

Remediation of a contaminated site

What is remediation:

Remediation: Cleanup of a site to levels determined to be health-protective for its intended use.

Mitigation: Actions taken to improve site conditions by limiting, reducing or controlling hazards and contamination sources.

Aeration (soil): The process by which air in the soil is replaced by air from the atmosphere.

Decontamination: The removal hazardous material from a site so as to prevent or minimize any adverse effects on the environment.

Terminology

Remedial Action Plan (RAP): A plan that outlines a specific program leading to the remediation of a contaminated site.

Work plan: The site work plan describes the technical activities to be conducted during the various phases of a remediation project.

Monitoring wells: Specially-constructed wells used exclusively for testing water quality.

Hazardous waste: Waste substances which can pose a substantial or potential hazard to human health or the environment when improperly managed.

Reasons for Remediation:

1. keeping environment clean and healthy
2. Removing sources of contamination to other sites.
3. Changing the contaminated site from harmful into usable site
 - a- Land development (residential, commercial, industrial)

b- Using the site for agricultural production

c- Maintaining historical and archeological sites

d. Creating recreational, social and educational centres

4. Adding value to the site after remediation

5. Maintaining the biodiversity

Remediation Methods

1. Physical Methods:
 - a. Ex-situ methods
 - b. In-Situ methods
2. Chemical Methods
3. Biological methods
4. Physico-Chemical methods

Physical Methods

The methods which do not change the physico-chemical properties of the pollutants accumulated in the soil to be cleaned.

The advantages

- The possibility of removal or disposal of a broad spectrum of pollutants

Disadvantages:

- They produce a considerable amount of wastes that need future management or utilization
- The management may need high costs in case of a large scale pollution.

Types of physical methods

1. Ex-situ: the methods require the transportation of polluted soil to the place of cleaning:

- a. Mechanical separation

- b. Extraction and storage

2. In-situ: the methods which is applied on-site without removal of the soil from polluted site.

This is can be achieved as in the following:

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- a. Electrokinetic cleaning methods
 - b. Cofferdam system
 - c. Soil covering

Ex-situ techniques

Mechanical separation

The mechanical separation of soil is a physico-chemical process in which the contaminated parts of soil are separated. This process leads to a decrease in volume of contaminated soil.

The techniques most often used for separation are: gravitational separation (based on differences in density between fractions) or in cyclones (based on the Coriolis effect), sieve analysis (different grain size of elements) or magnetic separation (based on magnetic induction). The separated fraction containing the pollutants must be cleaned up or neutralized in another process.

Method's advantages:

- Significant volume reduction of contaminated soil.
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- For many years, this technique has been applied in municipal waste management.

Method's disadvantages:

- This technique could not be applied in the case of homogenous distribution of pollutants in soil. In that case, there is not a satisfactory decrease in volume.
- This method is not effective for some soils types.
- The separated part of the contaminated soil must be cleaned up using another method.

Extraction and storage

This method is the simple extraction of contaminated soil cover, using a digger or bulldozer, and its storage in an appropriate place for further clean-up using another method (e.g. biodegradation, vitrification or other). The storage site has to be sheltered to prevent wind and water erosion.

Method's advantages:

- Short time of excavation of contaminated soil (even one day)
- Does not require highly specialist equipment
- Could be applied in the case of emergency, when other methods are not effective or are too costly.

Method's disadvantages: - Using a simple digger and bulldozer, the excavation is only possible up to a depth of 3 m.

- Not applicable in the case of small, local polluted sites because of high expenses.

Electrokinetic Separation, in situ

- The Electrokinetic Remediation (ER) process removes metals and organic contaminants from low permeability soil, mud, sludge, and marine dredging.
- ER uses electrochemical and electrokinetic processes to desorb, and then remove, metals and polar organics.
- This in situ soil processing technology is primarily a separation and removal technique for extracting contaminants from soils.

