Sustainable Site Remediation: Examples from Around the Globe

January 17, 2024

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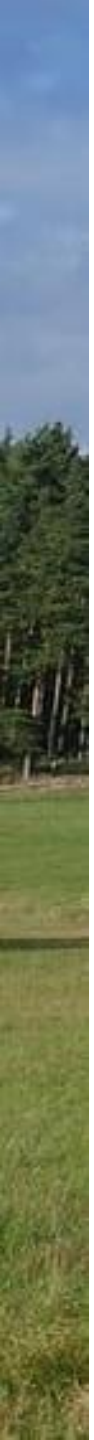
BALL STATE UNIVERSITY



John Pichtel

Director, Hazardous Materials Research Laboratory

Soil Chemistry

- Acid mine drainage
- Behavior of contaminants
  - heavy metals
  - hydrocarbons
  - nanoparticles

Site Investigation

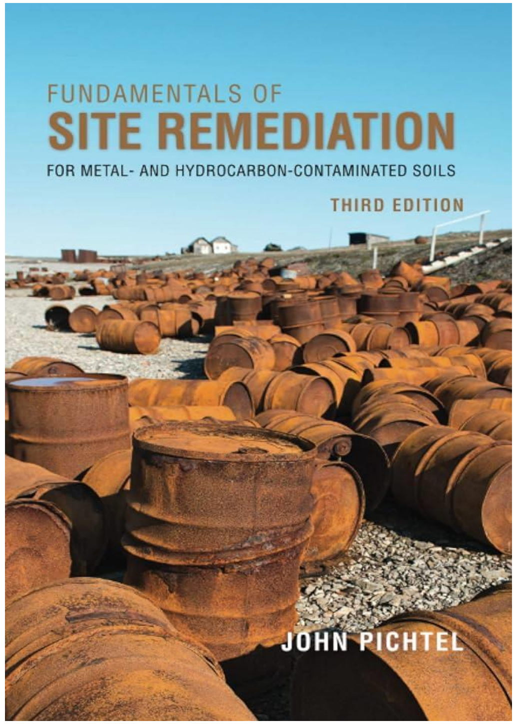
- Superfund sites
- Brownfields
- Military bases

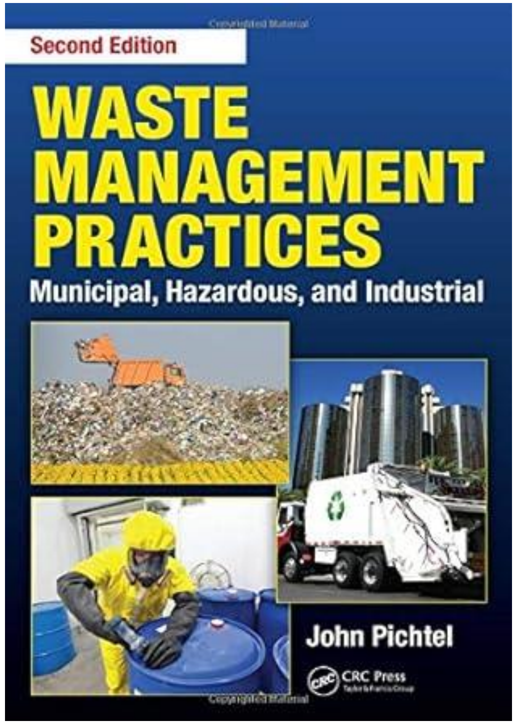
Waste Management

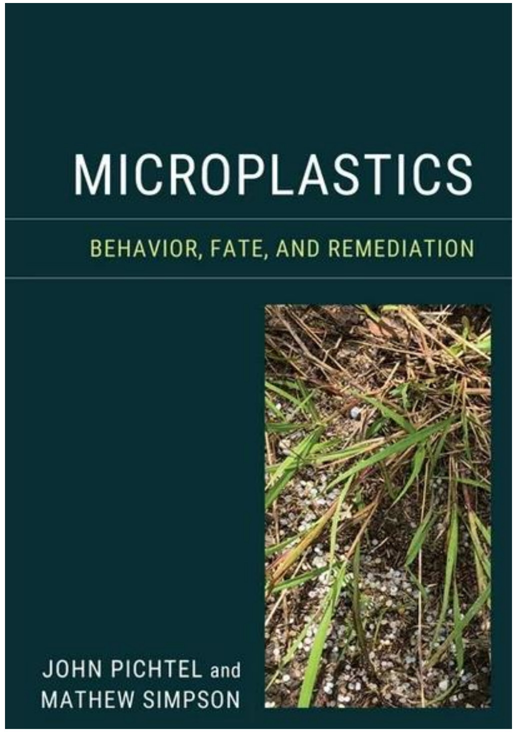
- Refuse-derived fuels
- Electronics wastes
- Compost technologies

Site Remediation

- Bioremediation
- Phytoremediation
  - heavy metals
  - petroleum products
- Soil flushing
  - heavy metals
- CVOC destruction by nanoparticles

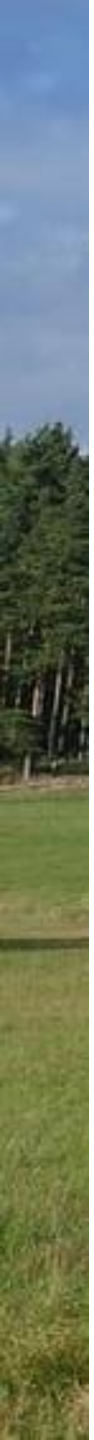






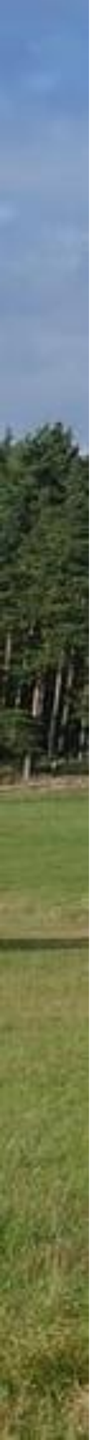
Ye et al. (2021): More than 5 million contaminated sites worldwide are in need of remediation.

Ye et al. 2019. *Chemosphere* 227, 681-702.



Sources of Soil Contamination Worldwide

- Releases from operating facilities
- Leaks from active landfills
- Leaks from former hazardous waste disposal sites
- Leaking USTs
- Accidental spills
- Mining
- Particulate matter from airborne sources
- Fertilizers and pesticides



Soil Contamination in Selected Nations

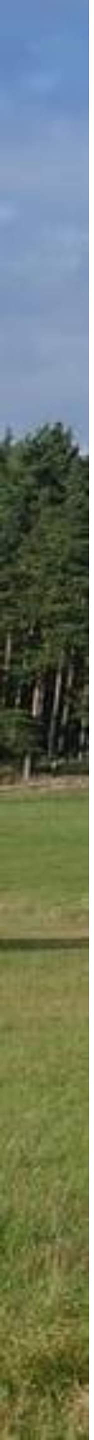
European Union[1]
- WHO: 2.8 million sites
- “60 to 70% of soils in the EU are currently unhealthy … ”

United States[2]
- 1,336 Superfund sites
- 450,000 brownfields (approx. one-half impacted by leaking USTs)

Canada[3]
- 2,500+ sites

Most frequent contaminants: petroleum products, heavy metals

1. https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_5917
2. https://www.epa.gov/superfund/superfund-national-priorities-list-npl
3. https://www.tbs-sct.gc.ca/fcsi-rscf/cen-eng.aspx?dataset=prov&sort=name



Soil Contamination in Selected Nations

P.R. China

- China Ministry of Environmental Protection: 16% of soil samples (19% of agricultural soils) are contaminated, (heavy metals and metalloids)
- Main sources: industry and agriculture
- Top three pollutants: Cd, Ni, As

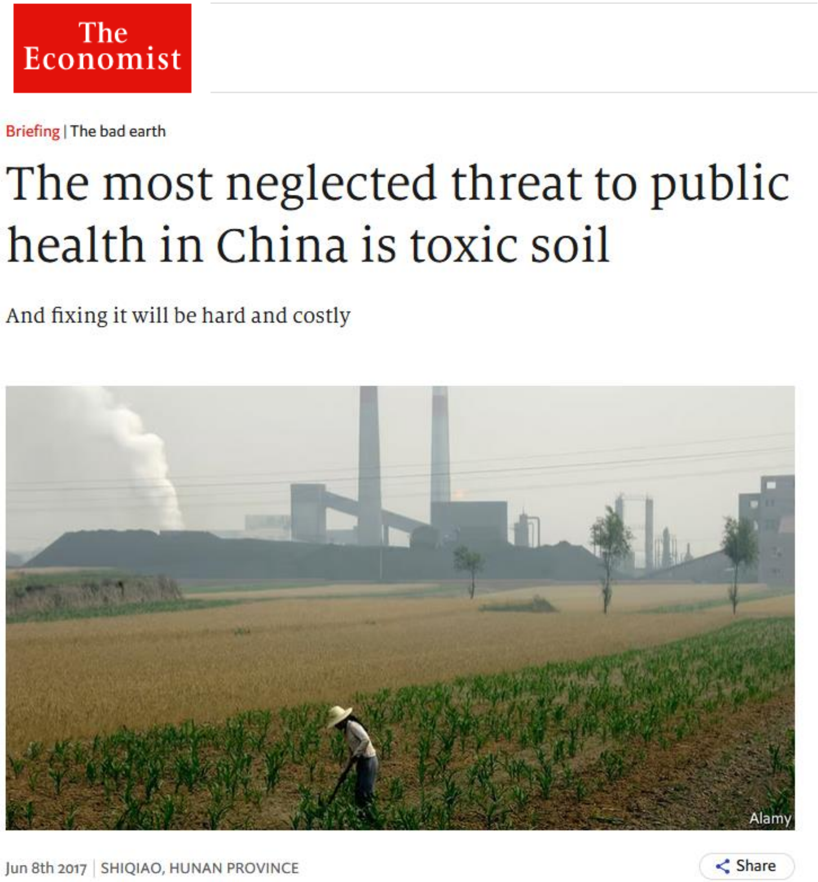
“The situation is not optimistic.”

