Soil Washing

Physical Mechanisms

- Soil washing is a process of scrubbing soils to separate contaminants from soils
- Commonly done in one of two main methods
  - Dissolving or suspending contaminants in a wash solution using a reagent
  - By concentrating the solids, and attrition scrubbing
- Which method you decide to use depends on characteristics of the soil, and of the contaminant

Physical Mechanisms (reagents)

$\Delta G=\sigma_{ow}+\sigma_{sw}+\sigma_{os}$

When ΔG is negative, this indicates that the particles will separate from each other.

Adding reagents help by reducing surface tension between the contaminant and the particle, causing them to release

Same idea as using dish soap to remove grease from cooking pan

Physical Mechanisms (attrition scrubbing)

Attrition scrubbing is more effective when separating organics from soils

Relies on friction between particles to separate contaminants

Once freed from each other, particles can be further separated using another method

Similar to washing pan with only a sponge

Influencing Factors (Physical Characteristics)

How will these characteristics limit or make soil washing useful during this remediation?

Examine characteristics of the contaminant and aquifer physical properties

Specific characteristics influence specific types of soil washing

- Alkali Soil Washing
- Cosolvent Soil Washing
- Surfactant Soil Washing
- Water Flooding and Groundwater Extraction (Pump and Treat)

Effectiveness controlled by phase equilibrium, heterogeneity, fluid properties

Media Characteristics

Isotropic Media

Front Stability

Controlled by - Mobility Ratio, M<1

- Gravity Number

$$M = \frac{V_w}{V_{nw}} = \frac{\mu_{nw} k_w}{\mu_w k_{nw}}$$

$$N_g = \frac{N_B}{N_c} = \frac{\text{gravity forces}}{\text{viscous forces}}$$

Heterogeneous Media complicates the issue

Alkali Soil Washing Influencing Factors

Enhance NAPL removal by “saponifying” the organic acids and produce natural surfactants which decreases the surface tension

Strong Alkali reacts with NAPL results in natural surfactant

Surfactants adsorb onto aquifer mineral material

NAPL wettability (Surface tension non-wetting x 1000)

DNAPLs do not contain acidic components

Alkalis reduces water viscosity

Compatibility Issues

Cosolvent Washing Influencing Factors

Stability of each front ($M<1$), adsorption, expansion, soil and aquifer properties

Action of gravity makes downflow most effective (front stable)

Solubility enhancement of hydrocarbons in soils

Alkali agents, surfactants, and polymers to improve mobility

Interfacial Instability ($M>1$) for large differences in viscosity

Heterogeneities largely influence behavior

Clay materials may cause desiccation to slug due to cosolvent reaction

Consideration for density

Surfactant Soil Washing Influencing Factors

Surfactant Concentration

Salinity

Temperature

Hydraulic Gradient

Interfacial Tension

DNAPL

Toxicity and recovery are key

Low Surface Tension

Water Flooding and Groundwater Extraction Influencing Factors

Low pumping rates

Stratigraphic depressions

High NAPL Conc

DNAPL (Low specific gravity)

Volume

Applied at EPA Superfund Record of Decision
Brodhead Creek Site, Stroudsburg PA
4.28 acres, approx 418,000 gallons of coal tar

Aquifer Influencing Factors

Unconfined Confined

Storage Transmission Viscosity Porosity Conductivity Permeability

Density Bulk Modulus Specific Yield Specific Retention Pressure Head

Water Table Transmissivity Storativity Stress Compressibility

Soil Washing Lab Experiment

Field Implementation

3 Main Processes in a Soil Washing Plant:

1. **Soil Preparation**
2. **Soil Washing**
    a. **Washing, Rinsing**
3. **Wastewater Treatment**

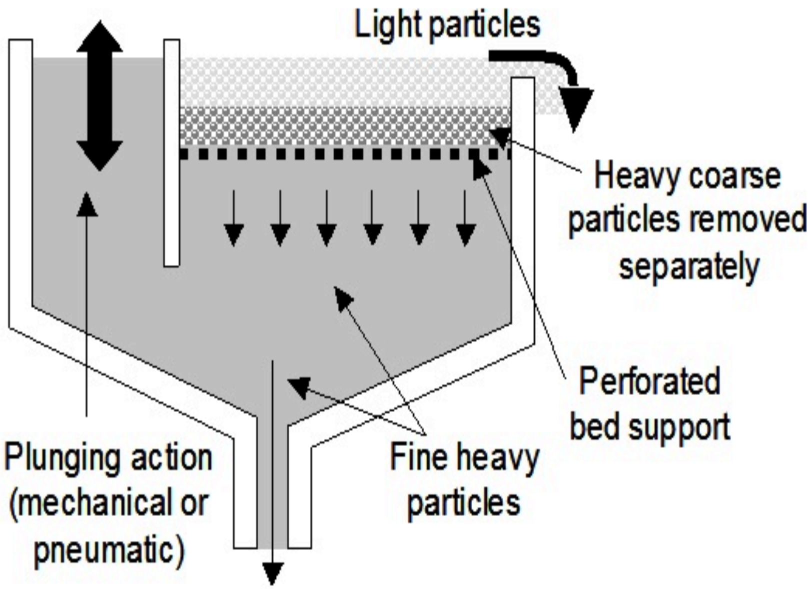
Field Implementation

- After site Excavation
- Coarse and Oversize Material Removed
- Techniques
  - Screening, Jigging, Hydrocyloning

- Large Rocks Removed
  - Usually impermeable
  - If contaminated will be crushed to fines.

