# Teknik Remediasi

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Teknik Lingkungan - FTSL ITB
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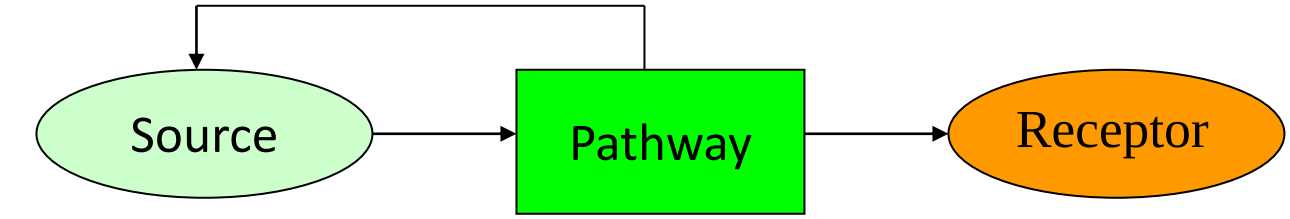
Pusat Studi Lingkungan Hidup ITB

# What is Remediation




-Biogenic
-Antrophogenic

-Atmosphere
-Hydrosphere
-Litosphere

-Human
-Other living things
-Material

Exposure Pathway of Contaminants to Receptor (portal of entry):

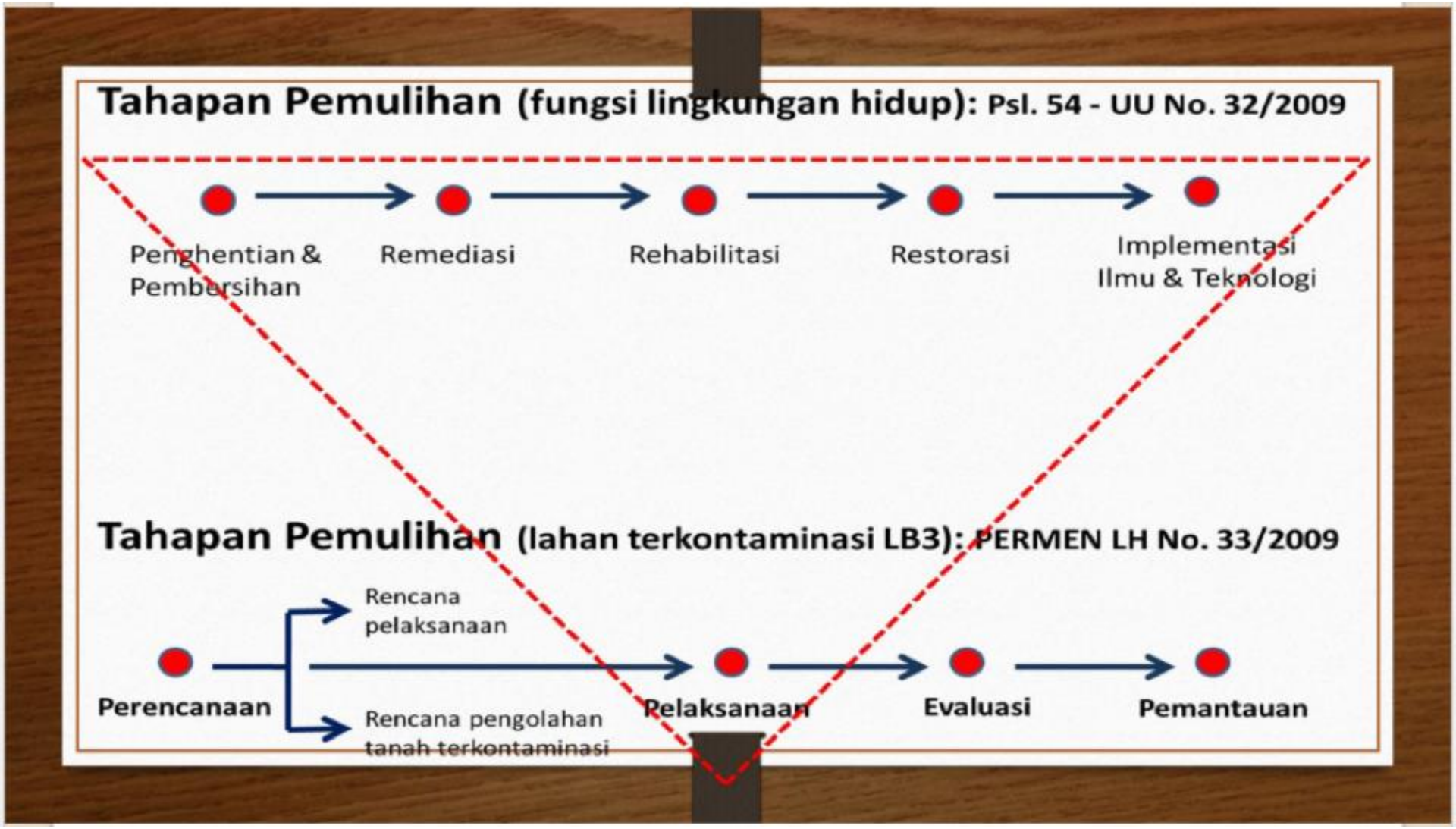
- Direct Ingestion via water, groundwater, and food
- Inhalation via blowing dust and volatilization
- Dermal Adsorption