Japan

- 400,000 contaminated sites

Many nations

- Unknown/insufficient data



The Economist

Briefing | The bad earth

The most neglected threat to public health in China is toxic soil

And fixing it will be hard and costly

Alamy

Jun 8th 2017 | SHIQIAO, HUNAN PROVINCE

Share

Zhao et al. 2015. *Environ. Sci. Technol*. 49:750-759

Remediation Technologies Employed Globally

Physical
- Excavation and haul
- Free product removal
- Pump and treat
- Soil vapor extraction
- Air sparging
- In-well air stripping

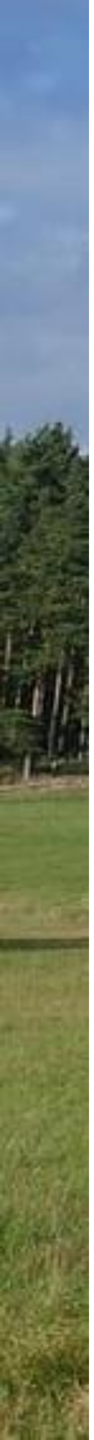
Biological
- In-situ bioremediation
- Bioslurries
- Biosparging
- Biopiles
- Bioreactors
- Landfarming
- Phytoremediation
- Constructed wetlands

Chemical
- In-situ chemical oxidation
- In-situ chemical reduction
- Soil flushing/washing
- Nanoparticle redox

Thermal
- Electrical resistance heating
- In-situ steam injection
- Thermal conduction
- In-situ vitrification
- In situ smoldering

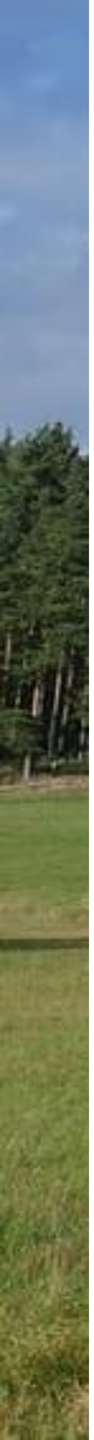
Immobilization
- Adsorption
- Solidification/stabilization
- Encapsulation
- Electrokinetic

1970s	Landfilling (‘Dig and haul’)	Decision-making to select cleanup technology based on cost considerations, technological limitations, political climate. Impacts not considered.



GC Environmental

1990-2000	Conventional Remediation	Decision-making evolved to technology feasibility and risk-based approaches.
1970s	Landfilling	Decision-making to select cleanup technology based on cost considerations, technological limitations, political climate. Impacts not considered.



2000-2010	Green and Sustainable Remediation	Incorporating sustainability benchmarks into the decision-making process to evaluate environmental and cost implications from remedial actions.
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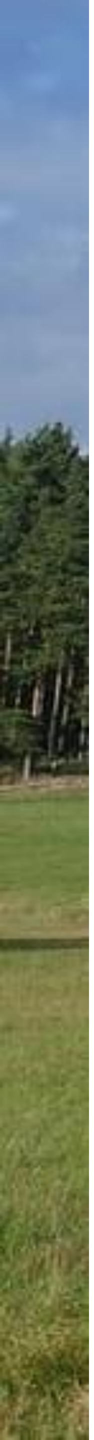
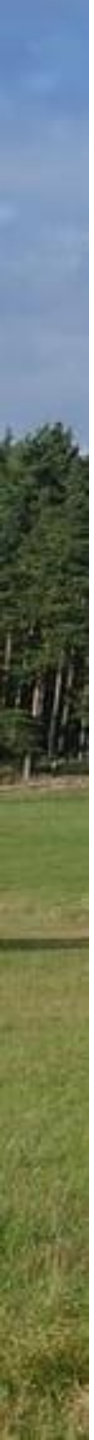


2010-present	Sustainable Resilient Remediation	Remedial actions that create resilience against increasing threats (wildfires, climate change).
2000-2010	Green and Sustainable Remediation	Incorporating sustainability benchmarks into the decision-making process to evaluate environmental and cost implications from remedial actions.
1990-2000	Conventional Remediation	Decision-making evolved to technology feasibility and risk-based approaches.
1970s	Landfilling	Decision-making to select cleanup technology based on cost considerations, technological limitations, political climate. Impacts not considered.



Technologies in Common Use

United States
Excavation/removal; pump and treat; physical/chemical treatment; thermal methods; biological treatment

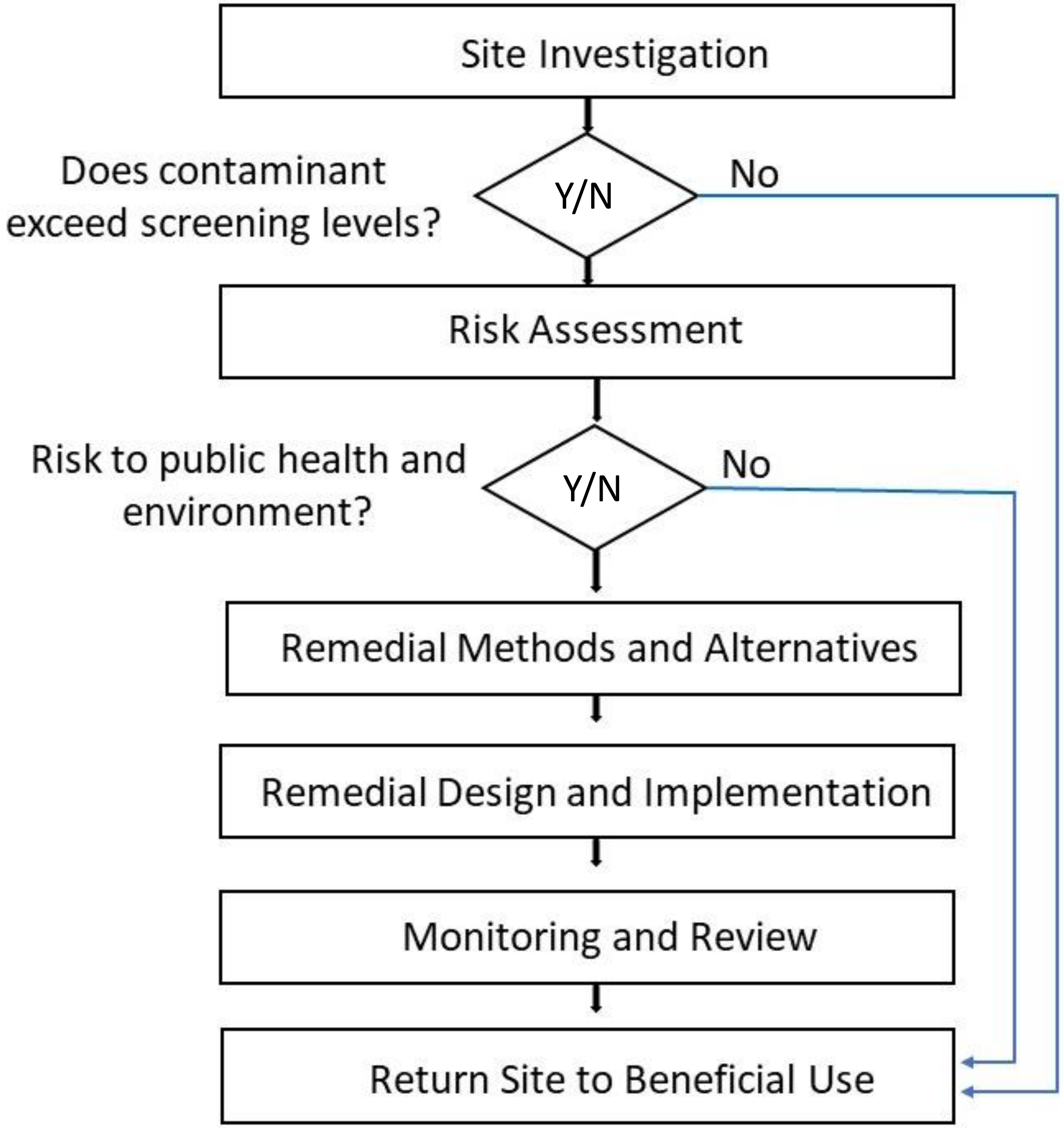
European Union
Excavation/removal (about one-third of management practices)
In-situ and ex-situ techniques applied more or less equally[1]

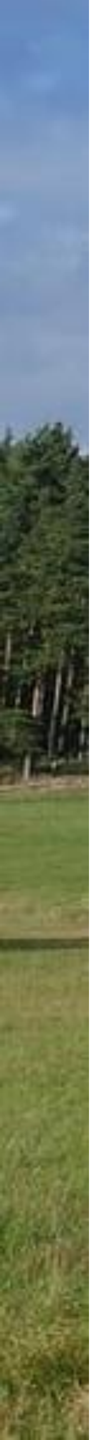
P.R. China
Excavation/removal; pump and treat; soil washing; ISCOR; SVE; bioremediation …

Latin America, central Africa, east Asia
Most common: excavation and storage in alternate location, typically off-site[2]

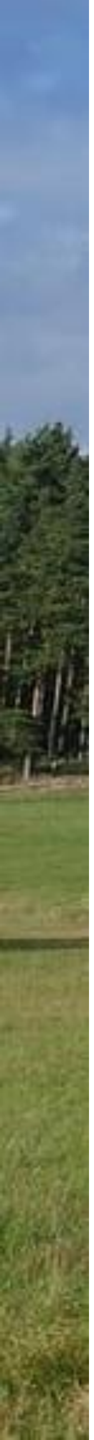
[1]https://www.eea.europa.eu/data-and-maps/indicators/progress-in-management-of-contaminated-sites-3/assessment
[2]O’Brien et al. 2021. *Crit. Rev. Env. Sci. Toxicol*. 51: 1259-1280.

Risk-Based Approach to Site Remediation





Sharma, H.D., and K.R. Reddy. 2004.
Geoenvironmental Engineering. John Wiley.



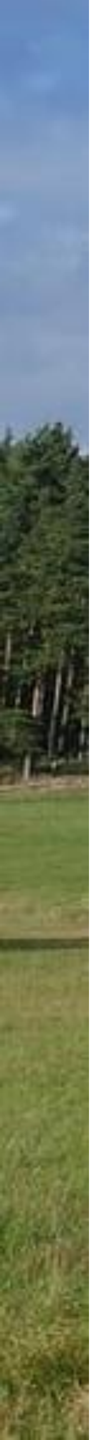
Concerns with Conventional Remediation Technologies

Many are considered outdated –

- expensive
- highly invasive
- consume substantial energy, water, other natural resources
  - on-site: excavation; pump-and-treat; SVE ...
  - off-site: transportation (workers, bulk supplies, treatment chemicals, construction materials, specialized equipment)

No consideration of –

- side effects (e.g., energy usage; air emissions; natural resources used; secondary wastes generated)
- sustainability
- resiliency (e.g., climate impacts)
- life cycle issues



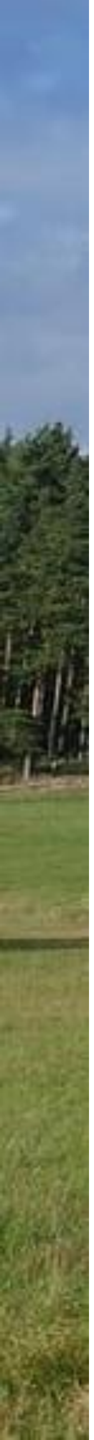
Sustainability Defined

The development that meets the needs of the present without compromising the ability of future generations to meet their needs."

