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Green Remediation Best Management Practices: Bioremediation

Office of Superfund Remediation and Technology Innovation

Quick Reference Fact Sheet

The U.S. Environmental Protection Agency (EPA) *Principles for Greener Cleanups* outlines the Agency's policy for evaluating and minimizing the environmental "footprint" of activities undertaken when cleaning up a contaminated site.[1] Use of the best management practices (BMPs) recommended in EPA's series of green remediation fact sheets can help project managers and other stakeholders apply the principles on a routine basis, while maintaining the cleanup objectives, ensuring protectiveness of a remedy, and improving its environmental outcome.[2]

Overview

Bioremediation actively enhances the effects of naturally occurring biological processes that degrade contaminants in soil, sediment, and groundwater. In situ processes involve placement of amendments directly into contaminated media while ex situ processes transfer the media for treatment at or near ground surface. Green remediation BMPs for bioremediation address the techniques for:

- *Biostimulation*: injection of amendments into contaminated media to stimulate contaminant biodegradation by indigenous microbial populations. Amendments may include air (oxygen) by way of bioventing, oxygen-releasing compounds to keep an aquifer aerobic, or reducing agents such as carbon-rich vegetable oil or molasses to promote growth of anaerobic microbial populations
- *Bioaugmentation*: injection of native or non-native microbes to a contaminated area to aid contaminant biodegradation; successful bioaugmentation may involve prior addition of biostimulation amendments to create the conditions favorable for microbial activity
- *Land-based systems*: treatment of contaminated soil or sediment through surface mixing with amendments or placement of soil/sediment in surface piles or treatment cells, such as composting or landfarming, and
- *Bioreactors*: treatment of contaminated soil or groundwater in a controlled environment to optimize degradation, such as an in situ bioreactor landfill or biological permeable reactive barrier (biobarrier) or an ex situ batch- or continuous-feed reactor.

Designing a Bioremediation System

Early and integrated planning will help design a bioremediation project involving activities with a minimal environmental footprint. Effective design will provide flexibility for modified site or engineering parameters as cleanup progresses while continuing to accommodate current or future use of a site. Options for reducing the footprint of bioremediation implementation can be affected by local, state, and federal regulatory requirements. Permits for underground injections, for example, vary considerably among state regulatory programs.[3] Option evaluation also examines the short- and long-term advantages and disadvantages of in situ versus ex situ bioremediation techniques in terms of green remediation core elements.

Core Elements of Green Remediation

- *Reducing total energy use and increasing renewable energy use*
- *Reducing air pollutants and greenhouse gas emissions*
- *Reducing water use and negative impacts on water resources*
- *Improving materials management and waste reduction efforts, and*
- *Enhancing land management and ecosystem protection*

Successful bioremediation relies on adequate site characterization and development of a good conceptual model to assure thorough delineation of the contaminant source area(s) and plumes. Effective modeling will typically lower the potential for unnecessary activities and associated natural resource consumption or waste generation.[4a] Techniques such as three-dimensional imaging, for example, can help optimize placement of injection boreholes. Representative field data are needed during in situ bioremediation design to assure: (1) influential factors such as aquifer hydraulic conductivity, groundwater geochemistry, and soil heterogeneity and adsorptive capacity are well understood, (2) the radius of influence for any injected substrates reaches the entire target area and spacing of multiple injection points provides optimal substrate control, and (3) any excavation for techniques such as installation of a trenched biobarrier are conducted in a surgical manner.[4b]

Efficiency in energy and natural resource consumption can be achieved through BMPs that optimize initial design of a bioremediation system. Early bench-scale treatability tests on soil collected from the target treatment area will help:

- Determine the onsite mass of contaminant parent and daughter products, other metabolic products, and existing microbial populations

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- Demonstrate specific biodegradation mechanisms of potential microbial cultures, chemical substrates, or amendments
- Evaluate potential delivery methods and dispersion characteristics under simulated aquifer conditions, including use of options such as biodegradable surfactants
- Select the most suitable reagents or amendments and optimal concentrations or proportions, and
- Determine any need for supplemental technologies to destroy contaminants in hot spots or areas anticipated to involve lengthy periods of microbial acclimation.

