas as well as for plu
reactions with various COCs applicable to many bio-recalcitrant organics and subsurface environments. Also, *in*
available equipment. Some potential limitations exist including the requirement for handling large quantities of ha
unproductive oxidant consumption of the formation; some COCs are resistant to oxidation; and there is a potenti
advance the science and engineering of *in situ* chemical oxidation and to increase its overall cost effectiveness

Cost:

No costs figures are currently available.

References:

EPA, 2000.Ground Water Currents, December 2000, Issue No. 41: Current Issue: Interagency Demonstrations o

EPA, 2000.Ground Water Currents, September 2000, Issue No. 37: Current Issue: *In Situ* Chemical Oxidation fo

MTBE Treatment Case Studies presented by the USEPA Office of Underground Storage Tanks.

Guide to Documenting and Managing Cost and Performance Information for Remediation Projects - Revised Ver

Abstracts of Remediation Case Studies, Volume 4, June 2000,EPA 542-R-00-006

Advanced Photochemical Oxidation - Abstract, EPA/625/R-98/004

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	●	○	○	◑	◑	○	◑	◑	◑	◑	◑	◑	○	●	◑	○
4.6 Fracturing	●	◑	◑	○	◑	◑	◑	●	◑	◑	◑	◑	◑	○	○	○
4.7 Soil Flushing	●	●	○	◑	◑	◑	◑	●	●	●	◑	◑	◑	●	○	○
4.8 Soil Vapor Extraction	●	○	○	◑	●	●	◑	●	●	●	○	○	●	○	○	○
4.9 Solidification/Stabilization	●	●	◑	○	●	●	●	●	○	○	◑	◑	○	●	●	○
3.3 In Situ Thermal Treatment																
4.10 Thermal Treatment	●	○	○	○	●	◑	●	●	●	●	●	●	●	○	○	○
3.4 Ex Situ Biological Treatment (assuming excavation)																
4.11 Biopiles	●	●	●	●	●	●	◑	●	●	●	◑	◈	●	◈	○	○
4.12 Composting	●	●	●	●	●	●	◑	●	◑	◑	◑	◈	●	○	○	●
4.13 Landfarming	●	●	●	●	●	●	◑	●	◑	◑	●	◑	●	○	○	◈
4.14 Slurry Phase Biological Treatment	●	○	○	○	◑	◑	◑	●	◑	●	●	◈	●	◈	○	●
3.5 Ex Situ Physical/Chemical Treatment (assuming excavation)																
4.15 Chemical Extraction	●	○	○	○	◑	◑	◑	●	◑	◑	●	●	◑	●	◑	○
4.16 Chemical Reduction /Oxidation	●	◑	◑	○	●	◑	●	●	◑	◑	◑	◑	◑	●	○	◑