UN. 1987. World Commission on Environment and Development. Our Common Future.

"A set of environmental, economic, and social conditions – the Triple Bottom Line" – in which all of society has the capacity and opportunity to maintain and improve its quality of life indefinitely, without degrading the quantity, quality or the availability of natural, economic, and social resources."

American Society of Civil Engineers
http://www.asce.org/sustainability-at-asce/



Sustainable Remediation

Site Investigation

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Risk Assessment; Establish Remedial Goals

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Identification of Potential Remediation Technologies

- Based on site characteristics, contaminant types

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Preliminary Design; Sustainability Assessment of Remedial Alternatives

- Use sustainability assessment tools

↓

Select Sustainable Remediation Method

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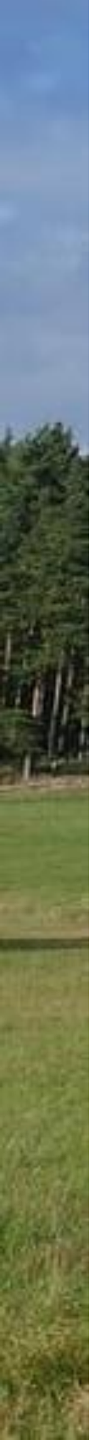
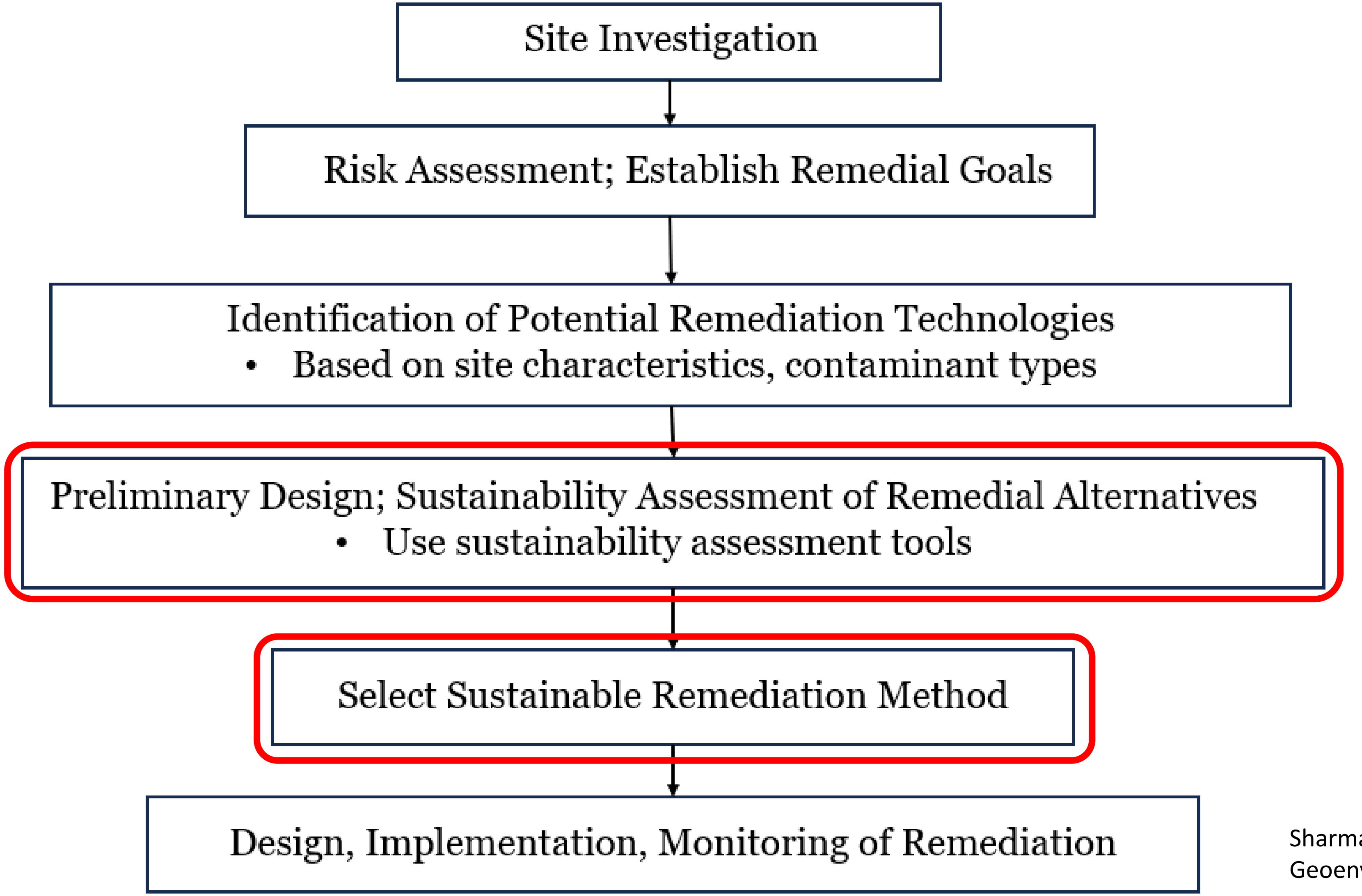
Design, Implementation, Monitoring of Remediation

Sharma, H.D., and K.R. Reddy. 2004. Geoenvironmental Engineering. John Wiley.

Sustainable Remediation





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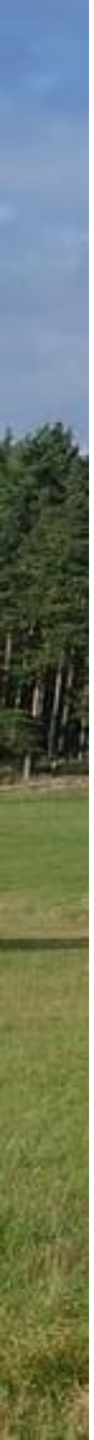


Green Remediation: Different from Sustainable Remediation?

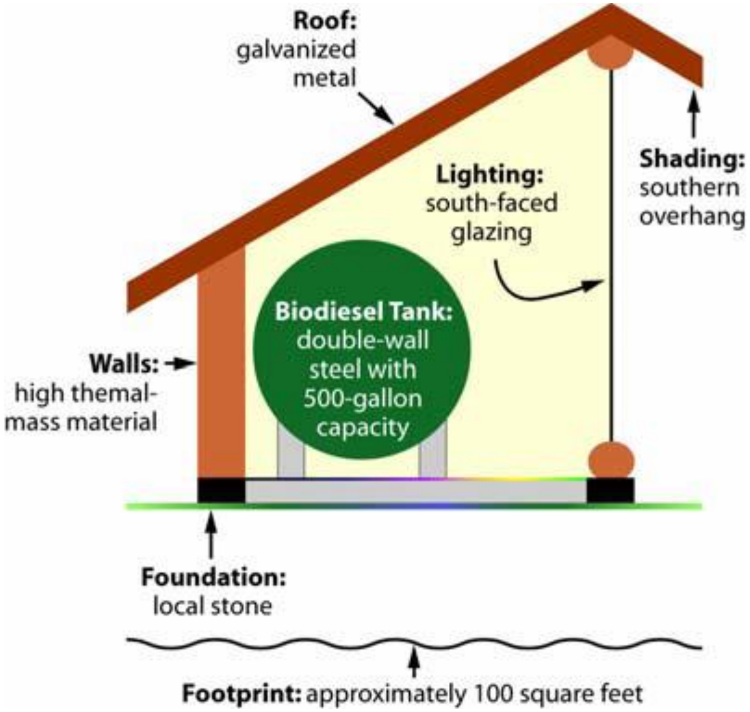
Green Remediation:

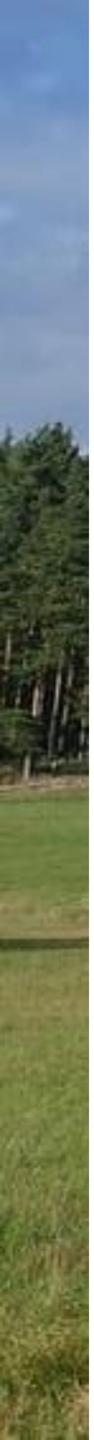
Focuses on minimizing environmental impact of remediation process itself. Emphasizes techniques that reduce energy consumption, water usage, resource utilization, waste generation and greenhouse gas emissions during cleanup activities.

Examples: Using biodiesel in equipment, utilizing solar panels for power, employing water recycling technologies.

Strategies involve choosing technologies and materials that have lower environmental burdens, such as using in-situ bioremediation instead of excavation and disposal.

Generally aligns with environmental regulations and standards designed to protect human health and the environment.





Sustainable Remediation:

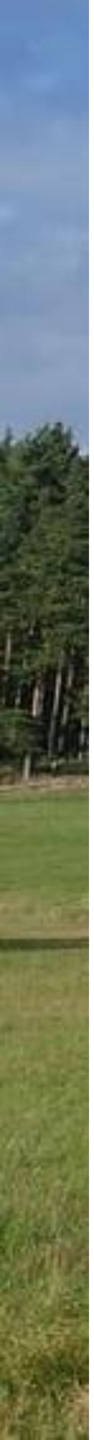
A broader view; considers not only the environmental impact of the cleanup but also its economic and social implications.

Aims to balance long-term environmental protection with social and economic well-being of the community surrounding the contaminated site.

Examples: Reusing recovered materials or properties, creating habitat for wildlife, fostering community green spaces on previously contaminated sites.

Involves engaging stakeholders, considering potential job creation, community redevelopment, and reuse of the cleaned-up site.

Strives to create a net positive impact, not just minimize negative impacts.