Field Implementation

Jig Processor



Field Implementation

Screening

190 Wills' Mineral Processing Technology

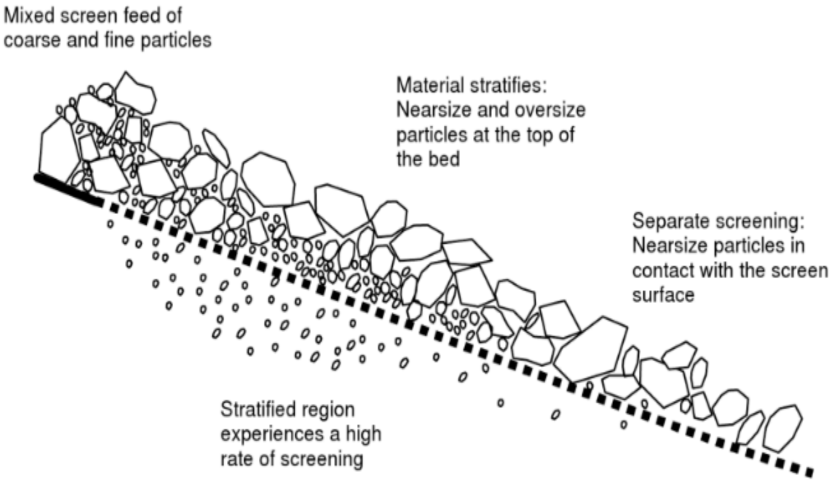


Figure 8.3 Stratification of particles on a screen (Courtesy JKMRC and JKTech Pty Ltd)

Field Implementation

Hydrocyclones

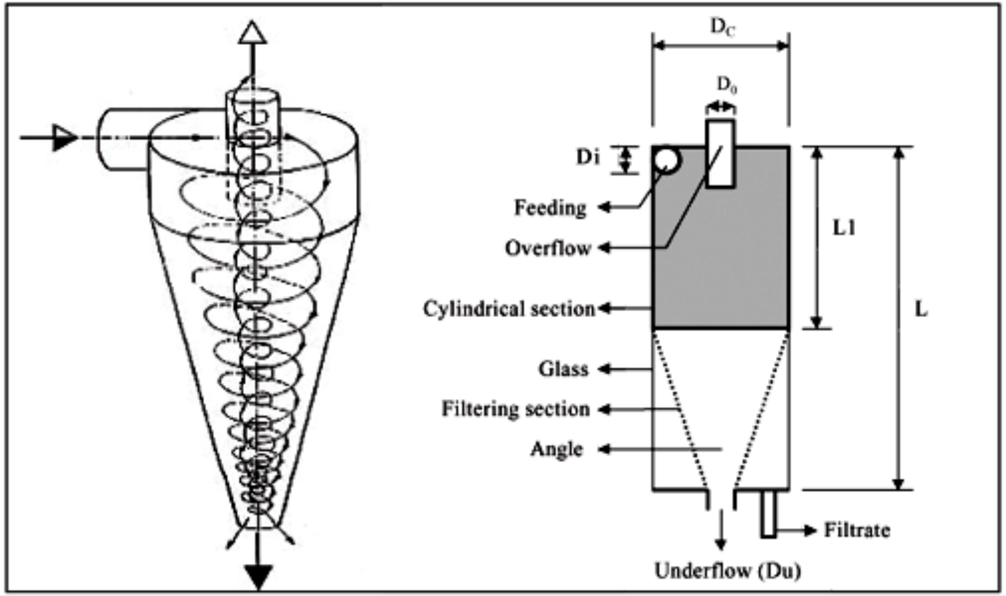


Figure 1: Trajectory of suspension for the conventional hydrocyclone and filtering device scheme

Parameter	*Purpose and Comment*
Key Physical	
Particle size distribution:	
>2 mm	Oversize pretreatment requirements
0.25-2 mm	Effective soil washing
0.063-0.25 mm	Limited soil washing
<0.063 mm	Clay and silt fraction—difficult soil washing
Other Physical	
Type, physical form, handling properties	Affects pretreatment and transfer requirements
Moisture content	Affects pretreatment and transfer requirements
Key Chemical	
Organics **Concentration** **Volatility** **Partition coefficient**	Determine contaminants and assess separation and washing efficiency, hydrophobic interaction, washing fluid compatibility, changes in washing fluid with changes in contaminants. May require preblending for consistent feed. Use the jar test protocol to determine contaminant partitioning.
Metals	Concentration and species of constituents (specific jar test) will determine washing fluid compatibility, mobility of metals, posttreatment.
Humic acid	Organic content will affect adsorption characteristics of contaminants on soil. Important in marine/wetland sites.
Other Chemical	
pH, buffering capacity	May affect pretreatment requirements, compatibility with equipment materials of construction, wash fluid compatibility.