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									
Ground Water, Surface Water, and Leachate																
3.9 In Situ Biological Treatment																
4.29 Enhanced Bioremediation	●	●	○	◑	◑	●	◇	●	●	◇	●	◇	●	◇	○	◑
4.30 Monitored Natural Attenuation	●	●	○	◑	◑	●	◇	●	●	◑	◑	◑	●	○	○	○
4.31 Phytoremediation	●	●	●	●	○	●	○	◑	◑	◑	◑	◑	◑	◇	○	○
3.10 In Situ Physical/Chemical Treatment																
4.32 Air Sparging	●	●	●	●	●	●	●	●	●	◑	◑	◑	●	○	○	○
4.33 Bioslurping	●	◑	●	●	◑	●	◑	●	◑	◑	●	●	●	◑	○	○
4.34 Chemical Oxidation	●	●	○	◑	◑	◑	●	●	◑	◑	○	◑	○	◇	○	◑
4.35 Directional Wells (enhancement)	●	●	◑	○	◑	◑	◑	●	◑	◑	◑	◑	◑	◑	○	◑
4.36 Dual Phase Extraction	●	○	○	○	◑	◑	◑	●	●	●	●	●	●	○	○	○
4.37 Thermal Treatment	●	○	○	○	◑	◑	●	●	◑	●	●	●	●	○	○	○
4.38 Hydrofracturing Enhancements	●	◑	●	●	●	◑	◑	●	◑	◑	◑	◑	◑	◑	○	◑
4.39 In-Well Air Stripping	●	◑	◑	○	◑	◑	○	●	◑	◑	◑	○	◑	○	○	○
4.40 Passive/Reactive Treatment Walls	●	●	◑	○	●	◑	○	●	●	●	●	●	◑	◇	○	●
3.11 Ex Situ Biological Treatment																
4.41 Bioreactors	●	●	◑	○	◑	●	◑	●	●	●	●	◇	●	○	○	●
4.42 Constructed Wetlands	●	●	◑	○	◇	◑	◇	○	◑	◑	◑	◇	◑	●	○	●
3.12 Ex Situ Physical/Chemical Treatment (assuming pumping)																
4.43 Adsorption/ Absorption	●	●	○	◑	◑	○	○	●	◑	◑	◑	◑	○	●	◇	○
4.44 Advanced Oxidation Processes	●	◑	○	○	◑	◑	○	●	●	●	●	●	●	◇	◇	●
4.45 Air Stripping	●	◑	○	◑	●	●	○	●	●	●	○	○	○	○	○	○
4.46 Granulated Activated Carbon/Liquid Phase Carbon Adsorption	●	◑	○	◑	●	◑	○	●	●	●	●	●	●	◇	○	◇
4.47 Groundwater Pumping/Pump & Treat	●	◑	○	○	●	○	○	●	◑	◑	◑	◇	◑	◑	○	◑
4.48 Ion Exchange	●	◑	○	○	●	◑	○	●	○	○	○	○	○	●	◑	○
4.49 Precipitation/Coagulation/Flocculation	●	◑	◑	○	●	◑	○	●	○	○	○	○	○	●	◑	○

Table 3-1: Definition of Symbols Used in the Treatment Technologies Screening Matrix

Factors		● Above Average	◑ Average	○ Below Average	Other
Development Status Scale status of an available technology		Implemented as part of the final remedy at multiple sites, well documented, understood, etc.	Has been implemented at full scale but still needs improvements, testing, etc.	Not been fully implemented but has been tested (pilot, bench, lab scale) and is promising	◇ Level of Effectiveness highly dependent upon specific contaminant and its application/ design
Treatment Train Is the technology only effective as part of the treatment train?		Stand-alone technology (not complex in terms of number of media/treatment technologies, maybe one "routine" technology in addition)	Relatively simple (two-car train or so), and well understood, widely applied, etc.	Complex (more technologies, media to be treated, generates excessive waste, etc.)	
Relative overall cost and performance	**O&M** Operation and Maintenance Intensive	Low degree of O&M intensity	Average degree of O&M intensity	High degree of O&M intensity	
	Capital Capital Intensive	Low degree of capital investment	Average degree of capital investment	High degree of capital investment	
	System Reliability /Maintainability The expected range of demonstrated reliability and maintenance relative to other effective technologies	High reliability and low maintenance	Average reliability and average maintenance	Low reliability and high maintenance	N/A "Not Applicable"
	Relative Costs Design, construction, and operations and maintenance (O&M) costs of the core process that defines each and pre-and post-treatment	Low degree of general costs relative to other options	Average degree of general costs relative to other options	High degree of general costs relative to other options	I/D "Insufficient Data"
	Time Time required to clean up a "standard" site using the technology — in situ soil	Less than 1 year	1-3 years	More than 3 years for in situ soil	
	Time — ex situ soil	Less than 0.5 year	0.5-1 year	More than 1 year for ex situ soil	
	Time — groundwater	Less than 3 years	3-10 years	More than 10 years for water	
Availability Number of vendors that can design, construct, and maintain the technology		More than 4 vendors	2-4 vendors	Fewer than 2 vendors	
Contaminants Treated Contaminants are classified into eight groups: - Nonhalogenated VOCs - Halogenated VOCs - Nonhalogenated SVOCs - Halogenated SVOCs - Fuels - Inorganics - Radionuclides - Explosives		Effectiveness Demonstrated at Pilot or Full Pilot or Full Scale	Limited Effectiveness Demonstrated at Pilot or Full Scale	No Demonstrated Effectiveness at Pilot or Full Scale	Same as above

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- *Remediation objectives*
- *General response scenarios*
- *Evaluation of response approaches*
- *Screening of remediation methods*
- *Assembly of remediation alternatives*
- *Evaluation of remediation alternatives*
- *Selection of the optimum alternative*

Assembly of Remediation Alternatives

In this step, the selected remediation methods are assembled to the preferred response approaches and particular remediation alternatives are created.