# Remediation

is an engineering effort to remedy contaminated site by treating the contaminated soils, GW & Sludge as well as the off gas produced and render them to non-hazardous, thus eliminating any future liability that may result from landfill problems or violations:

- Physical/Chemical Remediation
- Biological Remediation
- Thermal Remediation

# Aspek legal




**Permen LH 33/2009 telah digantikan oleh PerMen LHK P.101/2018 sbg pedoman pelaksanaan PP 101/2014 tentang Pengelolaan Limbah B3**

# Perencanaan Pemulihan - 1

- Delineasi Studi:
  - Kuantifikasi Tanah terkontaminasi
  - Identifikasi Penyebaran kontaminan: vertikal & horizontal
  - Segregasi: konsentrasi & jenis tanah (apabila memungkinkan)
  - Volume tanah terkontaminasi: bulk density
  - Conceptual Site Model (CSM): paparan
  - In-situ: diperlukan Studi hidrologi & hidrogeologi
  - Natural Attenuation: studi lanjut (flora, fauna, dlsb)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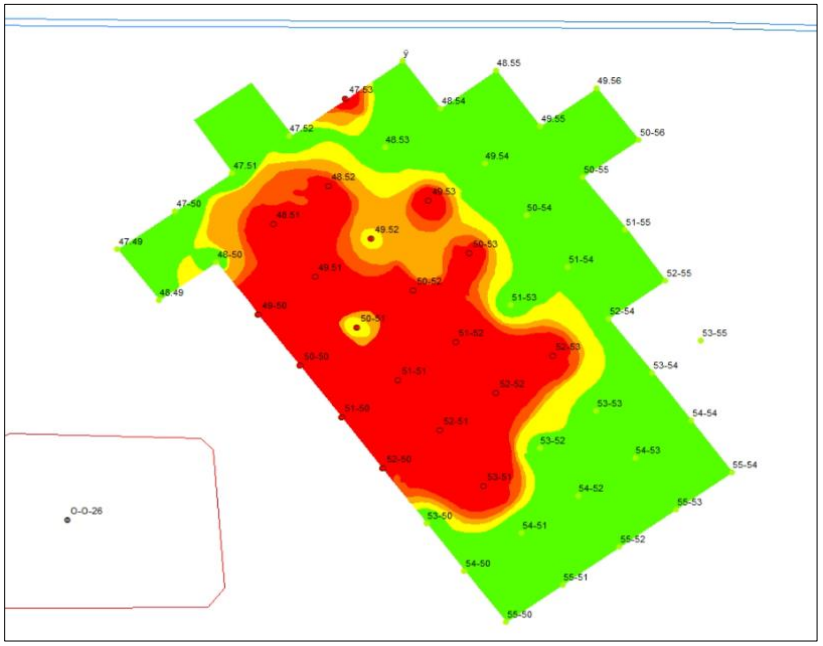
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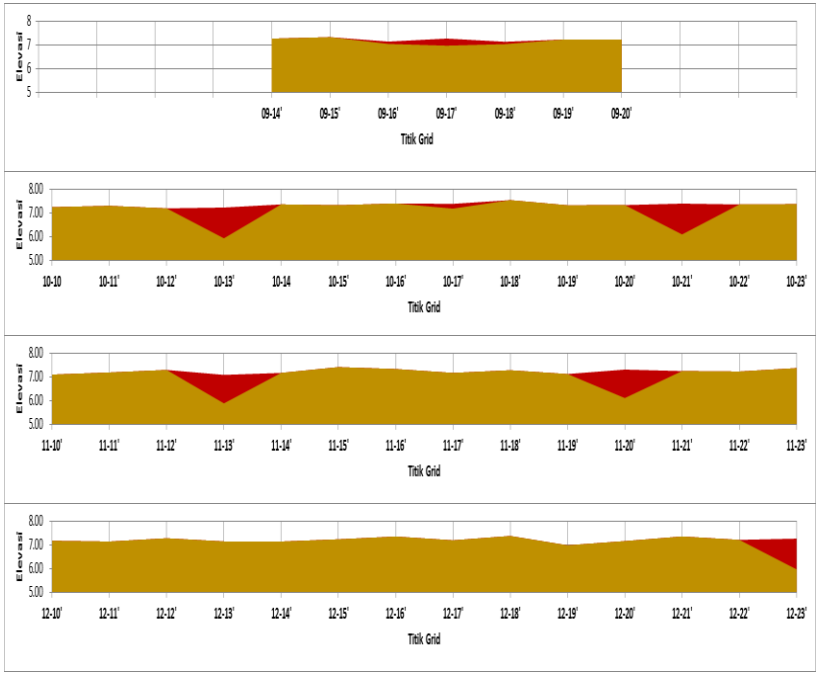
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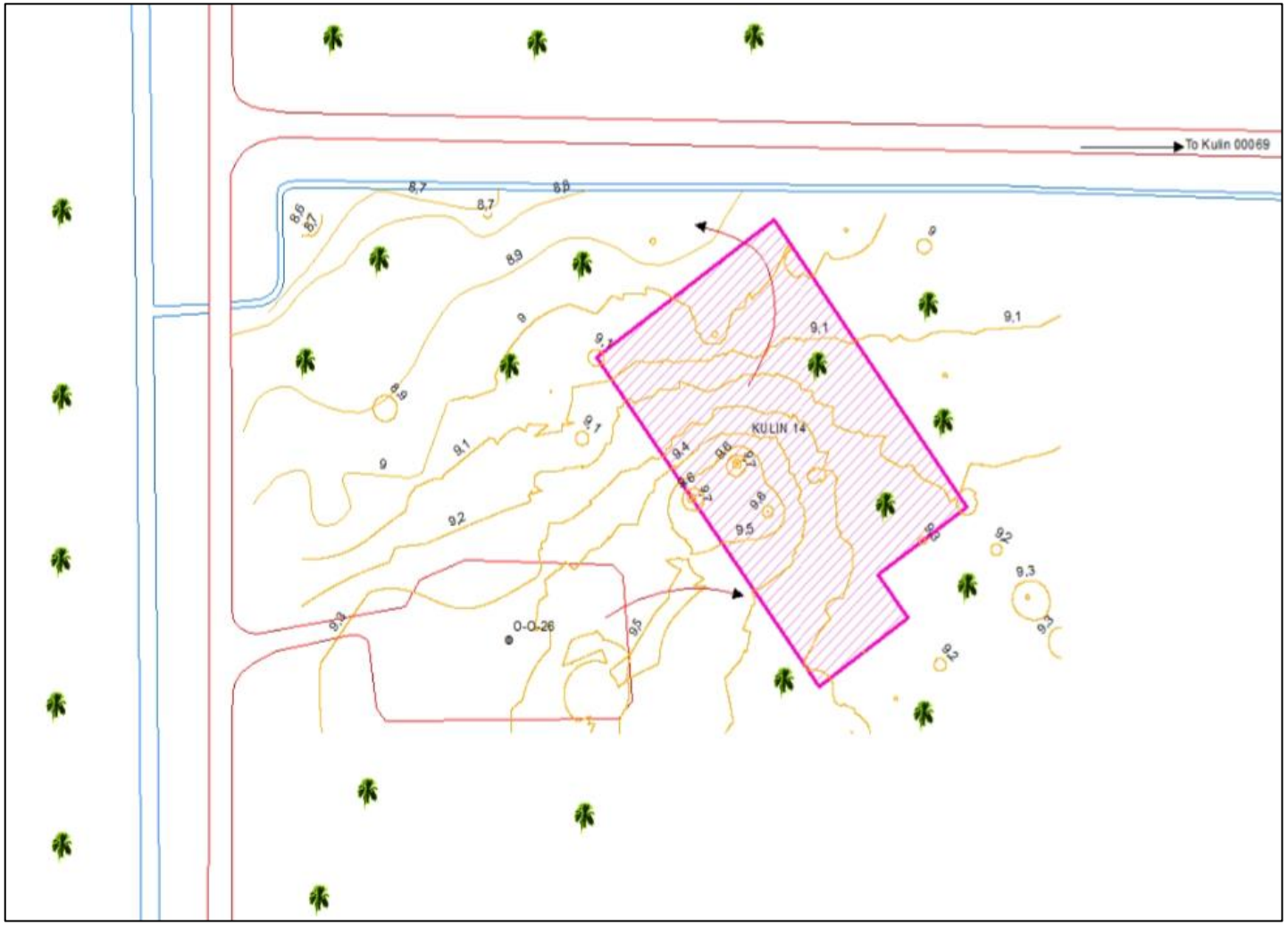
# CSM