Figure 1
Soil Washing Applicable Particle Size Range

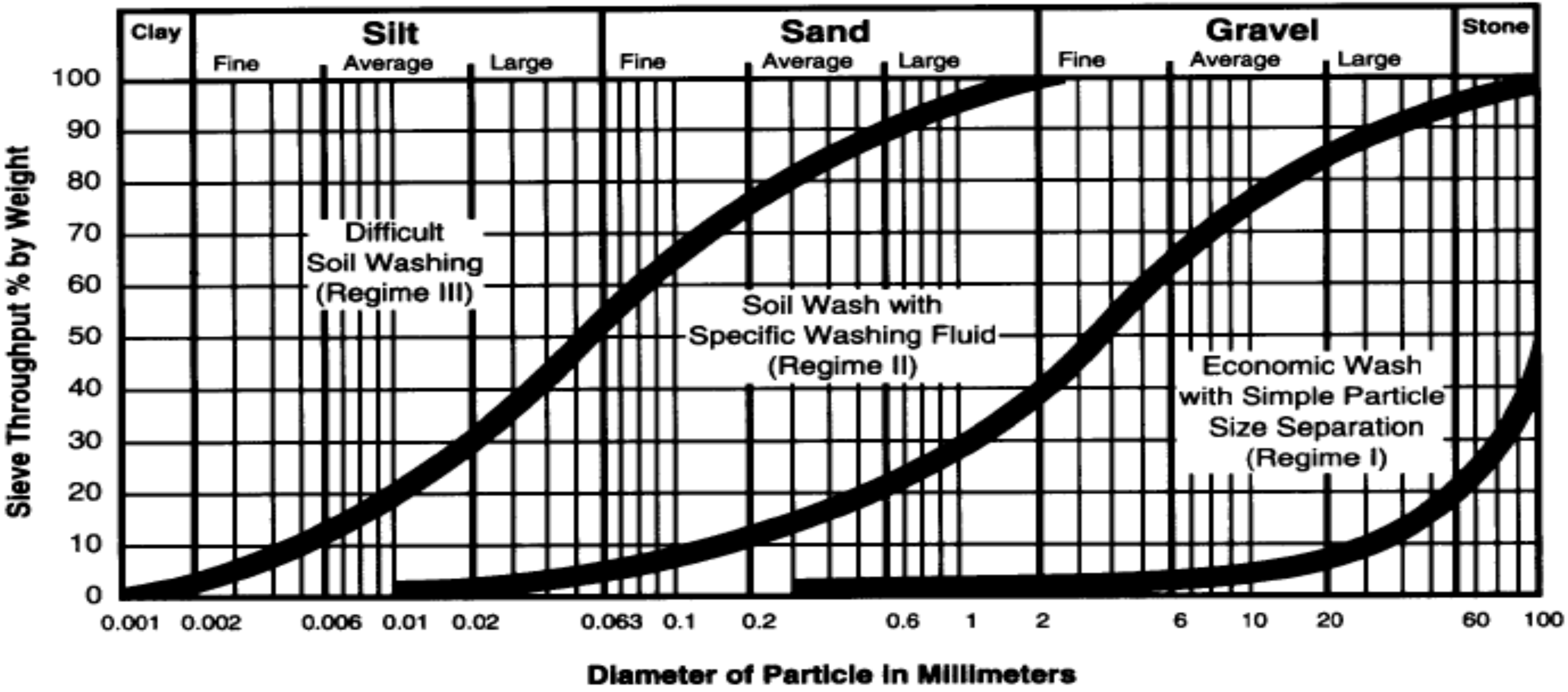


Table 1
Applicability of Soil Washing on General Contaminant Groups for Various Soils

	Contaminant Groups	*Matrix* *Sandy/ Gravelly Soils*	*Matrix* *Silty/Clay Soils*
Organic	Halogenated volatiles	■	▼
	Halogenated semivolatiles	▼	▼
	Nonhalogenated volatiles	■	▼
	Nonhalogenated semivolatiles	▼	▼
	PCBs	▼	▼
	Pesticides (halogenated)	▼	▼
	Dioxins/Furans	▼	▼
	Organic cyanides	▼	▼
	Organic corrosives	▼	▼
Inorganic	Volatile metals	■	▼
	Nonvolatile metals	■	▼
	Asbestos	❑	❑
	Radioactive materials	▼	▼
	Inorganic corrosives	▼	▼
	Inorganic cyanides	▼	▼
Reactive	Oxidizers	▼	▼
	Reducers	▼	▼

■ Good to Excellent Applicability: High probability that technology will be successful