Environmental

Energy usage
Water usage
Natural resources
Waste generation
Air pollution
Greenhouse gases
Biodiversity

Economic

Direct costs

- Materials
- Equipment
- Transportation
- Labor

Indirect benefits

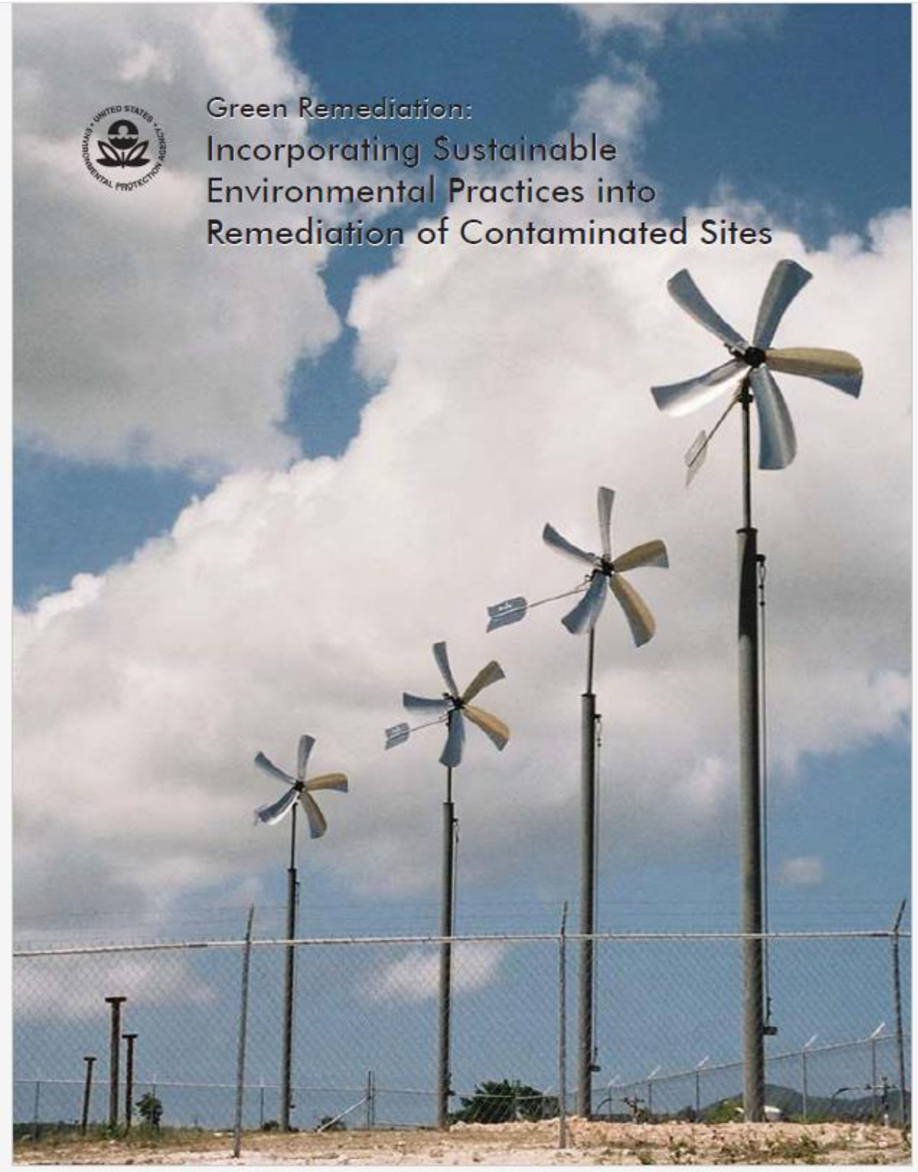
- Employments

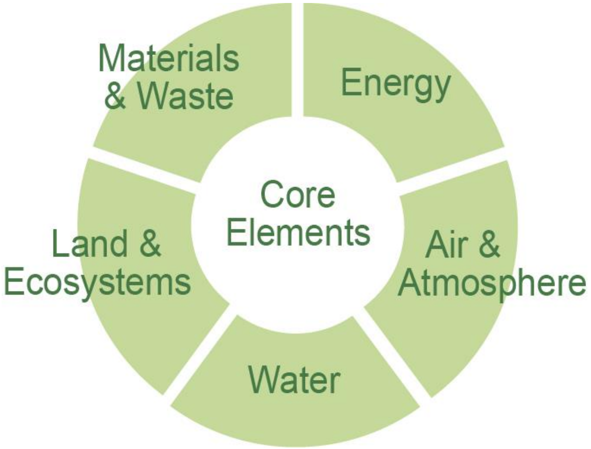
Social

Standard of living
Community
Equal opportunity

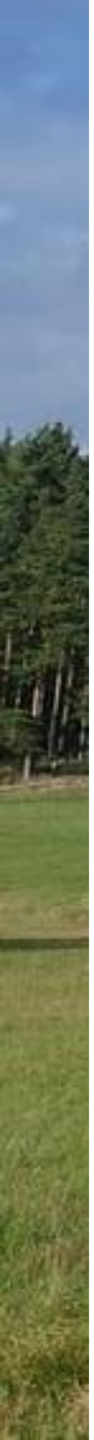
The 'Triple Bottom Line'

US EPA (2008). Sustainable Remediation





Category	Metric	Unit of Measure
Materials	Refined materials used or conserved	tons
	Unrefined materials used or conserved	tons
Waste	Hazardous waste generated or avoided	tons
	Non-hazardous waste generated or avoided	tons
Water	Public water used or conserved	million gallons
	Groundwater used or conserved	million gallons
	Wastewater generated or avoided	million gallons
	Other water used or conserved	million gallons
Energy	Grid electricity used or conserved	megawatt hours
	Diesel used or conserved for equipment	gallons
	Diesel used or conserved for transportation	gallons
	Gasoline used or conserved for equipment	gallons
	Gasoline used or conserved for transportation	gallons
	Other energy used or conserved	(variable)



ASTM Standard Guide for Greener Cleanups (2016)

INTERNATIONAL

Designation: E2893 – 16ε1

Standard Guide for Greener Cleanups[1]

This standard is issued under the fixed designation E2893; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

ε[1] NOTE—The adjunct order number for the X2. Technical Summary Form in Writable PDF format was editorially corrected (see 2.4) in January 2017.

1. Scope

1.1 Cleaning up *sites* improves environmental and public health conditions and as such can be viewed as "green." However, *cleanup* activities use energy, water, and natural resources. The process of *cleanup* therefore creates its own *environmental footprint*. This *guide* describes a process for evaluating and implementing activities to reduce the *environmental footprint* of a *cleanup* project in the United States while working within the applicable regulatory framework and satisfying all applicable legal requirements.

1.2 This *guide* may also be used as a process for *sites* that are not located in the United States; however, the specific legal references are not applicable.

1.3 This *guide* describes a process for identifying, evaluating, and incorporating *best management practices (BMPs)* and, when deemed appropriate, for integrating a *quantitative evaluation* into a *cleanup* to reduce its *environmental footprint*.

1.4 This *guide* is designed to be implemented in conjunction with any *cleanup* framework and should be used with other technical tools, guidance, policy, laws, and regulations to integrate *greener cleanup* practices, processes, and technologies into *cleanup* projects.

1.5 This *guide* provides a process for evaluating and implementing activities to reduce the *environmental footprint* of a *cleanup* and is not designed to instruct *users* on how to clean up contaminated *sites*.

1.6 ASTM also has a *guide* on Integrating Sustainable Objectives into *Cleanup* (E2876). That *guide* provides a broad framework for integrating elements of environmental, economic, and social aspects into *cleanups*. This *guide* may provide assistance with implementing E2876 and other sustainable remediation guidance, such as Holland, et al. (2011)(1).

1.7 This *guide* specifically applies to the *cleanup*, not the redevelopment, of a *site*. However, the reasonably anticipated use of a *site*, if known, may influence the *cleanup* goals and scope.

1.8 This *guide* should not be used as a justification to avoid, minimize, or delay implementation of specific *cleanup* activities. Nor should this *guide* be used as a justification for selecting *cleanup* activities that compromise *stakeholder* interests or goals for the *site*.

1.9 This *guide* does not supersede federal, state, or local regulations relating to protection of human health and the environment. No action taken in connection with implementing this *guide* should generate unacceptable risks to human health or the environment.

1.10 This *guide* may be integrated into complementary standards, *site*-specific regulatory documents, guidelines, or contractual agreements relating to sustainable or greener *cleanups*.

1.10.1 If the *cleanup* is governed by a regulatory program, the *user* should discuss with the regulator responsible for the *site* how this *guide* could be incorporated into the *cleanup* and whether the regulator deems it appropriate for the *user* to report the process and results to the regulatory program.

1.10.2 The contractual relationship or legal obligations existing between and among the parties associated with a *site* or *site cleanup* are beyond the scope of this *guide*.

1.11 This *guide* is composed of the following sections: Referenced Documents (Section 2); Terminology (Section 3); Significance and Use (Section 4); Planning and Scoping (Section 5); *BMP Process* (Section 6); *Quantitative Evaluation* (Section 7); Documentation and Reporting (Section 8); and Keywords (Section 9).

1.12 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the*

[1] This guide is under the jurisdiction of ASTM Committee E50 on Environmental Assessment, Risk Management and Corrective Action and is the direct responsibility of Subcommittee E50.04 on Corrective Action.