# Natural Attenuation

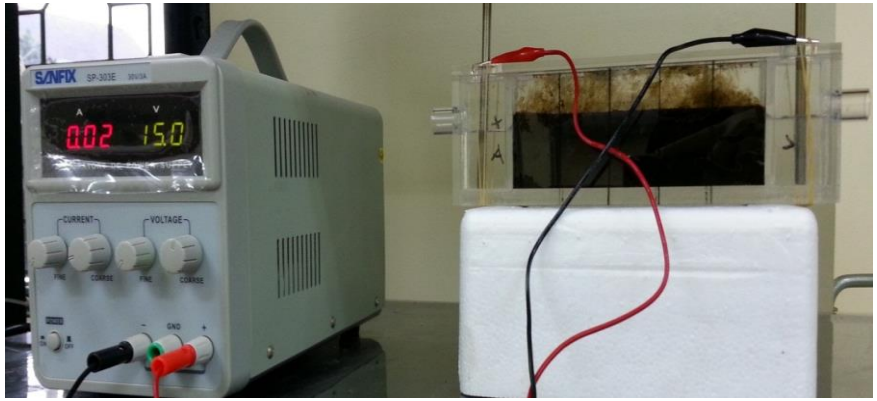
- These in situ processes include [biodegradation], [dispersion], [dilution], [adsorption], [volatilization], and chemical or biological stabilization or destruction of contaminants (USEPA, 1992).
- the process does require site characterization, source control, documentation of contaminant loss via field tests, and monitoring to establish its effectiveness (National Research Council, 1993)