▼ Moderate to Marginal Applicability: Exercise care in choosing technology

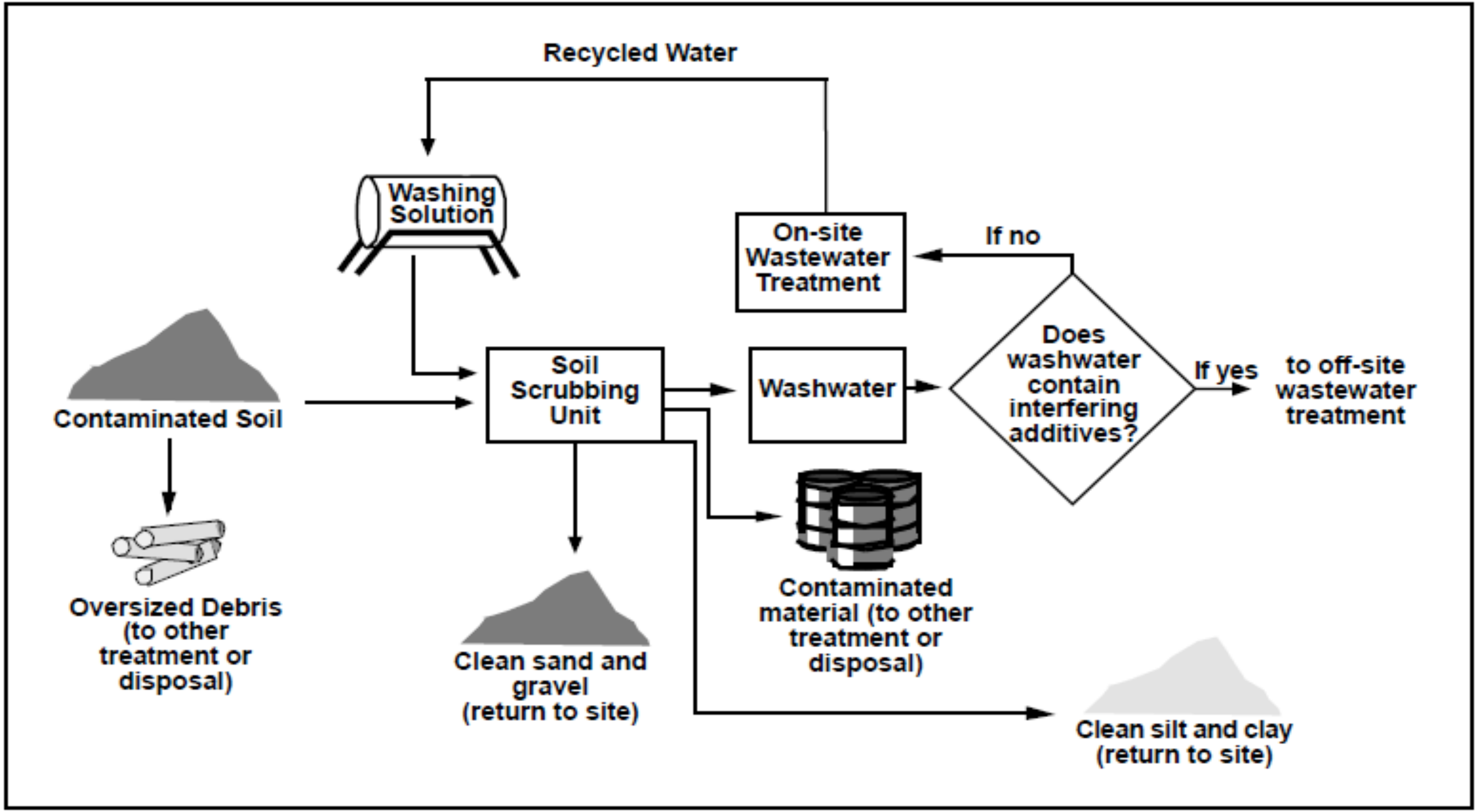
❑ Not Applicable: Expert opinion that technology will not work