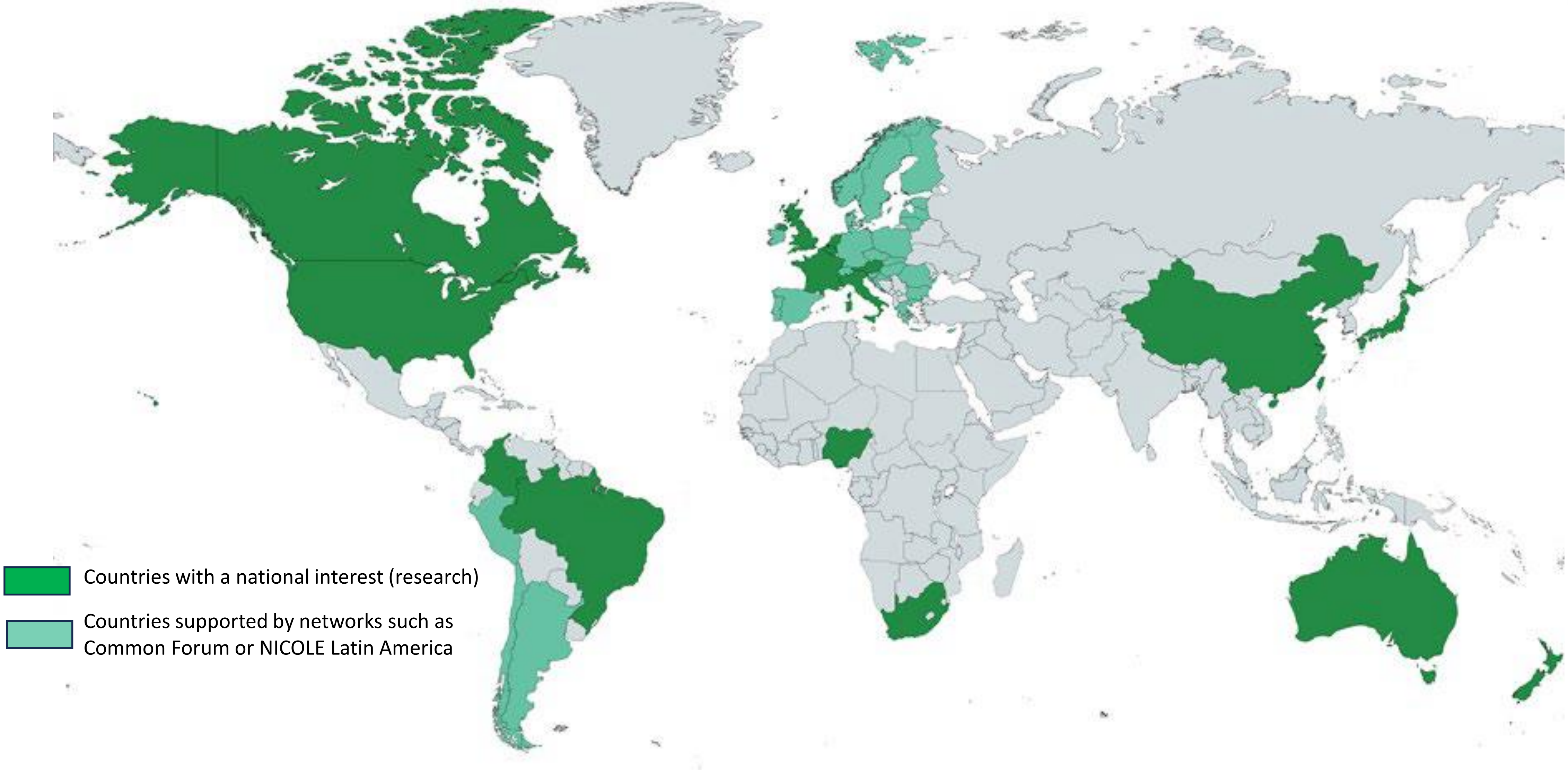
Current edition approved April 1, 2016. Published May 2016. Originally published in 2013. Last previous edition approved in 2013 as E2893–13ε1. DOI: 10.1520/E2893-16E01

		Core Eleme (at Si	
Category	Best Management Practice	Energy	Air
Buildings	Minimize the size of the housing for above-ground treatment system and equipment	X	
Buildings	Install energy recovery ventilators in buildings to allow incoming fresh air while capturing energy from outgoing, conditioned air	X	
Buildings	Reuse existing structures for treatment system, storage, sample management, etc.		
Buildings	Build energy efficent heating and cooling into new buildings by using natural conditions such as prevailing wind directions for cooling/heating, passive solar building design, and/or existing	X	
Buildings	Design energy efficient HVAC systems (e.g., programmable heating and cooling systems)	X	
Buildings	Properly insulate buildings	X	
Buildings	Build energy efficiency lighting into new buildings by using natural conditions such as passive lighting and by using designed systems such as energy star lighting.	X	
Materials	Use dedicated materials when performing multiple rounds of sampling of all matrices		
Materials	Purchase materials in bulk quantities and packed in reusable/recyclable containers and drums to reduce packaging waste		
Materials	Use products, packing material, and equipment that can be reused or recycled		
Materials	Prepare, store, and distribute documents electronically using an environmental management		
Materials	Recycle all non-usable/spent equipment/materials following completion of project		
Materials	Use materials that are made from recycled materials (e.g., steel, concrete, plastics and asphalt; tarps made with recycled or biobased contents instead of virgin petroleum-based contents)		
Materials	Link a deconstruction project with an on-site or local current construction or renovation project to facilitate reuse of clean salvaged materials.		

Sustainable Remediation Forum (SuRF)

Sustainable Remediation Forum (SuRF) initiatives are now well established in UK, US, Canada, Australia, New Zealand, Netherlands, Italy, Taiwan, Brazil and Columbia, with further interest in China and Japan. These networks meet to share knowledge and work collaboratively.

www.surf-nl.com
www.surfitaly.it
www.surfcanada.org
http://nicole.org
www.surf-taiwan.org.tw/web/surf_index.html



Globally, sustainable remediation still considered an emerging practice in management of contaminated sites. Direct regulatory drivers have been relatively few.

Phytoremediation

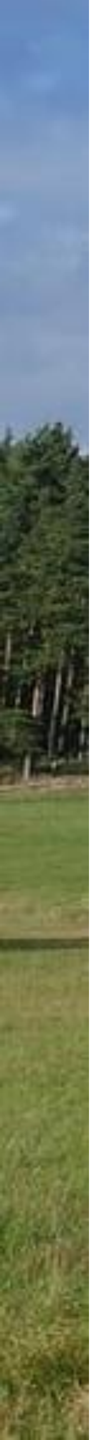
Site: Aberdeen Proving Grounds; J. Fields Site (US)

Contaminants: PCE, TCE, DCE, TCA
- Open burning facility for munitions and chemical agents; chlorinated solvents
- Total VOCs in groundwater: 20,000 µg/L - 220,000 µg/L

Proposed Remedial Actions: Removal; containment; ex-situ soil washing/incineration; vitrification; oxidation/reduction …

VA.gov

Contaminant	Concentration (µg/L)
1,1,2,2-tetrachloroethane	170,000
Trichloroethene (TCE)	61,000
cis-1,2-dichloroethene (*c*-DCE)	13,000
Tetrachloroethene (PCE)	9,000
Trans-1,2-dichloroethene (*t*-DCE)	3,900
1,1,2-trichloroethane (TCA)	930

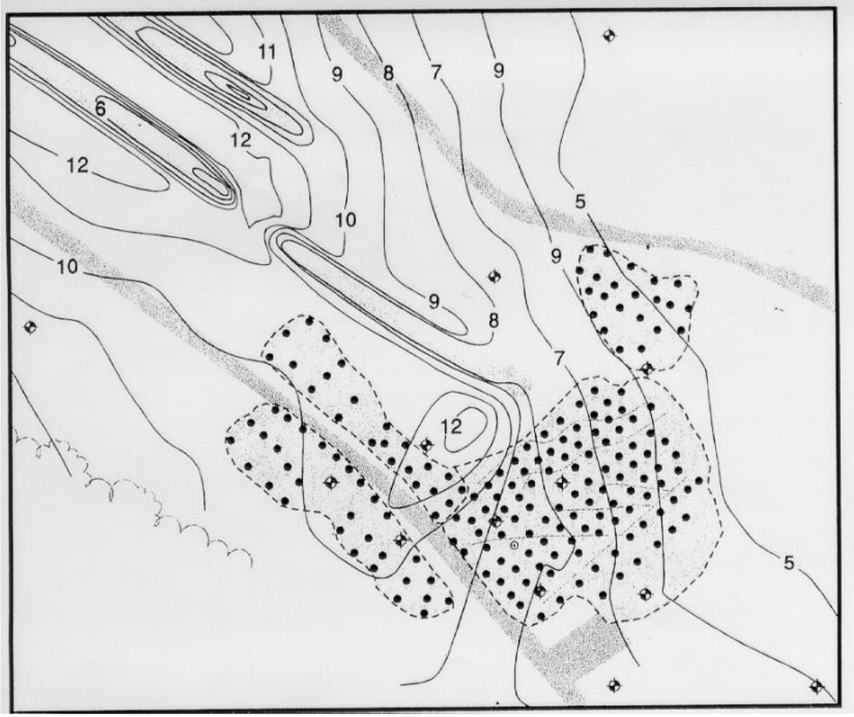


Phytoremediation

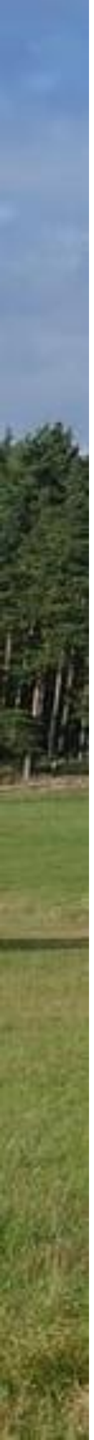
Site: Aberdeen Proving Grounds, J. Fields Site (US)

Contaminants: PCE, TCE, DCE, TCA

Remedial Action: Phytovolatilization and phytodegradation using hybrid poplars (*Populus trichocarpa* x deltoides [HP-510])



https://clu-in.org/products/intern/phytotce.htm#c



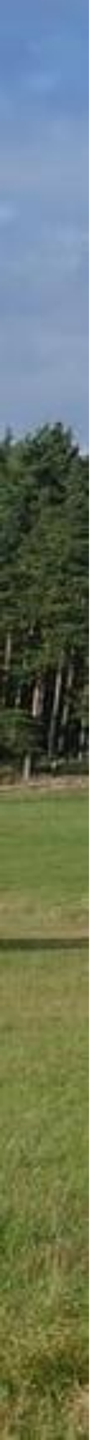
Phytoremediation

Site: Thailand, Mae Sot District

Contaminant: Severe Cd contamination of rice paddies (Cd and Zn runoff from zinc mine)

pH	8.1
Total Cd, mg/kg	31.6
Total Zn, mg/kg	874

Saengwilai et al., 2017



Phytoremediation

Remedial actions:
- Phytoextraction
- Phytostabilization
- Cd immobilization via application of amendments

Studies in progress:
- Selection of metal-excluding rice varieties

Property End Use: Agricultural, residential

Exposure and Health
https://doi.org/10.1007/s12403-019-00312-0

ORIGINAL PAPER

Check for updates

Immobilization of Cadmium in Contaminated Soil Using Organic Amendments and Its Effects on Rice Growth Performance

Patompong Saengwilai[1,2] · Weeradej Meeinkuirt[3] · Theerawut Phusantisampan[4] · John Pichtel[5]

Received: 5 Ja

Abstract
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significant

Environ Sci Pollut Res
DOI 10.1007/s11356-017-9157-4

CrossMark

RESEARCH ARTICLE

Influence of amendments on Cd and Zn uptake and accumulation in rice (*Oryza sativa* L.) in contaminated soil

Patompong Saengwilai[1] · Weeradej Meeinkuirt[2] · John Pichtel[3] · Preeyaporn Koedrith[4]

Phytoremediation

Site: Trecate, Italy

Contaminants: TPH (3700 mg/kg), PAHs (oil well blowout)

Remedial action: Use of eleven agricultural plant species to facilitate hydrocarbon removal (via rhizodegradation, phytodegradation).
- Landfarming; natural attenuation.