# Perencanaan Pemulihan - 2

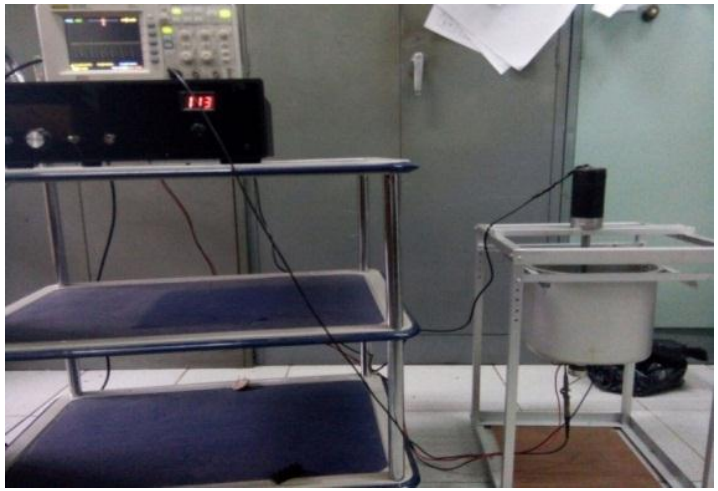
- Karakterisasi Media Terkontaminasi:
  - Fisik: PSD, kandungan air, bulk density, soil permeability, dsb
  - Kimia: pH, humic acid content, ORP, Kow, dsb
  - Biologi: Enumerasi Bakteri, electron acceptor, nutrient, dsb
- Sifat Kontaminan:
  - Volatile organic compounds
  - Semi-volatile organic compounds
  - pesticides and herbicides
  - PCBs
  - Metals
  - Cyanide
  - Hydrocarbon
- Treatability test: Uji coba skala laboratorium