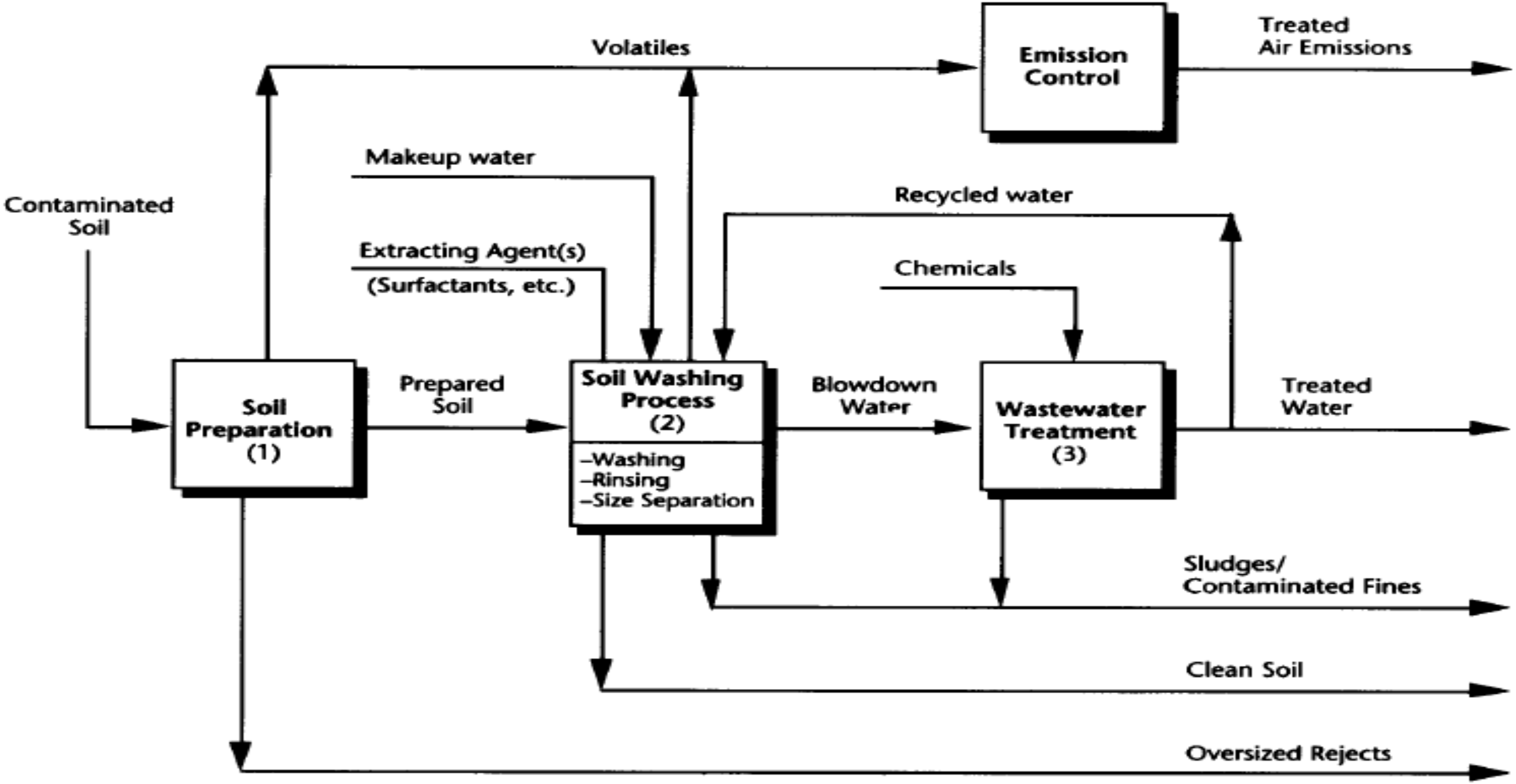
Primary Extraction		
Chemical solvents	**Effective For**	**Application/Limitations**
Inorganic Salts	Thorium, Radium	Large Solution to Solid Ratio
Mineral Acids Sulfuric Acid Nitric Acid Hydrochloric Acid	Radium, Thorium, Uranium	High Cost, Waste Stream difficult to clean
Complexing Agents EDTA CTA Citrate	Radium	Expensive, low concentrations needed.

Secondary Extraction		
Method	**Extractants**	**Application/Limitations**
Precipitation and Coprecipitation	Gaseous Ammonia, NaOH, H_2O_2, Magnesia	Adjustment of pH, costly operation
Solvent-solvent Extraction	alkyl phosphoric acids tri-n-butyl phosphate tioctyl phophine	Transferring radionuclides from aqueous leach liqueur to no aqueous dilutant. Can't be used with Carbonate solutions
Ion Exchange Fixed bed Moving Bed Resin-in-pulp	Sulfuric Acid Carbonate Leach Solution Chloride Nitrate bicarbonate	Uranium and Radium Recovery. Impurities may overload circuits
ACT*DE*CON	Chelant and Oxidant	Contaminants dissolved and recovered by ion exchange or evaporation

Field Implementation: Site Requirements

- Access Roads
- 20 ton/hour unit
- 4 acres
- 130,000-800,000 gallons of water per thousand cubic yards of soil
- Cannot be done in winter, cold weather affects chemical processes


Recycled Water
Washing Solution
On-site Wastewater Treatment
If no
Contaminated Soil
Soil Scrubbing Unit
Washwater
Does washwater contain interfering additives?
If yes
to off-site wastewater treatment
Oversized Debris (to other treatment or disposal)
Clean sand and gravel (return to site)
Contaminated material (to other treatment or disposal)
Clean silt and clay (return to site)



Volatiles
Emission Control
Treated Air Emissions
Makeup water
Recycled water
Contaminated Soil
Extracting Agent(s)
(Surfactants, etc.)
Chemicals
Soil Preparation (1)
Prepared Soil
Soil Washing Process (2)
–Washing
–Rinsing
–Size Separation
Blowdown Water
Wastewater Treatment (3)
Treated Water
Sludges/ Contaminated Fines
Clean Soil
Oversized Rejects

Field Implementation: Video

https://www.youtube.com/watch?v=mwIWaZXoZZ4

https://www.youtube.com/watch?v=k18kPpJc1is

Case Study #1: King of Prussia Technical Corporation Superfund Site, Winslow Township, NJ