Applicability for pollutants: heavy metals, anions, and polar organics in soil, mud, sledge, and marine dredging

Duration: Short to medium-term technology. Cleanup ranges from a few weeks to several months.

Fracturing, *In Situ*

Cracks are developed by fracturing beneath the surface in low permeability and over-consolidated sediments to open new passageways that increase the effectiveness of many in situ processes and enhance extraction efficiencies.

Applicability: Fracturing is applicable to the complete range of contaminant groups with no particular target group. The technology is used primarily to fracture silts, clays, shale, and bedrock.

Duration: Normal operation employs a two-person crew, making 15 to 25 fractures per day with a fracture radius of 4 to 6 meters to a depth of 15 to 30 meters. For longer remediation programs, refracturing efforts may be

Soil Flushing, *In Situ*

- Water, or water containing an additive to enhance contaminant solubility, is applied to the soil or injected into the ground water to raise the water table into the contaminated soil zone.
- Contaminants are leached into the ground water, which is then extracted and treated.

Applicability: used with pollutants such as inorganics including radioactive contaminants. The technology can be used to treat VOCs, SVOCs, fuels, and pesticides.

Duration: Short to medium-term technology. Cleanup ranges from a few weeks to several months.

Soil Vapor Extraction, *In Situ*

- Vacuum is applied through extraction wells to create a pressure/concentration gradient that induces gas-phase volatiles to be removed from soil through extraction wells.
- This technology also is known as in situ soil venting, in situ volatilization, enhanced volatilization, or soil vacuum extraction.

Applicability for pollutants: The target contaminant groups for in situ SVE are VOCs and some fuels

Duration: The duration of operation and maintenance for in situ SVE is typically medium- to long-term.

Solidification/Stabilization, *In Situ*

Contaminants are physically bound or enclosed within a stabilized mass (solidification), or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility (stabilization).

Applicability for pollutants: The target contaminant group for in situ S/S is generally inorganics (including radionuclides).

Duration: The timeframe for in situ S/S is short- to medium-term, while in situ ISV process is typically short-term.

Chemical Extraction, *Ex Situ*

■ **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.

Chemical Oxidation, *In Situ*

- 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.
- Applicability for pollutants: many toxic organic chemicals, unsaturated aliphatic (e.g., trichloroethylene, TCE) and aromatic compounds (e.g., benzene)

Duration: Medium to long-term technology. Cleanup ranges from a few months to several years.

Chemical Extraction, *Ex Situ*



(FRTR 2001)

■ **Introduction:**

- Waste contaminated soil and extractant are mixed in an extractor, thereby dissolving the contaminants.
- The extracted solution is then placed in a separator, where the contaminants and extractant are separated for treatment and further use.
- Two main types of extraction are Acid Extraction, Solvent Extraction



Chemical extraction, Applicability, duration, limitations, costs (FRTR 2001)

- ***Applicability for pollutants***

- primarily organic contaminants such as PCBs, VOCs, halogenated solvents (Fluorine, chlorine, bromine, iodine), and petroleum wastes.

- ***Duration***

- The duration of operations and maintenance for chemical extraction is medium-term.