Aerated Static Biopile

Soil Washing




Electokinetic Remediation

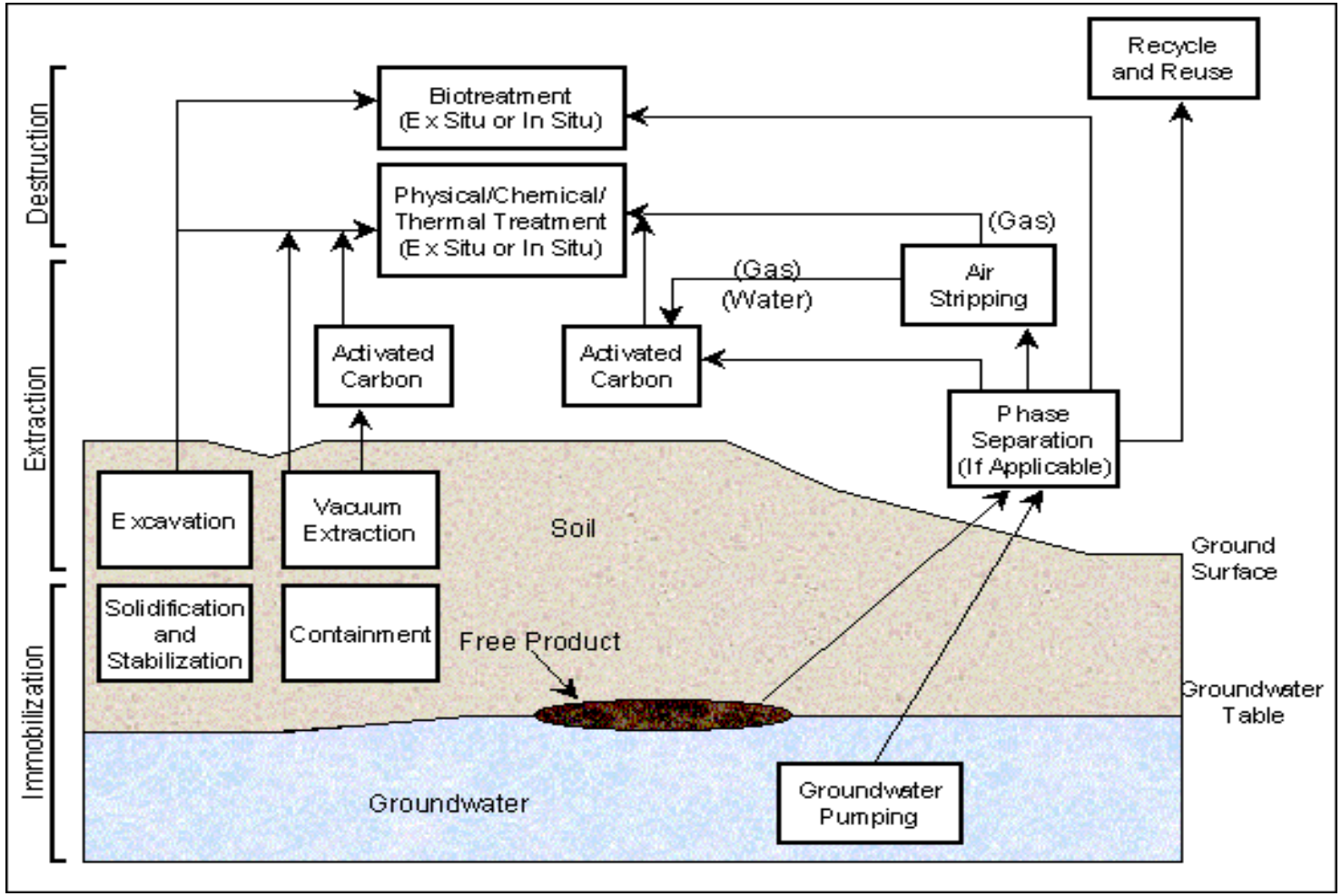


Ultrasonic Remediation

# Karakteristik Aplikasi Remediasi

- Pathway treatment: kuratif/pengobatan
- Aliran masa: batch system
- Cost: mahal dibandingkan pencegahan pencemaran (pollution prevention):
  - Bioremediasi: USD20 – USD80/ton
  - Soil Washing: USD70 – USD190/ton (Tanah tercemar merkuri di Lebak: Rp. 2,2 Juta/ton)
  - Thermal desorption: USD80 – USD200/ton
  - Pengolahan Air Limbah (WWTP): (??)

# Classification of remediation methods on base of activities (FRTR 2001)



# Teknik Remediasi untuk Soil, Sediment, Bedrock dan Sludge

Federal Remediation Technologies Roundtable (FRTR, 2001)

**In Situ Biological Treatment**

- Bioventing
- Enhanced Bioremediation
- Phytoremediation

**In Situ Physical/Chemical Treatment**

- Chemical Oxidation
- Electrokinetic Separation
- Fracturing
- Soil Flushing
- Soil Vapor Extraction
- Solidification/Stabilization

**In Situ Thermal Treatment**

- Thermal Treatment

**Ex Situ Biological Treatment**

- Biopiles
- Composting
- Landfarming
- Slurry Phase Biological Treatment

**Ex Situ Physical/Chemical Treatment (Assuming Excavation)**

- Chemical Extraction
- Chemical Reduction/Oxidation
- Dehalogenation
- Separation
- Soil Washing
- Solidification/Stabilization

**Ex Situ Thermal Treatment (assuming excavation)**

- Hot Gas Decontamination
- Incineration
- Open Burn/Open Detonation
- Pyrolysis
- Thermal Desorption
- Landfill Cap
- Landfill Cap Enhancements/Alternatives

**Other Treatment**

- Excavation, Retrieval, and Off-Site

# Teknik Remediasi untuk Groundwater & Leachate

Federal Remediation Technologies Roundtable (FRTR, 2001)

**In Situ Biological Treatment**

- Enhanced Bioremediation
- Monitored Natural Attenuation
- Phytoremediation

**In Situ Physical/Chemical Treatment**

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

**Ex Situ Biological Treatment**

- Bioreactors
- Constructed Wetlands

**Ex Situ Physical/Chemical Treatment (assuming pumping)**

- Adsorption/Absorption
- Advanced Oxidation Processes
- Air Stripping
- Granulated Activated Carbon (GAC)/Liquid Phase Carbon Adsorption
- Ground Water Pumping/Pump and Treat
- Ion Exchange
- Precipitation/Coagulation/Flocculation
- Separation
- Sprinkler Irrigation