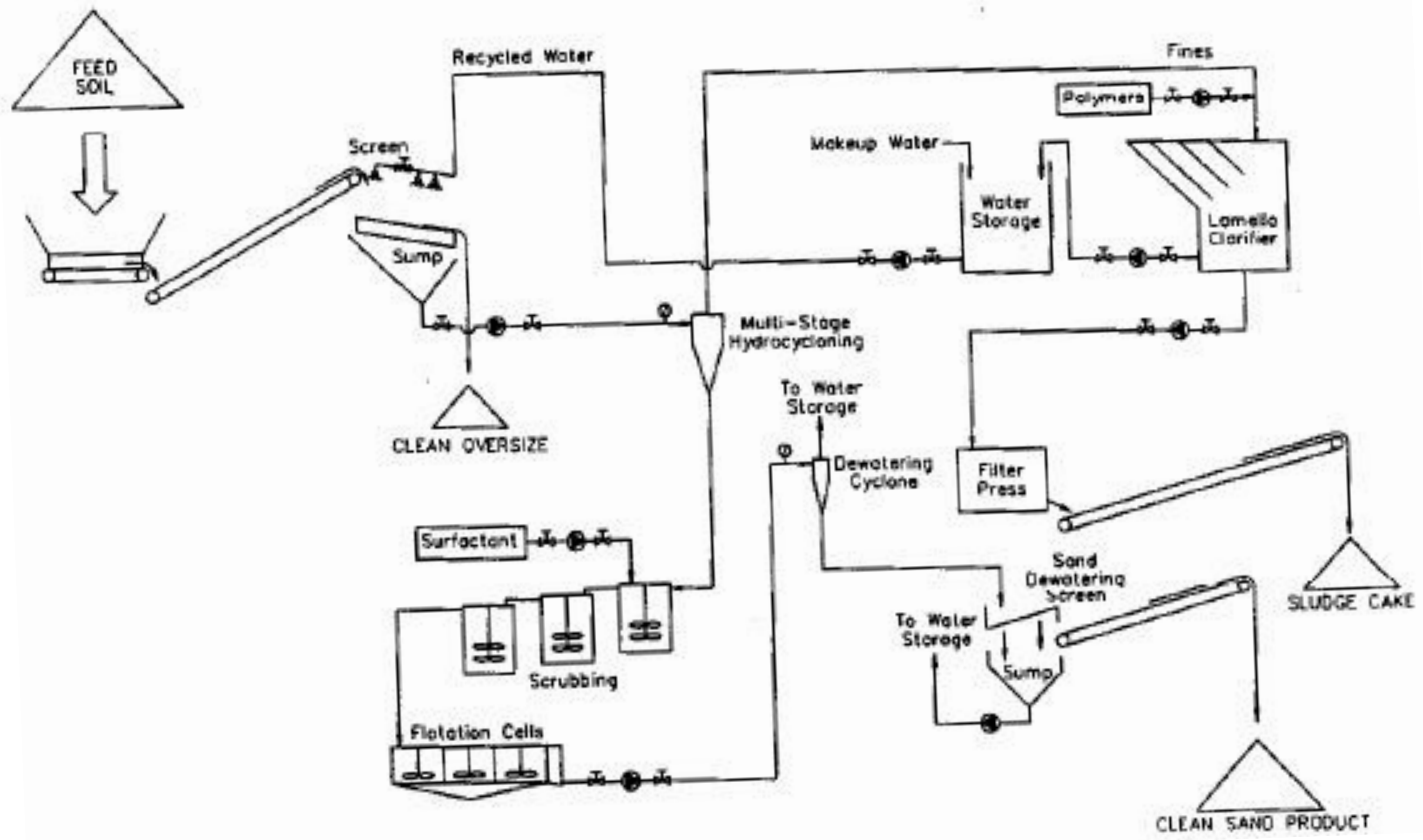
- King of Prussia Technical Corporation processed 15 million gallons of industrial waste in 6 lagoons from 1971 to 1974
- 11 metals contaminated the soil after the industrial waste facility was shut down
- Superfund Site designated by the US EPA

Contaminant	Original Soil Concentrations (mg/kg)	Regulatory Requirements (mg/kg)
Chromium	500 - 5,000	483
Copper	800 - 8,000	3,571
Nickel	300 - 3,500	1,935

Source: U.S. EPA “Remediation Case Studies Thermal Desorption, Soil Washing, and In Situ Vitrification

- Alternative Remedial Technologies, Inc. designed and operated the soil washing plant in 1993
- Selective excavation: used X-ray fluorescence (XRF) to determine which soil needed to be treated
- Soil ar were blend

Photos Source: ART Technologies, Inc. “Soil Washing at King of Prussia (KOP) Superfund Site

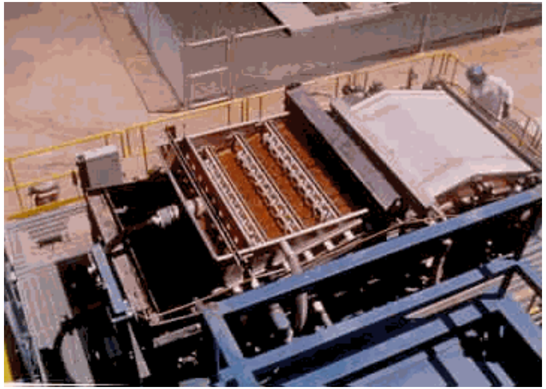

FEED SOIL
Recycled Water
Screen
Sump
CLEAN OVERSIZE
Multi-Stage Hydrocycloning
Fines
Polymers
Makeup Water
Water Storage
Lamella Clarifier
To Water Storage
Dewatering Cyclone
Filter Press
Surfactant
Scrubbing
Flotation Cells
Sand Dewatering Screen
To Water Storage
Sump
SLUDGE CAKE
CLEAN SAND PRODUCT