Schwitzguébel et al. 2002. J. Soil & Sediments. DOI: 10.1007/BF02987877

Phytoremediation

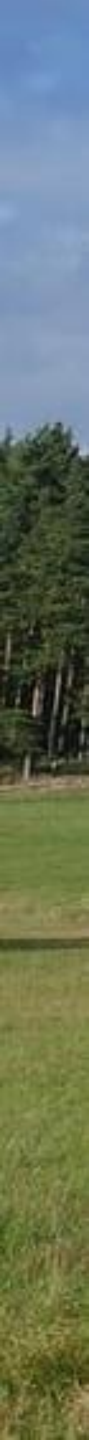
Site: Trecate, Italy

Contaminants: TPH (3700 mg/kg), PAHs (oil well blowout)

Results: Phytoremediation at least as effective as landfarming.

- Offers protection against erosion
- Maintains proper soil conditions
- Less laborious than landfarming

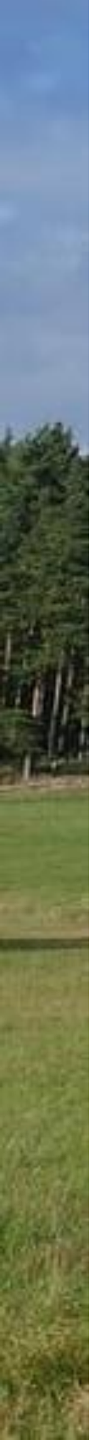
Schwitzguébel et al. 2002. J. Soil & Sediments. DOI: 10.1007/BF02987877



Phytoremediation

Site Name	Plant species	Contaminant
Czechowice oil refinery (Katowice, Poland)	*Brassica juncea*	Pb, Cd
Sewage disposal site (UK)	Salix species	Ni, Cu, Zn, Cd
Zinc waste landfill (Hlemyzdi, Czech Republic)	*H. annuus, Z. mays, C. halleri*	Zn
Zinc/copper contaminated site (Dornach, Switzerland)	Improved tobacco plants	Cu, Cd, Zn
Zinc/cadmium contaminated soil (Balen, Belgium)	*Brassica napus* for phytoextraction	Zn, Cd, Pb

Schwitzguébel et al. 2002. J. Soil & Sediments. DOI: 10.1007/BF02987877



Phytoremediation

Site Name	Plant species	Contaminant
Guadiamar river area, (Aznalcollar mine, Spain)	Various	Pb, Cu, Zn, Cd, Ti, Sb, As
BTEX-contaminated groundwater (Genk, Belgium)	*Populus x canadensis* (poplar)	BTEX
Eka Chemicals site (Bohus, Sweden)	Various	Chlorinated organics, mercury
Former municipal gaswork site (Holte, Denmark)	Poplar and willow	Cyanide, BTEX, PAHs, oil
Pesticides storage (Niedwiady, Poland)	Poplars	Pesticides

Schwitzguébel et al. 2002. J. Soil & Sediments. DOI: 10.1007/BF02987877

Bioremediation

Site: Lieve Canal (Belgium)
Near harbor of Ghent

Contaminants: aliphatic and aromatic hydrocarbons (BTEX, C_6-C_{10} hydrocarbons, PAHs).

- Contamination from industrial production of tar and carbon black.

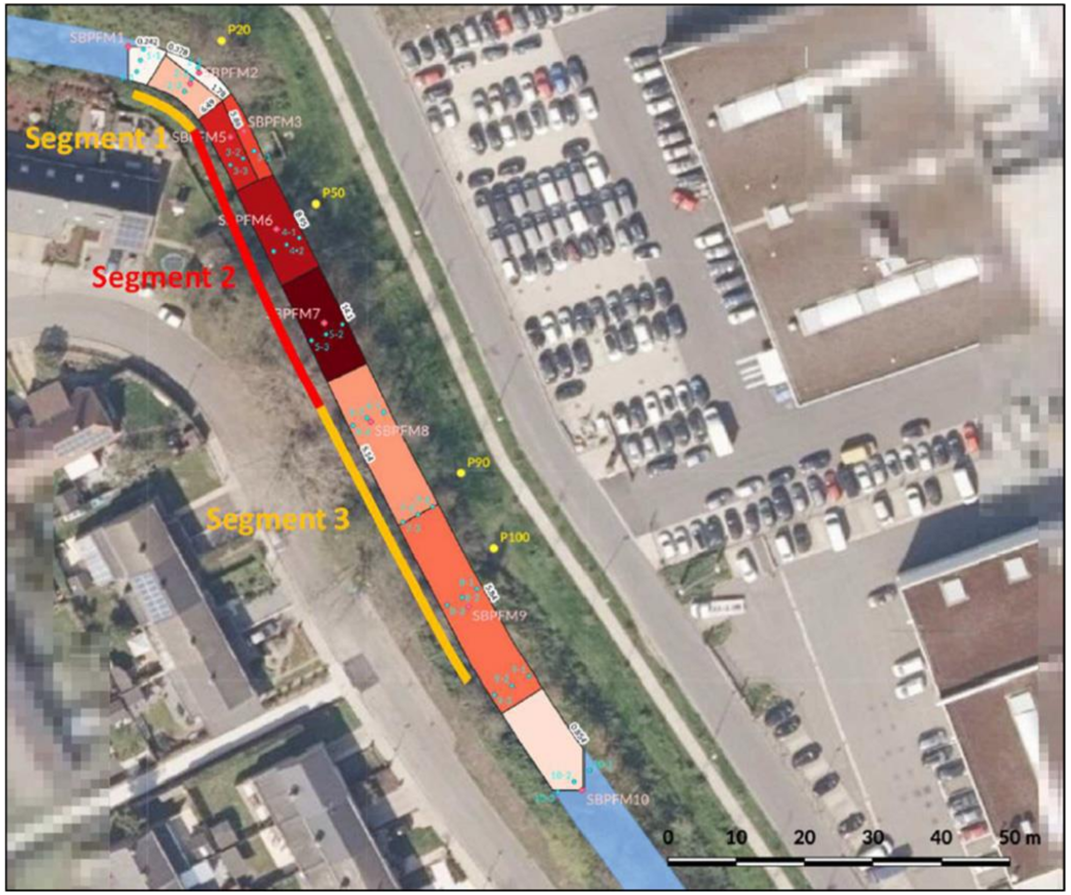
	Well 20	Well 50
Benzene (µg/l)	15	38,000
Toluene (µg/l)	15	11,000
Ethylbenzene (µg/l)	5.5	1,100
Xylenes (µg/l)	9.9	4,600
Naphthalene (µg/l)	240	6,100
Acenaphthene (µg/l)	1.1	280
C_6-C_{10} (µg/l)	99	60,000

Bioremediation

Remedial action: Installation of reactive ‘green’ mats. Use of natural materials as adsorbent in a permeable barrier. Mat structure intercepts contaminated groundwater that drains into it.

Nature-based processes using reactive mat:

- Use natural drainage capacity of the canal, so no pump needed
- Use of a naturally-occurring renewable adsorbent in the mat that has high adsorption capacity
- A biologically active interface at the mat surface that provides aerobic biodegradation



Concawe. 2023. Case Studies and Analysis of Sustainable Remediation Techniques and Technologies. Ghent, Belgium.

Bioremediation

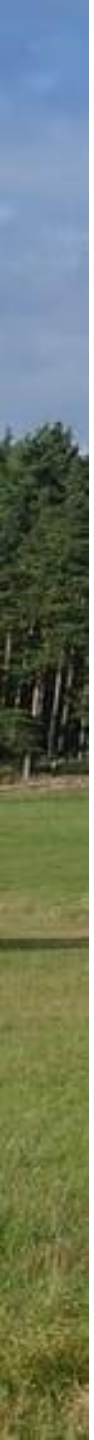
Site: Umatilla Army Depot, Hermiston, OR (US)

Contaminants: 320 m liters of explosives-contaminated wastewater discharged into unlined lagoons
~ 14,000 MT soil contaminated with explosives (TNT and RDX)

Remedial Action: Composted with locally obtained feedstock
- Windrows (placement of soil in elongated piles)
- Periodically mixed soil with cattle/chicken manure, alfalfa, potato waste, sawdust
- Mixing inside mobile buildings to control fumes and optimize biological activity



https://clu-in.org/greenremediation/profiles/umatilladepot
Photos by Debra Tabron



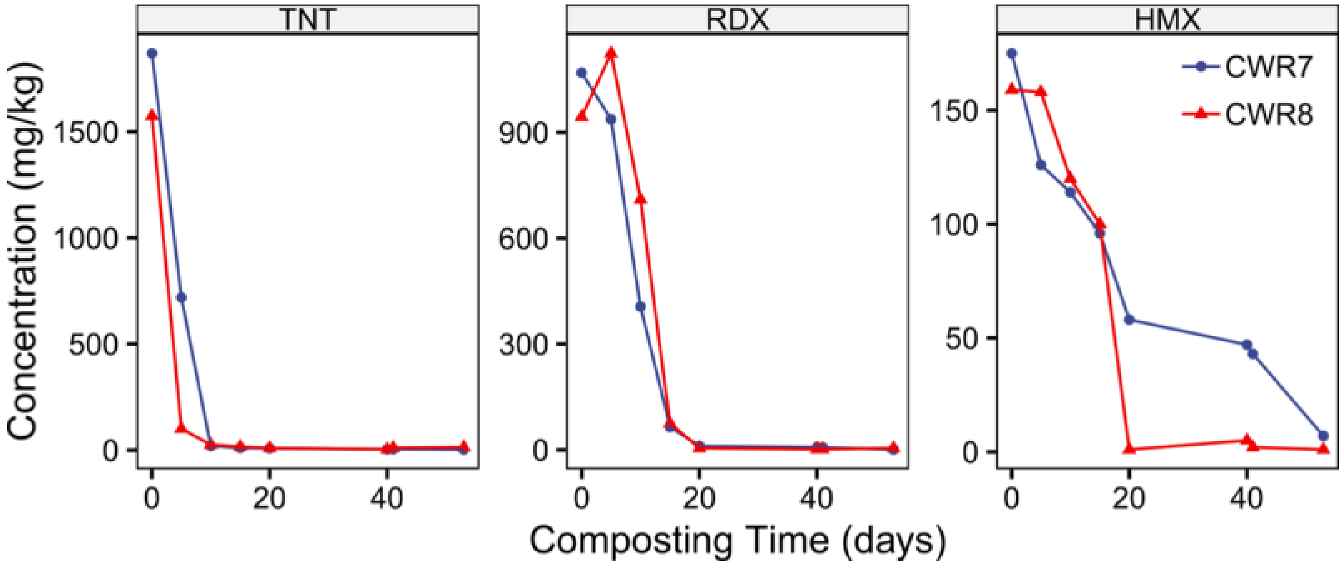
Bioremediation

Site: Umatilla Army Depot, Hermiston, OR (US)