- ***More detailed data***

- <http://www.frtr.gov/matrix2/section4/4-15.html>



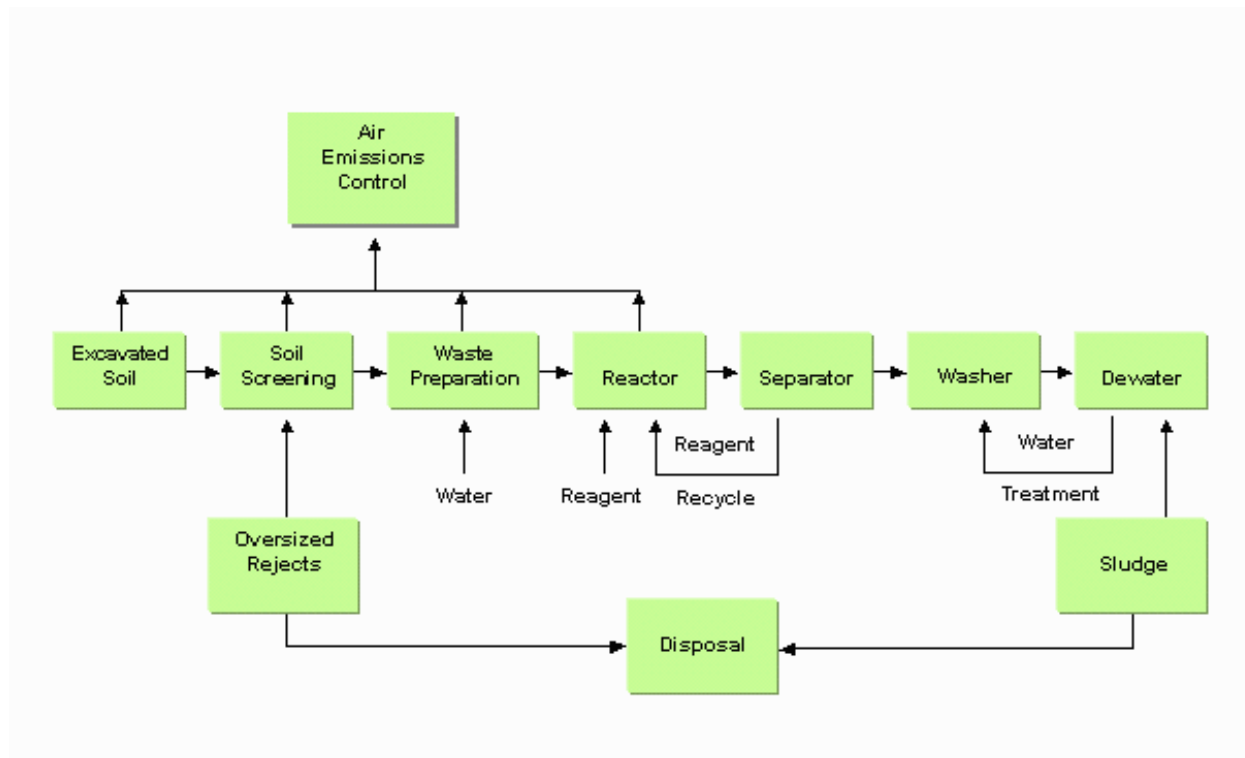
Chemical Reduction/Oxidation,

Ex Situ (FRTR 2001)

■ **Introduction:**

- Reduction/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.

Typical Chemical Reduction/Oxidation Process (FRTR 2001)



<http://www.frtr.gov/matrix2/section4/D01-4-16.html>



Chemical Reduction/Oxidation ,

Applicability, duration, limitations, costs (FRTR 2001)

- ***Applicability for pollutants***
 - Mainly for inorganics, but also effect against nonhalogenated VOCs and SVOCs, fuel hydrocarbons, and pesticides.

- ***Duration***
 - a short- to medium-term technology.

- ***More detailed data***
 - <http://www.frtr.gov/matrix2/section4/4-16.html>



Dehalogenation,

Ex *Situ* (FRTR 2001)

■ **Introduction:**

- Reagents are added to soils contaminated with halogenated organics.
- The dehalogenation process is achieved by either the replacement of the halogen molecules or the decomposition and partial volatilization of the contaminants.



Dehalogenation, Applicability, duration, limitations, costs (FRTR 2001)

- ***Applicability for pollutants***
 - halogenated SVOCs and pesticides

- ***Duration***
 - a short- to medium-term process

- ***More detailed data***
 - <http://www.frtr.gov/matrix2/section4/4-17.html>



Chemical Oxidation, *In Situ*

(FRTR 2001)

■ **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.