**Containment**

- Physical Barriers
- Deep Well Injection

**Air Emissions/Off-Gas Treatment**

- Biofiltration
- High Energy Dest

**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 | ● | ◑ | ◑ | ○ | ● | ◑ | ● | ● | ◑ | ◑ | ◑ | ◑ | ◑ | ● | ○ | ◑ |
| 4.17 Dehalogenation | ● | ◑ | ○ | ○ | ○ | ○ | ◑ | ◑ | ○ | ● | ○ | ● | ○ | ○ | ○ | ◑ |
| 4.18 Separation | ● | ◑ | ○ | ◑ | ● | ◑ | ● | ● | ◑ | ◑ | ◑ | ◑ | ○ | ◑ | ○ | ○ |
| 4.19 Soil Washing | ● | ○ | ○ | ○ | ● | ◑ | ● | ● | ◑ | ◑ | ◑ | ◑ | ◑ | ◑ | ○ | ○ |
| 4.20 Solidification/Stabilization | ● | ● | ◑ | ○ | ● | ● | ● | ● | ○ | ○ | ◑ | ◑ | ○ | ● | ● | ○ |
| **3.6 Ex Situ Thermal Treatment (assuming excavation)** | | | | | | | | | | | | | | | | |
| 4.21 Hot Gas Decontamination | ○ | ● | ○ | ○ | ● | ● | ● | ◑ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 4.22 Incineration | ● | ● | ○ | ○ | ◑ | ○ | ● | ● | ● | ● | ● | ● | ● | ○ | ○ | ● |
| 4.23 Open Burn/Open Detonation | ● | ● | ○ | ○ | ● | ● | ● | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● |
| 4.24 Pyrolysis | ● | ● | ○ | ○ | ○ | ○ | ● | ● | ◑ | ◑ | ● | ● | ◑ | ○ | ○ | ○ |
| 4.25 Thermal Desorption | ● | ● | ○ | ○ | ◑ | ◑ | ● | ● | ● | ● | ● | ● | ● | ○ | ○ | ● |
| **3.7 Containment** | | | | | | | | | | | | | | | | |
| 4.26 Landfill Cap | ● | ● | ◑ | ○ | ● | ● | ○ | ● | ◑ | ◑ | ◑ | ◑ | ◑ | ◑ | ○ | ◑ |
| 4.27 Landfill Cap Enhancements/Alternatives | ● | ● | ◑ | ○ | ● | ● | ○ | ● | ◑ | ◑ | ◑ | ◑ | ◑ | ◑ | ○ | ◑ |
| **3.8 Other Treatment** | | | | | | | | | | | | | | | | |
| 4.28 Excavation, Retrieval, Off-Site Disposal | ● | ● | ● | ● | ● | ◈ | ● | ● | ◑ | ◑ | ◑ | ◑ | ◑ | ◑ | ○ | ◑ |