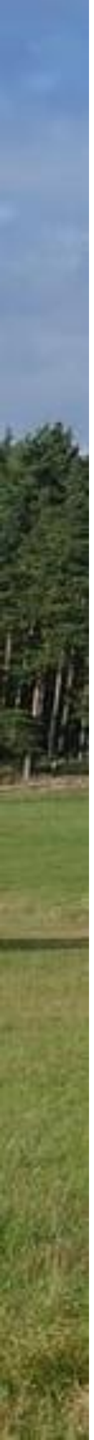
Results:

- Contaminant byproducts destroyed or bound to humus ⟶ non-detectable concentrations of explosives
- Saved $2.6 million compared to incineration (common alternative for explosives treatment)
- $150,000 potential revenue from sale of humus-rich soil
- Avoided significant fossil fuel consumption by incinerator
- Avoided fuel consumption associated with transporting soil to offsite incinerator

Property End Use: Privatization



https://clu-in.org/greenremediation/profiles/umatilladepot
Weston, R. F. U.S. Army Toxic and Hazardous Materials Agency, Report No. CETHA-TS-CR-91053



Utilizing Renewable Energy Sources

Utilizing renewable energy sources such as solar or wind power to operate remediation systems can reduce greenhouse gas emissions and reliance on non-renewable energy sources.

Renewable Energy Sources

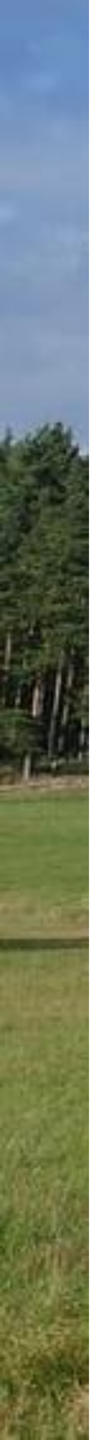
Site: Nebraska Ordnance Plant (US)
7,000 ha facility. Produced ordnance World War II and Korean Conflict; construct Atlas missiles.

Contaminants: Explosives including RDX; TCE; released to soil and entered unconfined aquifer (used regionally for water supply)

Remedial action: Groundwater circulation well for air stripping and UV treatment (10 kW wind power)

- Treats 10,200 liters/min to remove TCE and RDX contamination from groundwater produced by 11 extraction wells.

https://clu-in.org/greenremediation/profiles/formernop



Renewable Energy Sources

Site: Nebraska Ordnance Plant (US)
7,000 ha facility. Produced ordnance World War II and Korean Conflict; construct Atlas missiles.

Contaminants: Explosives including RDX; TCE; released to soil and entered unconfined aquifer (used regionally for water supply)

Results: Wind system generates sufficient energy to operate treatment system, including submersible well pump

- Returns surplus electricity to the grid for other consumer use
- Wind turbine has no known negative impacts on wildlife, local environment, or land use

Property end-use: Agricultural research and development, residential, commercial use

Renewable Energy Sources

Site: Elizabeth Mine Superfund Site (US)

Contaminants: Cd, Cr, Pb, Ag; cyanides

Remedial action: Capping for 2.3 million m^3 of mine tailings
- Off-road vehicles equipped with diesel-electric power trains and Tier 4 compliant engines

Results: Use of dozer with electric power train decreased fuel consumption by 30 percent

- Excavators powered by Tier 4 engines reduced PM emissions by 90 percent and NOx by 50 percent; improved fuel efficiency by 5 percent

US EPA. 2023. Green Remediation Best Management Practices. EPA 542-F-23-001.

Renewable Energy Sources

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Contaminants: Cd, Cr, Pb, Ag; cyanides

Remedial action: Capping for 2.3 million m^3 of mine tailings
- Off-road vehicles equipped with diesel-electric power trains and Tier 4 compliant engines

- Tier 4 standards require that emissions of PM and NOx be reduced by about 90%
- Emission reductions via advanced exhaust gas after-treatment technologies
- Specialized catalysts for NOx control

Property End Use: Greenspace, environmental and historic education, renewable energy development

US EPA. 2023. Green Remediation Best Management Practices. EPA 542-F-23-001.

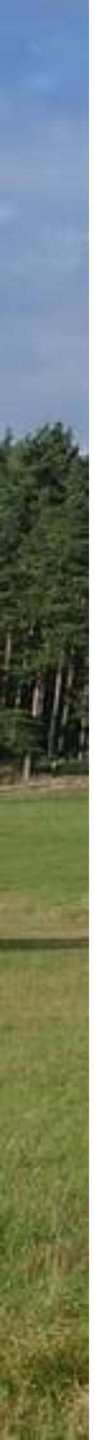
Renewable Energy Sources

Site: Former St. Croix Alumina Plant, St. Croix, VI

Contaminants: 7.5 m liters of petroleum

Remedial Strategy: Petroleum recovery for use as fuel; hybrid system employing solar and wind energy
- Four wind-driven turbine compressors to drive compressed air into hydraulic skimming pumps
- Three 55-watt photovoltaic panels to power recovery wells
- Three 110-watt photovoltaic panels and two wind-driven electric generators to power submersible total fluid pumps and fluid gathering system
- Recycles recovered petroleum product -- transfer to adjacent oil refinery for use as feedstock

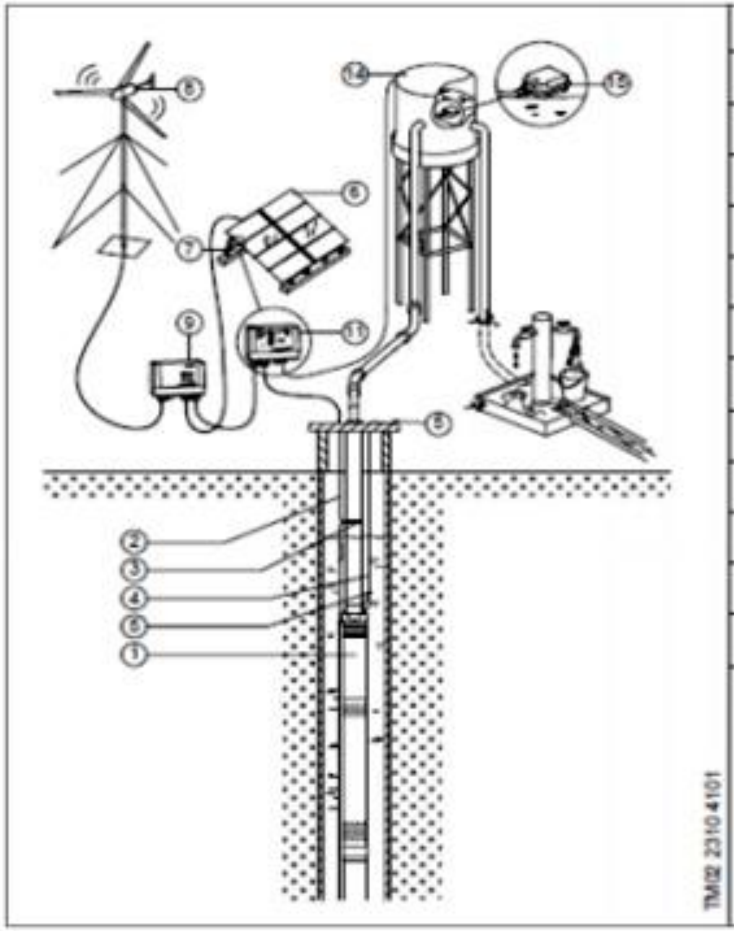
https://clu-in.org/greenremediation/profiles/formerscalumina



Renewable Energy Sources

Results:
- Recovered 900,000 liters of free product (approx. 20% of the estimated volume)
- Avoid offsite transfer and disposal of petroleum product

Property End Use: Industrial operations



Pos.	Description
1.	SQF pump
2.	Submersible drop cable
3.	Cable clips
4.	Straining wire
5.	Wire clamps
6.	Solar panel(s)
7.	Support structure
8.	Wind generator
9.	Breaker box
11.	CU 200 control unit
14.	Water reservoir
15.	Level switch

https://clu-in.org/greenremediation/profiles/formerscalumina

Renewable Energy Sources

Site: BP Paulsboro, Paulsboro, NJ

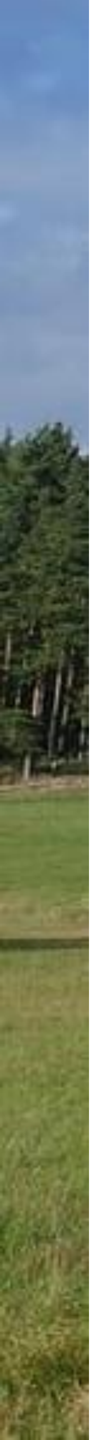
Contaminants: Petroleum products and chlorinated compounds in surface and ground water

Green Remediation Strategy: P&T system extracting 1100 liters of groundwater/min using solar power
- 275-kW solar field encompassing 5,880 PV panels
- Solar energy operates six recovery wells including pump motors, aerators, and blowers
- Transfers extracted groundwater to biologically activated carbon treatment system

Results:
- Supplies 350,000 kWh of electricity each year, meeting 20-25% of P&T system energy demand
- Eliminates 260,000 kg of CO_2 emissions annually [equivalent to avoiding consumption of 110,000 liters of gasoline]
- Prevents emission of 725 kg of SO_2 and 500 kg of NOx each year

Property End Use: Deep water port on Delaware River

https://clu-in.org/greenremediation/profiles/bppaulsboro



Water Reuse and Recycling

Conservation of freshwater: Utilizing recycled water sources for remediation activities reduces reliance on freshwater, preserving it for human needs like agriculture.