Chemical Oxidation, Applicability, duration, limitations, costs (FRTR 2001)

- ***Applicability for pollutants***

- *many toxic organic chemicals, unsaturated aliphatic (e.g., trichloroethylene, TCE) and aromatic compounds (e.g., benzene)*

- ***Duration***

- *Medium to long-term technology. Cleanup ranges from a few months to several years.*

- ***More detailed data***

- <http://www.frtr.gov/matrix2/section4/4-30.html>



Physical-Chemical Methods

- Separation Ex Situ
- Soil Washing Ex Situ
- Solidification/Stabilization Ex Situ



Separation,

Ex Situ (FRTR 2001)

■ **Introduction:**

- Separation techniques concentrate contaminated solids through physical and chemical means.
- These processes seek to detach contaminants from their medium (i.e., the soil, sand, and/or binding material that contains them).



Separation, Applicability, duration, limitations, costs (FRTR 2001)

- ***Applicability for pollutants***
 - SVOCs, fuels, and inorganics (including radionuclides)

- ***Duration***
 - a short-term process

- ***More detailed data***
 - <http://www.frtr.gov/matrix2/section4/4-18.html>



Soil Washing,

Ex Situ (FRTR 2001)

■ **Introduction:**

- Contaminants sorbed onto fine soil particles are separated from bulk soil in an aqueous-based system on the basis of particle size.
- The wash water may be augmented with a basic leaching agent, surfactant, pH adjustment, or chelating agent to help remove organics and heavy metals.



Soil Washing, Applicability, duration, limitations, costs (FRTR 2001)

- ***Applicability for pollutants***
 - SVOCs, fuels, and heavy metals

- ***Duration***
 - typically short- to medium-term

- ***More detailed data***
 - <http://www.frtr.gov/matrix2/section4/4-19.html>



Solidification/Stabilization,

Ex *Situ* (FRTR 2001)

■ **Introduction:**

- Contaminants are physically bound or enclosed within a stabilized mass (solidification), or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility (stabilization).



Solidification/ stabilization, Applicability, duration, limitations, costs (FRTR 2001)

- ***Applicability for pollutants***

- The target contaminant group for ex situ S/S is inorganics, including radionuclides

- ***Duration***

- Typical ex situ S/S is a short- to medium-term technology

- ***More detailed data***

- <http://www.frtr.gov/matrix2/section4/4-21.html>



Thermal Treatments

Soil, Sediment, Bedrock and Sludge Treatment Technologies

Thermal Treatment (FRTR 2001)

- Thermal Treatment, *In Situ*
- Hot Gas Decontamination, *Ex Situ*
- Incineration, *Ex Situ*
- Pyrolysis, *Ex Situ*
- Thermal Desorption, *Ex Situ*



Thermal Treatment, *In Situ* (FRTR 2001)

■ **Introduction:**

- Steam/hot air injection or electrical resistance/electromagnetic/fiber optic/radio frequency heating is used to increase the volatilization rate of semi-volatiles and facilitate extraction.



Soil Heating, Applicability, duration, limitations, costs (FRTR 2001)

- ***Applicability for pollutants***
 - SVOCs and VOCs

- ***Duration***
 - Thermally enhanced SVE is normally a short-to medium-term technology

- ***More detailed data***
 - <http://www.frtr.gov/matrix2/section4/4-9.html>



Hot Gas Decontamination, *Ex Situ* (FRTR 2001)

■ **Introduction:**

- The process involves raising the temperature of the contaminated equipment or material for a specified period of time.
- The gas effluent from the material is treated in an afterburner system to destroy all volatilized contaminants.



Hot Gas Decontamination, Applicability, duration, limitations, costs (FRTR 2001)

- ***Applicability for pollutants***
 - explosive items, such as mines and shells, being demilitarized (after removal of explosives) or scrap material contaminated with explosives.