Response Approach 1
Methods A

→ Remediation Alternative 1
Remediation Alternative 2

....

....

Response Approach X
Methods X

→ Remediation Alternative x
Remediation Alternative y
Remediation Alternative z

Evaluation of Remediation Alternatives

- Multi-criteria expert evaluation is used to evaluate the created remediation alternatives.
- Especially the following aspects of particular remediation alternatives are the subject of evaluation:
  - *Compliance with legal (and other obligatory) requirements* – Clean-up action has to be in compliance with all applicable legislation, relevant documents issued by authorities (such as decisions specifying target limits for the site remediation etc.) and obligatory technical standards (e.g. the technical standard for construction of ecological landfills and impermeable capping systems).
  - *Compliance with the project-specific requirements* – Site-specific limitations and Client´s requirements must be respected (e.g. on-site operating activities, fire / explosion risk environment, etc.)

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Evaluation of Remediation Alternatives

- *Effectiveness* – Remediation objectives have to be achievable by application of particular remediation alternatives. Implementation of laboratory and pilot-scale treatability tests is recommended to verify effectiveness of a proposed remediation methods.
- *Long-term reliability* – Once the remediation objectives are achieved, they should be sustainable for a long-term period. For example, there must be no continuing migration of pollution from the remediated source zone to groundwater.
- *Implementation risks* – Public health, environmental, occupational safety, fire and explosion, technological and other risks related to implementation of each remediation alternative should be evaluated.

Evaluation of Remediation Alternatives

- *Remediation cost* – Total costs related to implementation of the remediation alternative should be estimated (capital costs, operation costs, maintenance cots, costs for disposal of all waste streams generated during remediation etc.)
- *Duration of remediation*

- Expert evaluation is applied to compare individual remediation alternatives using the multi-criteria analysis. A scoring system is usually used to evaluate how the alternative meets the individual evaluation criteria (for example the scoring scale from 1 - worst alternative to 5 - best alternative).

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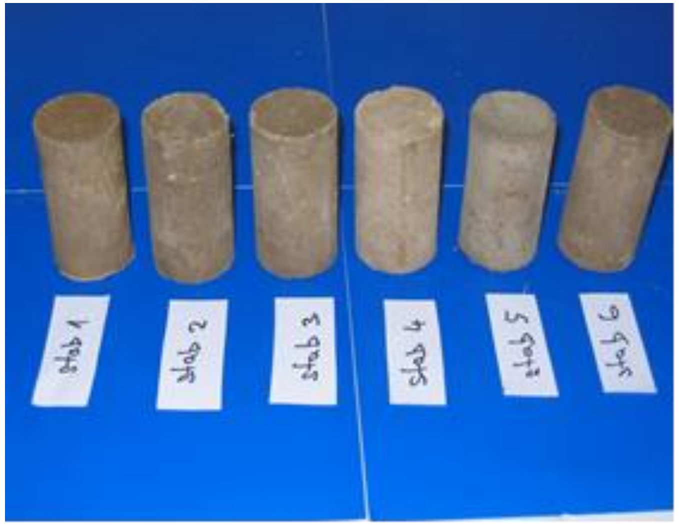
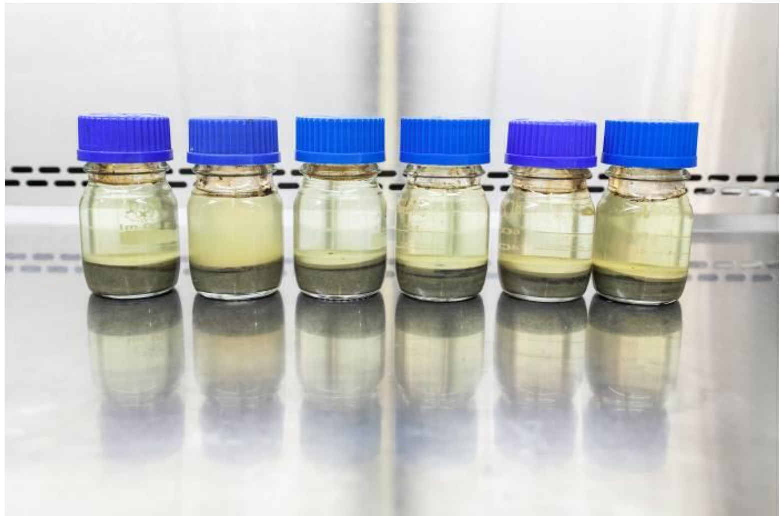
Treatability tests – Laboratory scale