Soil Feed

Screening

Hydrocyclone

Flotation



Dewatering

- The soil washing process successfully reduced all 11 metal concentrations well below regulated limits
- Final project costs were $7.7 million

Contaminant	Original Soil Concentrations (mg/kg)	Regulatory Requirements (mg/kg)	Clean Sand Product Concentrations (mg/kg)
Chromium	500 - 5,000	483	73
Copper	800 - 8,000	3,571	110
Nickel	300 - 3,500	1,935	25

Case Study #2: A Washing Procedure to Mobilize Mixed Contaminants from Soil

Combination of cosolvent and surfactant soil washing

Simultaneous removal of PCB and heavy metals

High permeability and low water retention soils with history of organic pollutant and heavy metals contamination

1. Ehsan, S., S. O. Prasher, and W. D. Marshall. 2006. A Washing Procedure to Mobilize Mixed Contaminants from Soil . J. Environ. Qual. 35:2084-2091. doi:10.2134/jeq2005.0475

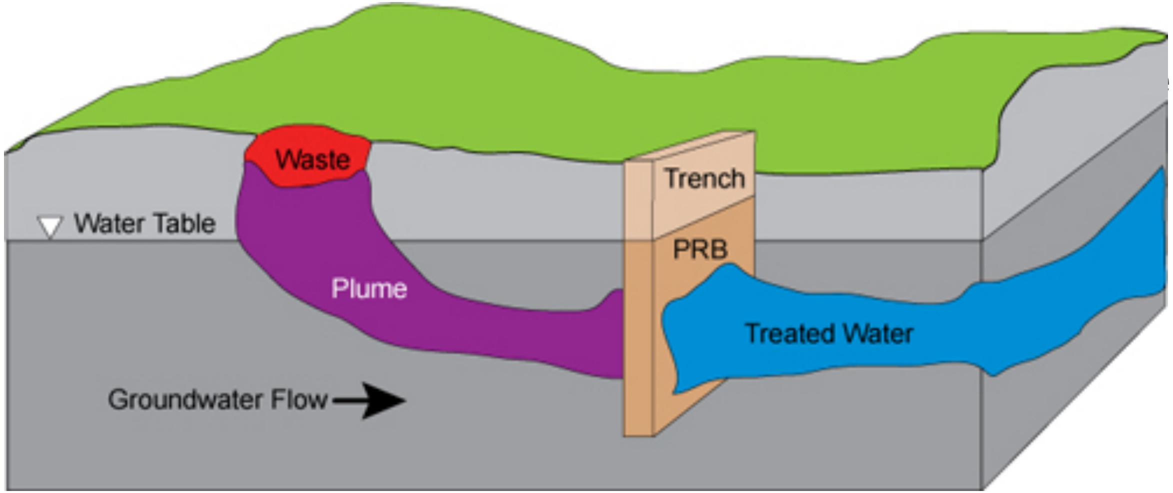
Ultrasonic mixing

Centrifuging of soil

Dissolution of PCB in aqueous hexane

Zerovalent magnesium for precipitation of heavy metals

rsu



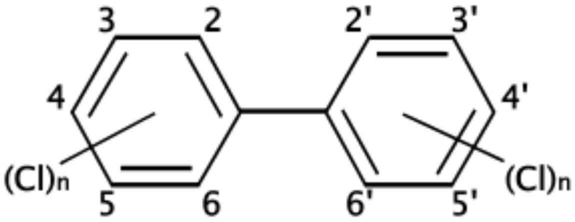


Table 4. Mean cumulative mobilization of PCBs for three successive washes of the soil (3 g) with the same charge of EDTA plus surfactant (30 mL L^{-1}).

Surfactant	First extraction (n = 15)	Second extraction (n = 6)	Third extraction (n = 4)	Sum	Cumulative PCB mobilized
	mg kg^{-1} ± RSD† (%)			mg kg^{-1}	%
Brij 98	28 ± 2 (60)	8 ± 7 (18)	2 ± 9 (4)	38	83
Triton X-301	27 ± 3 (58)	6 ± 10 (12)	0.8 ± 11 (2)	34	71
Triton XQS-20	24 ± 7 (52)	6 ± 14 (14)	1 ± 12 (3)	31	68

† Relative standard deviation.

Table 5. Mean cumulative PCB mobilization for three successive washes of the soil (3 g) with EDTA plus surfactant (30 mL L^{-1}) using fresh reagents each time.

Surfactant	First extraction (n = 3)	Second extraction (n = 3)	Third extraction (n = 3)	Sum	Cumulative PCB mobilized
	mg kg^{-1} ± RSD† (%)			mg kg^{-1}	%
Brij 98	27 ± 5 (59)	9 ± 2 (20)	4 ± 6 (8)	40	87
Triton X-301	27 ± 8 (58)	8 ± 9 (17)	3 ± 14 (6)	38	81
Triton XQS-20	24 ± 2 (51)	8 ± 6 (18)	3 ± 5 (6)	35	76

† Relative standard deviation.