- ***Duration***
 - a short-term technology

- ***More detailed data***
 - <http://www.frtr.gov/matrix2/section4/4-22.html>



Incineration, *Ex Situ* (FRTR 2001)

■ **Introduction:**

- High temperatures, 870-1,200 °C, are used to combust (in the presence of oxygen) organic constituents in hazardous wastes.

- Different types of combustion processes
 - *Circulating Bed Combustor (CBC)*
 - *Fluidized Bed*
 - *Infrared Combustion*
 - *Rotary Kilns*



Incineration, Applicability, duration, limitations, costs (FRTR 2001)

- ***Applicability for pollutants***
 - explosives and hazardous wastes, particularly chlorinated hydrocarbons, PCBs, and dioxins.

- ***Duration***
 - incineration technology ranges from short- to long-term

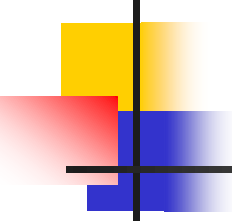
- ***More detailed data***
 - <http://www.frtr.gov/matrix2/section4/4-23.html>



Pyrolysis, *Ex Situ* (FRTR 2001)

■ **Introduction:**

- Chemical decomposition is induced in organic materials by heat in the absence of oxygen.
- Organic materials are transformed into gaseous components and a solid residue (coke) containing fixed carbon and ash.



Pyrolysis, Applicability, duration, limitations, costs (FRTR 2001)

- ***Applicability for pollutants***
 - SVOCs and pesticides

- ***Duration***
 - incineration technology ranges from short- to long-term

- ***More detailed data***
 - <http://www.frtr.gov/matrix2/section4/4-25.html>



Thermal Desorption, *Ex Situ* (FRTR 2001)

■ **Introduction:**

- Wastes are heated to volatilize water and organic contaminants.
- A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system.
- *High Temperature Thermal Desorption (HTTD)*
 - *320 – 560 °C*
- Low Temperature Thermal Desorption (LTTD)
 - 90 – 320 °C



Thermal desorption, Applicability, duration, limitations, costs (FRTR 2001)

- ***Applicability for pollutants***
 - SVOCs, PAHs, PCBs, and pesticides

- ***Duration***
 - short-term technology

- ***More detailed data***
 - <http://www.frtr.gov/matrix2/section4/4-26.html>



Thermal desorption, Applicability, duration, limitations, costs (FRTR 2001)

- ***Applicability for pollutants***
 - SVOCs, PAHs, PCBs, and pesticides
- ***Duration***
 - short-term technology
- ***More detailed data***
 - <http://www.frtr.gov/matrix2/section4/4-26.html>



Water Remediation Treatments

Physical Treatment

- Monitored Natural Attenuation In Situ
- Constructed Wetland, *Ex Situ*



Monitored Natural Attenuation, *In Situ*

(FRTR 2001)

■ **Introduction:**

- Natural subsurface processes—such as dilution, volatilization, biodegradation, adsorption, and chemical reactions with subsurface materials—are allowed to reduce contaminant concentrations to acceptable levels.



Monitored Natural Attenuation,

Applicability, duration, limitations, costs (FRTR 2001)

- ***Applicability for pollutants***
 - VOCs and SVOCs and fuel hydrocarbons, maybe also halogenated VOCs

- ***Duration***
 - long-term technologies, which may take several years

- ***More detailed data***
 - <http://www.frtr.gov/matrix2/section4/4-32.html>



Constructed Wetland, *Ex Situ*

(FRTR 2001)

■ **Introduction:**

- The constructed wetlands-based treatment technology uses natural geochemical and biological processes inherent in an artificial wetland ecosystem to accumulate and remove metals, explosives, and other contaminants from influent waters.
- The process can use a filtration or degradation process.