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- *Remediation objectives*
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- *Selection of the optimum alternative*

Treatability tests – Pilot scale

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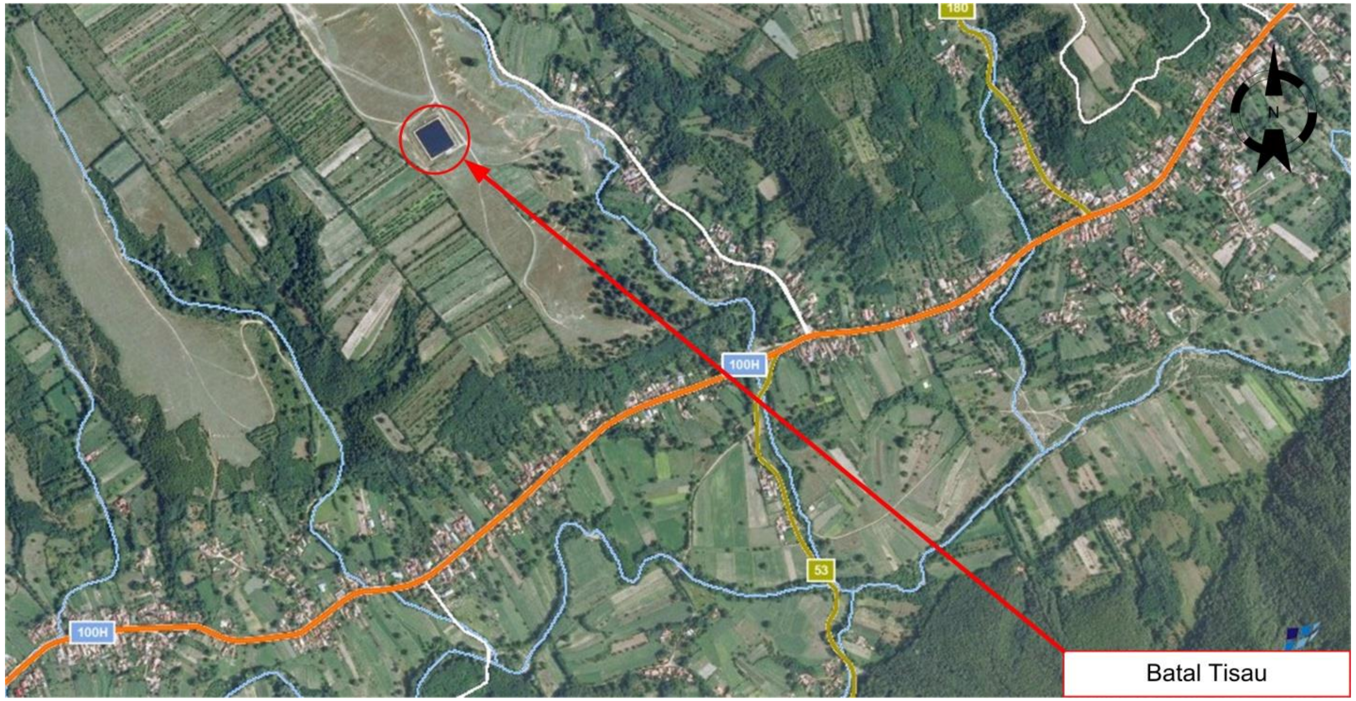
Case Study – Teccuci site, Romania



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Neither “No action scenario” nor “Institutional control scenario” nor „Engineering control scenario” meet the requirements issuing from the Romanian legislation for the Tecuci site. Considering the available investigation data application of the “Treatment scenario” is recommended for remediation of soil contaminated by petroleum hydrocarbons at the site..