Reduced environmental impact: Using recycled water minimizes environmental footprint of the remediation project, lessening the burden on ecosystems.

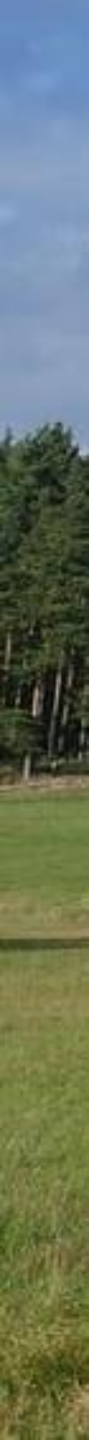
Ecosystem restoration: Treated recycled water can be used to restore degraded desert landscapes. By creating wetlands or revegetating arid areas, water reuse contributes to long-term environmental revitalization.

Public image and community engagement: Demonstrating a commitment to water conservation and sustainable practices through water reuse can enhance a project's public image and foster positive community engagement.

Cost-effectiveness: Importing freshwater for remediation can be expensive. Implementing water reuse and recycling systems can significantly reduce project costs, making sustainable remediation strategies more financially viable.

Resource Recovery and Reuse

Recycling or reusing materials generated during remediation, such as excavated soil, or incorporating recovered construction materials into site redevelopment, can help conserve natural resources and reduce reliance on new, energy-intensive resources.



Resource Recovery and Reuse

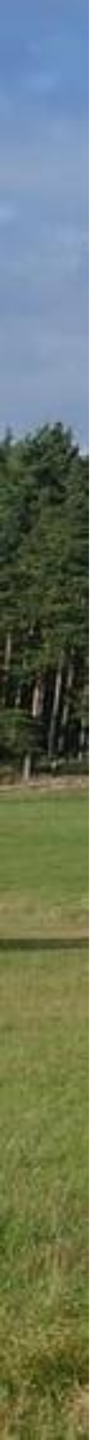
Site: Brownfield, Austin, TX (US)

Contaminants: Hydrocarbons and metals at illegal dump containing 5,000 yd^3 (3800 m^3) of debris

Remedial Strategy:
- Constructed four-foot-thick evapotranspiration cover
- Shredded wood to create mulch for recreational trails
- Salvaged wood scraps and concrete for erosion control
- Recycled 31.6 tons of metal
- Powered equipment through use of biofuel generators and photovoltaic panels
- Salvaged concrete for later use as fill for building infrastructure
- Planted native grasses, wildflowers, and trees

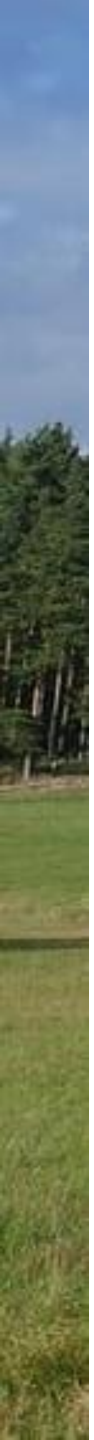
Results:
- Gained community help to restore the property within a single year
- Reestablished wildlife habitat for native and endangered species

Property End Use: Environmental education park



Green and Natural Infrastructure

Integrating green and natural infrastructure, such as wetlands or vegetated swales, into the remediation design can improve stormwater management, habitat provision, and climate resilience, while enhancing the site’s aesthetic appeal to the surrounding community.

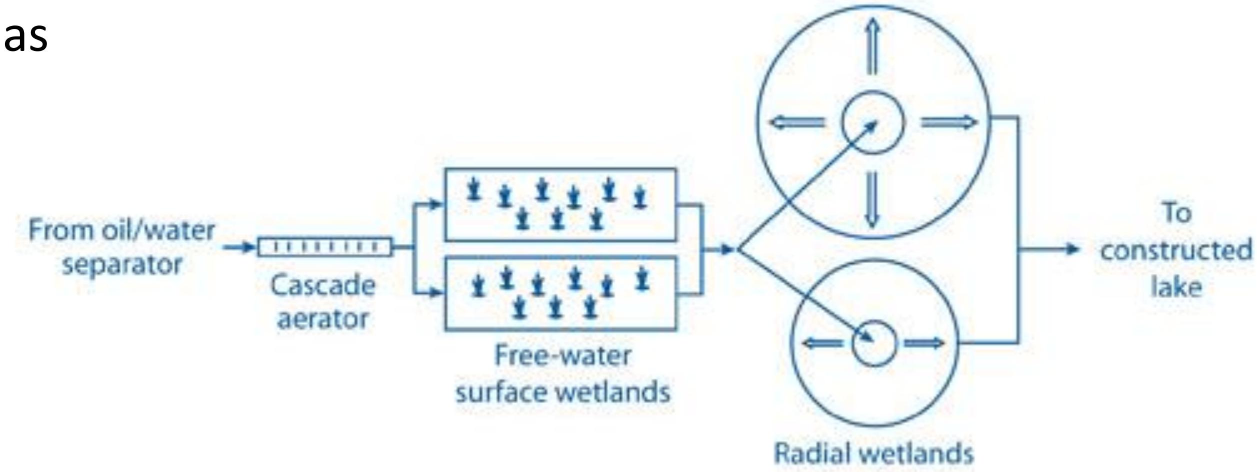


Green and Natural Infrastructure

Site: British Petroleum Site, Casper, WY (US)

Contaminants: Gasoline in groundwater

Remedial Strategy: Engineered radial-flow constructed wetland system
- Wetland treatment cells for subsurface location to increase operational control, reduce offensive odors and insects, and avoid disruption of surface activity
- Constructed treatment beds of crushed concrete reclaimed from demolition of the site's former refinery
- Insulated each treatment cell with 6-inch layer of mulch to withstand temperatures to -35°F
- Installed native, emergent wetland plants such as bulrush, switchgrass, and cordgrass in each treatment cell



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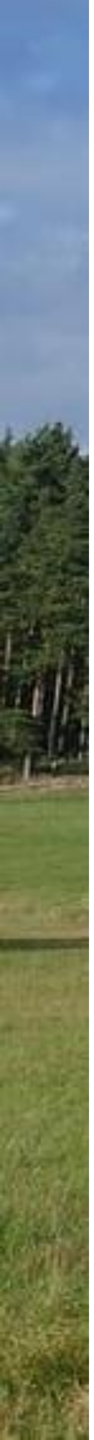



Naturally Wallace Construction

Green and Natural Infrastructure

Results:

- Achieves non-detectable concentrations of benzene and other hydrocarbons
- Treats up to 2.6 m liters of contaminated ground water/d
- Operates year-round despite cold climate
- Construction costs totaled $3.4 million (in contrast to $15.9 million for the alternative pump and treat system employing air stripping and catalytic oxidation)

Property End-Use: Office park and recreation facilities including golf and kayak courses

https://clu-in.org/greenremediation/profiles/bpcasper

Green and Natural Infrastructure

Site: Bridal Veil Superfund Site, Minneapolis/St. Paul (US)

Contaminants: Pentachlorophenol (PCP)

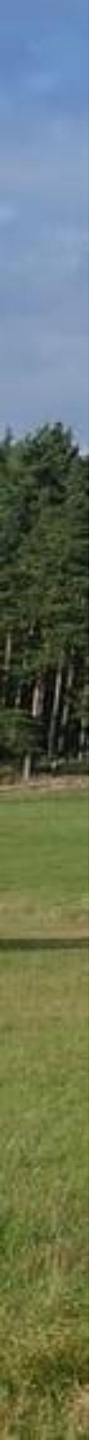
Remedial Action: Conversion of stormwater pond to a wetland; construction of treatment stream within wetland to degrade PCP by photolysis and bioremediation.

- Design completed in partnership with Minnesota Pollution Control Agency, the City of Minneapolis, and local citizens' organization.

Results: Design created flowing water, a wetland, and an oak savanna while reducing or eliminating human health risks.

Property End-Use: The community's small green oasis was maintained within a heavily industrial portion of the city.

AECOM, no date.



Initiatives in Green and Sustainable Remediation

European Union

Horizon Europe

https://commission.europa.eu/strategy-and-policy/eu-budget/performance-and-reporting/programme-performance-statements/horizon-europe-performance_en

European Green Deal

https://ec.europa.eu/commission/presscorner/detail/en/ip_21_5916

A Soil Deal for Europe

https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe/soil-deal-europe_en

Sustainable Remediation of Contaminated Land

https://www.eea.europa.eu/data-and-maps/indicators/progress-in-management-of-contaminated- sites-3

CLARINET

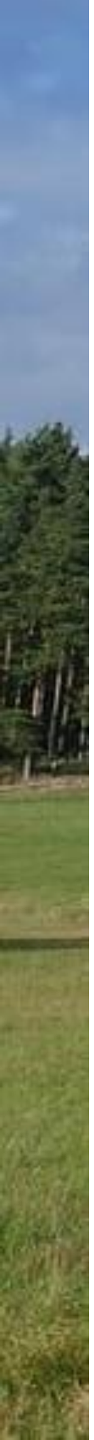
A risk-based land management framework. Sustainability is a key objective; includes evaluation and optimization of environmental, economic, and social factors.

https://clarinet.org/

United Kingdom

CL:AIRE

https://www.claire.co.uk/home/about-us



Initiatives in Green and Sustainable Remediation

United States

EPA Greener Cleanups Initiative

- https://www.epa.gov/greenercleanups
- https://www.epa.gov/greenercleanups/greener-cleanup-consensus-standard-initiative

ASTM E2893-16, Standard Guide for Greener Cleanups, ASTM International

Interstate Technology & Regulatory Council (ITRC)

- https://itrcweb.org/teams/projects/green-and-sustainable-remediation
- https://srr-1.itrcweb.org/

Naval Facilities Engineering Command (NAVFAC)

- Department of the Navy Guidance on Green and Sustainable Remediation, UG-2093-ENV Rev.1

Japan

Sustainable Remediation of Contaminated Sites

- http://josen.env.go.jp/en/

Environmental Restoration and Conservation Agency

- https://www.erca.go.jp/erca/English/

“Excuse me . . . *sustainable* remediation??”

Thank you.

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BALL STATE
UNIVERSITY