**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

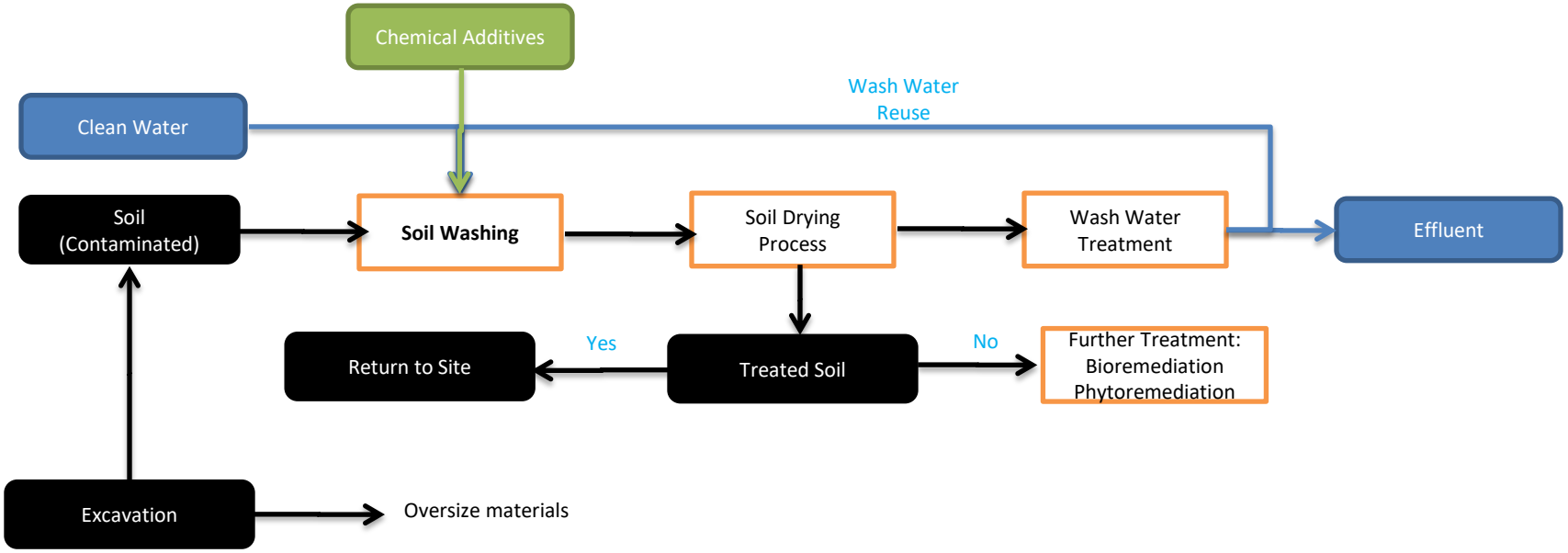
| | Development Status | Treatment Train | Relative Overall Cost & Performance | | | | | Availability | Nonhalogenated VOC's | Halogenated VOC's | Nonhalogenated SVOC's | Halogenated SVOC's | Fuels | Inorganics | Radionuclides | Explosives |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 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 | ● | ◑ | ◑ | ○ | ● | ◑ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ● | ◑ | ○ |
| 4.50 Separation | ● | ◑ | ○ | ○ | ● | ○ | ● | ● | ● | ● | ● | ● | ● | ⟐ | ⟐ | ○ |
| 4.51 Sprinkler Irrigation | ● | ● | ● | ● | ● | ○ | ○ | ● | ● | ● | ○ | ○ | ○ | ○ | ○ | ○ |
| **3.13 Containment** | | | | | | | | | | | | | | | | |
| 4.52 Physical Barriers | ● | ● | ◑ | ○ | ● | ● | ○ | ● | ● | ● | ● | ● | ● | ● | | ● |
| 4.53 Deep Well Injection | ● | ● | ● | ● | ◑ | ● | ○ | ● | ◑ | ◑ | ◑ | ◑ | ◑ | ◑ | ◑ | ◑ |
| **3.14 Air Emissions/Off-Gas Treatment** | | | | | | | | | | | | | | | | |
| 4.54 Biofiltration | ● | N/A | ● | ● | ⟐ | ● | ● | ○ | ● | ⟐ | ⟐ | ⟐ | ● | ○ | I/D | ⟐ |
| 4.55 High Energy Destruction | ○ | N/A | I/D | I/D | ○ | ◑ | I/D | ◑ | ● | ● | ● | ● | ● | ◑ | I/D | ○ |
| 4.56 Membrane Separation | ○ | N/A | I/D | I/D | ○ | ◑ | I/D | ◑ | ● | ● | ◑ | ◑ | ◑ | ○ | I/D | ◑ |
| 4.57 Oxidation | ● | N/A | ● | ● | ● | ● | I/D | ● | ● | ● | ● | ● | ● | ○ | I/D | ◑ |
| 4.58 Scrubbers | ● | N/A | ◑ | ○ | ● | ● | I/D | ● | ○ | ○ | ○ | ○ | ○ | ● | I/D | I/D |

# BMPs for Remediation Activities

Four Major Remedial Stages:

- Site Preparation and Staging
- Pre-Treatment
- Treatment
- Post-Treatment/Residuals Management

# Exp: Soil Washing Outline



**“Plan the Work, and Work the Plan”**

Terimakasih