The “Treatment scenario” can be implemented by application one of the following three basic technologies or their combination:

- *„Ex situ” remediation of contaminated soil (excavation with subsequent disposal / treatment)*
- *„In situ” remediation of contaminated soil*
- *Natural or enhanced attenuation*

The recommended approach to subsoil remediation combines „Ex situ” and „In situ” technologies the following way:

- „Ex situ” technology: Excavation of 6 000 m3 most contaminated soil at the identified hotspot areas, treatment of contaminated soil and backfilling of excavations.
- „In situ” technology: In situ bioremediation will be applied for remediation of les contaminated clayey soil (slightly above the intervention limit). The soil will be treated without removal by application of biopreparation and nutrient solution, humidification and by aeration to the necessary depth.

The “In situ” remediation will comprise the following main activities:

- *Mobilization and installation* of equipment for In situ remediation
- *Operation* and *monitoring* of In situ remediation technology
- *Removal of floating phase* of petroleum hydrocarbons from groundwater table

The “Ex situ “ soil remediation technology will comprise the following main activities:

- *Removal of non-contaminated soil* overlaying the areas with soil contaminated in deeper horizons and shipment of the excavated soil to an on-site deposit

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- *Excavation of* heavy contaminated soil
- *Shipment contaminated soil* to a treatment facility
- *Treatment / disposal* of the excavated soil (on-site or off-site)
    - *On-site treatment:*
        - *Construction of an on-site treatment facility* with sufficient capacity
        - *On-site treatment* of excavated soil to achieve the remediation limits
        - *Loading* treated soil and *shipment* for backfilling of excavations
    - *Off-site treatment:*
        - *Treatment / disposal* of excavated soil in off-site facility
        - *Purchasing, loading and shipment* inert soil for backfilling of excavations
- *Backfilling* of excavations with soil meeting the remediation limits

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- *Alternative 1:*

- Excavation of non-contaminated soil overlaying contaminated soil horizons and temporary depositing of excavated soil at the site
- Excavation the most contaminated soil using dozers and dredgers
- Shipment of excavated soil by trucks for off-site treatment/disposal
- Off-site treatment / disposal of heavy contaminated soil
- Installation of system for enhanced attenuation (to decrease residual contamination after heavy contaminated soil excavation)
- Backfilling of excavations , compacting backfilled material, surface levelling

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- *Alternative 2:*

- Construction a facility for on-site treatment of contaminated soil
- Excavation of non-contaminated soil overlaying contaminated soil horizons and temporary depositing of excavated soil at the site
- Excavation the most contaminated soil using dozers and dredgers
- Shipment of excavated soil by trucks to the developed on-site treatment facility
- On-site treatment of heavy contaminated soil
- Operation In situ bioremediation technology (to decrease residual contamination after heavy contaminated soil excavation)
- Backfilling of excavations , compacting backfilled material, surface levelling

- Alternative 3:

- "No action" scenario

Evaluation criterion	Alternative		
	„1”	„2”	„3”
Compliance with legal requirements	3	3	1
Compliance with Client´s requirements	3	3	1
Effectiveness	3	3	1
Implementation risks	3	3	1
Remediation costs	2	3	3
Duration	3	3	3
TOTAL	**17**	**18**	**10**

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- *Evaluation of remediation alternatives*
- *Selection of optimum alternative*

Selection of Optimum Alternative

- Based on the multi-criteria expert evaluation of individual remediation alternatives, the best one (e.g. the alternative with the highest score) is recommended for implementation.
- Detailed description of the recommended remediation alternative (Preliminary design) should be prepared and presented to all stakeholders (client, authorities etc.).
- After the Preliminary design is accepted, detailed Implementation design needs to be elaborated and approved.