Constructed Wetland, Applicability, duration, limitations, costs (FRTR 2001)

- ***Applicability for pollutants***

- organic matter; nutrients, such as nitrogen and phosphorus; and suspended sediments

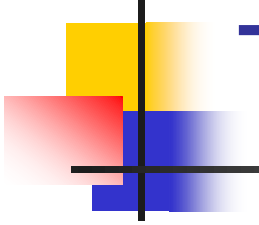
- ***Duration***

- Wetland treatment is a long-term technology intended to operate continuously for years.

- ***More detailed data***

- <http://www.frtr.gov/matrix2/section4/4-43.html>

Water: Physical-Chemical Treatment Methods



Ground Water, Surface Water, and

Leachate Physical/Chemical Treatment

(FRTR 2001)

- Air Sparging, *In Situ*
- Bioslurping, *In Situ*
- Chemical Oxidation, *In Situ*
- Directional Wells, *In Situ*
- Dual Phase Extraction, *In Situ*
- Thermal Treatment, *In Situ*
- Hydrofracturing, *In Situ*
- In-Well Air Stripping, *In Situ*
- Passive/Reactive Treatment Walls, *In Situ*
- Containment



Air Sparging, *In Situ*

(FRTR 2001)

■ **Introduction:**

- Air is injected into saturated matrices to remove contaminants through volatilization.



Air Sparging, Applicability, duration, limitations, costs (FRTR 2001)

- ***Applicability for pollutants***
 - VOCs and fuels

- ***Duration***
 - a medium to long duration which may last, generally, up to a few years
 -

- ***More detailed data***
 - <http://www.frtr.gov/matrix2/section4/4-34.html>



Bioslurping, *In Situ*

(FRTR 2001)

■ **Introduction:**

- Deep well injection is a liquid waste disposal technology.
- This alternative uses injection wells to place treated or untreated liquid waste into geologic formations that have no potential to allow migration of contaminants into potential potable water aquifers.



Bioslurping, Applicability, duration, limitations, costs (FRTR 2001)

- ***Applicability for pollutants***
 - VOCs, SVOCs, fuels, explosives, and pesticides

- ***Duration***
 - no data

- ***More detailed data***
 - <http://www.frtr.gov/matrix2/section4/4-54.html>



Chemical Oxidation, *In Situ*

(FRTR 2001)

■ **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.



Chemical Oxidation, Applicability, duration, limitations, costs (FRTR 2001)

- ***Applicability for pollutants***

- *many toxic organic chemicals, unsaturated aliphatic (e.g., trichloroethylene, TCE) and aromatic compounds (e.g., benzene)*

- ***Duration***

- *Medium to long-term technology. Cleanup ranges from a few months to several years.*

- ***More detailed data***

- <http://www.frtr.gov/matrix2/section4/4-30.html>



Directional Wells, *In Situ*

(FRTR 2001)

■ **Introduction:**

- Drilling techniques are used to position wells horizontally, or at an angle, to reach contaminants not accessible by direct vertical drilling.
- Directional drilling may be used to enhance other in-situ or in-well technologies such as ground water pumping, bioventing, SVE, soil flushing, and in-well air stripping.



Directional Wells, Applicability, duration, limitations, costs (FRTR 2001)

- ***Applicability for pollutants***
 - *no particular target group*

- ***Duration***
 - *no data*

- ***More detailed data***
 - <http://www.frtr.gov/matrix2/section4/4-36.html>



Dual Phase Extraction, *In Situ*

(FTRT 2001)

■ **Introduction:**

- A high vacuum system is applied to simultaneously remove various combinations of contaminated ground water, separate-phase petroleum product, and hydrocarbon vapor from the subsurface.



Dual Phase Extraction, Applicability,

duration, limitations, costs (FRTR 2001)

- ***Applicability for pollutants***
 - *VOCs and fuels (e.g., LNAPLs)*

- ***Duration***
 - *Medium to long-term technology.*

- ***More detailed data***
 - <http://www.frtr.gov/matrix2/section4/4-37.html>



Thermal Treatment, *In Situ*

(FRTR 2001)

■ **Introduction:**

- Steam is forced into an aquifer through injection wells to vaporize volatile and semivolatile contaminants.
- Vaporized components rise to the unsaturated zone where they are removed by vacuum extraction and then treated.