Table 5. Mean cumulative metal recoveries in the supernatant fraction after equilibration of soil (3 g) with the same charge (recycling mode) of EDTA (2 mmol) or with fresh reagent each time.

Analyte	Cumulative metal mobilized					
	Recycled EDTA	Fresh EDTA	Recycled EDTA–Triton QSX-20	Fresh EDTA–Triton QSX-20	Recycled EDTA–Brij 98	Fresh EDTA–Brij 98
	% ± SD†					
Al	7 ± 0.3c‡	16 ± 0.9a	9 ± 0.2b	16 ± 1a	9 ± 0.8b	16 ± 0.8a
Cd	42 ± 4a	49 ± 7a	42 ± 3a	49 ± 5a	41 ± 0.8a	49 ± 0.8a
Cr	4 ± 0.3c	10 ± 0.4b	4 ± 0.04c	11 ± 4a	5 ± 0.4c	11 ± 0.4a
Cu	57 ± 4c	71 ± 4ab	57 ± 4c	72 ± 6ab	64 ± 4bc	78 ± 4a
Fe	2 ± 0.1c	10 ± 0.6b	2 ± 0.1c	12 ± 0.7a	3 ± 0.3c	12 ± 0.3a
Mn	33 ± 3b	38 ± 0.4a	30 ± 2b	36 ± 0.4a	31 ± 2b	37 ± 2a
Ni	20 ± 2d	33 ± 0.1b	20 ± 0.8d	31 ± 0.6c	19 ± 1d	36 ± 1a
Pb	78 ± 5b	85 ± 4ab	77 ± 0.8b	88 ± 2ab	84 ± 0.8ab	92 ± 0.8a
Zn	51 ± 4b	62 ± 4a	47 ± 5b	65 ± 3a	52 ± 2b	69 ± 2a

† Standard deviation based on three replicate trials.
‡ Numbers in the same row followed by the same letter are not significantly different ($P = 0.05$).

Applicability

The soil washing process is used for soils that are contaminated with:

- Semi volatile Organic compounds
- Fuels
- Heavy metals
- Some selected Volatile organic compounds
- Pesticides

Limitations

Soil washing does not clean the soil, it separates the contaminated fraction from the clean fraction, hence minimizing the amount of soil need to be cleaned.

It is a technique of concentrating contaminants through separation

Soil washing does not destroy or immobilize the contaminants

Limitation (cont)

Sometimes soil washing alone does not clean the polluted soil enough (therefore other methods must be used after)

If there is a high organic content in the soil, it may require pretreatment.

Since it does not destroy or immobilize the contaminants the resulting contaminated soil must be disposed of carefully.

Cost and Availability

Initial Costs

Studies and Pre-Tests

Operational Costs

Labor, Equipment, Fuel

Set-up and Break-down Costs

Permits, Design

Chemical Analysis

Disposal Costs

Source: Hubler, Jon, and Ken Metz. "Soil Washing." *Soil Washing* | *Geoengineer.org*. N.p., n.d. Web. 27 Mar. 2017.

Cost and Availability

$150-$250 per ton

Most effective with large quantities

Not effective with silty soils

Low-cost alternative for separating waste and volume reduction

Hardware readily available

Source: United States Environmental Protection Agency (USEPA). (1996, April). “A Citizen's Guide to Soil Washing.” EPA 542-F-96-002

Cost and Availability

Cost less with higher volume

RACER PARAMETERS	Scenario A Small Site	Scenario B Large Site
Remedial Action:		
Media/Waste Type	Soil	Soil
Contaminant	SVOC	SVOC
Approach	Ex situ	Ex situ
System Definition:		
Volume (CY)	10,000	200,000
Density (Lbs/CY)	2,600	2,600
Quantity (Tons)	13,000	260,000
Size of Soil Washing Plant (Tons/Hr)	50	100
Mobilization Distance (Mi)	100	100
Safety Level	D	D
Additives:		
Surfactant Additive Rate (Lbs/ton)	4	4
Soil Type	sand-silt/sand clay mixture	sand-silt/sand clay mixture
Supply Water Temperature (°F)	55	55
Process Water Temperature (°F)	55	55
Make up Water (GPM)	50	100
Boiler Capacity (MBH)	0	0
Operation:		
Hours of Operation per Day	16	16
Hours of Downtime per Day	2	2
Days of Operation per Week	5	5
Weeks of Operation per Year	42	42
O&M:		
Years of O&M		
Additional Costs:		
O&M	$0	$0
Remedial Design (10% or 10K)	$129,147	$960,991
Soil Washing Marked-Up Costs	$1,291,468	$9,609,909
TOTAL MARKED-UP COSTS	$1,420,615	$10,570,900
COST PER CUBIC FOOT	**$5**	**$2**
COST PER CUBIC METER	**$187**	**$70**
COST PER CUBIC YARD	**$142**	**$53**