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- *Investigation*
- *Risk Assessment*
- *Feasibility Study*
- *Implementation Design*
- *Remediation & Supervision*
- *Post-Remediation Monitoring*

Implementation Design

- Complete design documentation, which to the necessary extent describes all activities that will be carried out at a specific site during the implementation of remediation measures.
- Primarily, the design must comply with all requirements of applicable legislation, including law related to: (i) environmental protection and water management (soil contamination, water protection, waste management, air protection, etc.), (ii) construction and demolition works; (iii) fire protection and occupational safety and (iv) freight transport (transport of dangerous goods).
- In addition, the remediation project must comply with:
  - Decisions of the relevant state and local government authorities concerning the contaminated site (requirement for remediation, monitoring etc.)

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- Binding national technical standards (e.g. a standard for rehabilitation of former landfill sites)
- Applicable methodological guidelines

- Unlike other (e.g. construction) designs, a remediation design is usually burdened by a certain inaccuracy of the initial information on the basis of which the remediation measures were proposed (contamination data, geological / hydrogeological conditions etc.). Therefore, it is necessary that the design includes remediation monitoring, which will enable ongoing evaluation of the effectiveness of the implemented measures.
- Due to the potential impacts of a remediation project on various components of the environment, its approval may be more complicated than for other projects (involvement of river basin management, public etc.)
- Environmental impact assessment may be required to implement the designed remediation measures.

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- *Investigation*
- *Risk Assessment*
- *Feasibility Study*
- *Implementation Design*
- *Remediation & Supervision*
- *Post-Remediation Monitoring*

Implementation Design - Content

1. Introduction
   - Project background and objectives
   - Document organization
2. Site description and background information
   - Site description and location
   - Site history
   - Summary of previous investigations and findings
   - Site characterization investigations
   - Human health risk assessment
   - Cleanup levels
   - Feasibility study

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Implementation Design - Content

3. Implementation of selected remediation alternative
   - Preparatory activities (electric power connection, construction of service roads and facilities for contaminated materials handling etc.)
   - Mobilization
   - Removal of waste and contaminated equipment
   - Demolition works
   - Handling with contaminated debris
   - Soil remediation - Ex situ
   - Soil remediation - In situ
   - Groundwater remediation
   - Demobilization and handover of the site

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- *Investigation*
- *Risk Assessment*
- *Feasibility Study*
- *Implementation Design*
- *Remediation & Supervision*
- *Post-Remediation Monitoring*

Implementation Design - Content

4. Remediation Monitoring
   - Soil excavation monitoring
   - Construction waste monitoring
   - Groundwater monitoring
   - Material quantity monitoring
   - Air quality monitoring at work areas
   - Noise monitoring
   - Technological monitoring
   - Air emission (dust and odor) monitoring
   - Meteorological Monitoring

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Implementation Design - Content

5. Waste management
   - Overview of generated waste streams (waste codes and quantities)
   - Waste characterization
   - Excavation of contaminated soil
   - Handling with generated waste streams
   - On-site facilities for temporary storage of generated waste
   - Waste transportation
   - Final disposal of hazardous waste streams
   - handling and disposal of generated non-hazardous waste
   - Waste management records (quality, transportation, disposal etc.)

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- *Investigation*
- *Risk Assessment*
- *Feasibility Study*
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Implementation Design - Content

6. Permitting requirements
   - Construction permit
   - Demolition and asbestos handling / disposal permit
   - Waste management permit
   - Water management permit
   - Electric power connection permit

   etc.
7. Health and safety measures
8. Project organization roles and responsibilities
9. Reporting

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- *Investigation*
- *Risk Assessment*
- *Feasibility Study*
- *Implementation Design*
- *Remediation & Supervision*
- *Post-Remediation Monitoring*

Implementation Design - Content

10. Supporting plans and documentation
    - Health and safety plan
    - Excavation plan
    - Backfilling plan
    - Stormwater pollution prevention plan
    - Construction traffic management plan and haul route plan
    - Emergency response plan
    - Post-excavation documentary sampling plan
    - Surface containment and soil management plan
    - Validation sampling plan
    - Long-term monitoring plan

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