Thermal Treatment, Applicability, duration, limitations, costs (FRTR 2001)

- ***Applicability for pollutants***
 - *SVOCs and fuels*

- ***Duration***
 - *typically short to medium duration, lasting a few weeks to several months*

- ***More detailed data***
 - <http://www.frtr.gov/matrix2/section4/4-38.html>



Hydrofracturing, *In Situ*

(FRTR 2001)

■ **Introduction:**

- Injection of pressurized water through wells cracks low permeability and over-consolidated sediments.
- Cracks are filled with porous media that serve as substrates for bioremediation or to improve pumping efficiency.



Hydrofracturing, Applicability, duration, limitations, costs (FRTR 2001)

- ***Applicability for pollutants***
 - *a wide range of contaminant groups with no particular target group*

- ***Duration***
 - *no data*

- ***More detailed data***
 - <http://www.frtr.gov/matrix2/section4/4-39.html>



In-Well Air Stripping, *In Situ*

(FRTR 2001)

■ **Introduction:**

- Air is injected into a double screened well, lifting the water in the well and forcing it out the upper screen.
- Simultaneously, additional water is drawn in the lower screen.
- Once in the well, some of the VOCs in the contaminated ground water are transferred from the dissolved phase to the vapor phase by air bubbles.
- The contaminated air rises in the well to the water surface where vapors are drawn off and treated by a soil vapor extraction system.



In-Well Air Stripping, Applicability, duration, limitations, costs (FRTR 2001)

- ***Applicability for pollutants***
 - halogenated VOCs, SVOCs, and fuels

- ***Duration***
 - *no data*

- ***More detailed data***
 - <http://www.frtr.gov/matrix2/section4/4-40.html>

Passive/Reactive Treatment

Walls, *In Situ* (FRTR 2001)

■ **Introduction:**

- These barriers allow the passage of water while causing the degradation or removal of contaminants.

- Different types of walls:
 - *Funnel and Gate*
 - *Iron Treatment Wall*

Passive/Reactive Treatment

Walls, Applicability, duration, limitations, costs

(FRTR 2001)

- ***Applicability for pollutants***

- VOCs, SVOCs, and inorganics

- ***Duration***

- generally intended for long-term operation to control migration of contaminants in ground water.

- ***More detailed data***

- <http://www.frtr.gov/matrix2/section4/4-41.html>



Ground Water, Surface Water, and Leachate

Containment (FRTR 2001)

- Physical Barriers
- Deep Well Injection



Physical Barriers, (FRTR 2001)

■ **Introduction:**

- These subsurface barriers consist of vertically excavated trenches filled with slurry.
- The slurry, usually a mixture of bentonite and water, hydraulically shores the trench to prevent collapse and retards ground water flow.



Physical Barriers, Applicability, duration, limitations, costs (FRTR 2001)

- ***Applicability for pollutants***
 - Slurry walls contain the ground water itself, thus treating no particular target group of contaminants

- ***Duration***
 - no data

- ***More detailed data***
 - <http://www.frtr.gov/matrix2/section4/4-53.html>



Deep Well Injection,

(FRTR 2001)

■ **Introduction:**

- Deep well injection is a liquid waste disposal technology.
- This alternative uses injection wells to place treated or untreated liquid waste into geologic formations that have no potential to allow migration of contaminants into potential potable water aquifers.



Deep Well Injection, Applicability, duration, limitations, costs (FRTR 2001)

- ***Applicability for pollutants***
 - VOCs, SVOCs, fuels, explosives, and pesticides

- ***Duration***
 - no data

- ***More detailed data***
 - <http://www.frtr.gov/matrix2/section4/4-54.html>