Profile: Bioaugmentation at MAG-1 Site, Fort Dix, NJ

- *Began bioaugmentation design through laboratory tests on MAG-1 groundwater samples to evaluate efficacy of a commercial bacterial culture in degrading targeted chlorinated volatile organic compounds (CVOCs) that were resistant to degradation by native bacteria*
- *Dispersed the microbial inoculant through a groundwater recirculation system, which minimized construction of new wells and associated resource consumption*
- *Optimized the system within six months of the first (of two) injections to reduce the initially high volume of buffering agents and extensive well fouling, resulting in reduced material consumption and equipment maintenance*
- *Decreased CVOCs nearly 99% within one year of project startup without negative impacts to natural groundwater conditions*

Natural resource efficiencies also are gained by conducting an onsite pilot test that evaluates methods for delivering the selected substrate or amendment to a portion of the treatment area. Green remediation BMPs applied during a bioremediation pilot test will help optimize full-scale operations and may identify adverse environmental impacts in the field; for example, improper addition of nutrients in certain aquatic environments could quickly cause algal blooms.

Use of innovative reagents from non-traditional sources can significantly reduce consumption of virgin natural resources while beneficially using various waste products. For instance, enzymes are often introduced into the remedial process to additionally stimulate microbial degradation of contaminants. These enzymes commonly exist in agricultural or industrial byproducts that may be readily available from local sources. One example is manure compost, which can provide various enzymes depending on the feedstock and maturity. Another byproduct gaining use for bioremediation purposes is spent-mushroom compost, which can be supplied at little or no cost by local producers. Evaluating potential use of products often considered to be waste will include examining the product's traditional fate and demand in markets other than site remediation.

Land-based systems and in situ bioreactors can particularly benefit from use of commercial waste. "Supermulch" contains common byproducts such as municipal biosolids, wood ash, and paper sludge that can be included in recipes for soil amendments or placed in a permeable reactive barrier to enhance activity of indigenous microbial populations. This approach can also be integrated with phytoremediation to encourage contaminant degradation and volatilization while enriching soil for revegetation in significantly disturbed areas such as mining sites.

Project designers can establish a schedule for periodic review of the selected bioremediation process and related decision points to:

- Determine if any improvements to field operations could reduce natural resource consumption and waste generation while maintaining bioremediation efficacy
- Identify any innovative materials that recently demonstrated success in biologically degrading contaminants while reducing the project's environmental footprint
- Identify unanticipated environmental impacts such as uncontrolled production of secondary byproducts, sub-optimal nutrient levels, or changes in non-targeted indigenous microbial populations, and
- Identify other processes that could accelerate biodegradation in certain areas without significantly increasing the project footprint; for example, some injection wells could be equipped with passive air flow-control devices and renewable energy-powered blowers to deliver air to the subsurface after bioaugmentation is conducted.

Future optimization may include introduction of alternate amendments to remediate portions of a site showing marginal biodegradation progress or alternate methods to increase efficiency of reagent delivery.

Integrated planning of bioremediation activities at Marine Corps Base Camp Lejeune enabled injections of emulsified vegetable oil and sodium lactate in four borings to be completed within only one week, which reduced field redeployment and associated fuel use.

Profile: Soil Composting at Former Joliet Army Ammunition Plant, Will County, IL

- *Conducted pilot-scale field tests on compost windrows to optimize the designed soil amendment recipe, amendment timing, loading rate, and turning frequency*
- *Constructed a 20-acre composting facility to treat 280,000 tons of excavated explosives-contaminated soil with amendments such as manure, wood chips, stable bedding, and spent biodigestor waste from local producers*
- *Installed a one-million-gallon basin to capture stormwater runoff for onsite aquifer infiltration*
- *Began early transfer of uncontaminated acreage to the U.S. Forest Service in 1997 to the newly formed Midewin National Tallgrass Prairie, with subsequent transfers of additional parcels as remediation progressed; by 2002, all (19,000) targeted acres were conveyed to the Prairie*
- *Completed soil cleanup in 2008, three years ahead of schedule, through implementation of an integrated cleanup and reuse plan for 3,000 acres now under development as business parks and an engineer training center*

Constructing a Bioremediation System

Best management practices initiated during bioremediation design can continue in the construction phase and during operation and maintenance (O&M). A significant portion of the environmental footprint left by construction of a bioremediation system involves the installation and testing of wells used to deliver the selected reagents and monitor performance. Recommended practices include:

- Using direct-push technology for constructing temporary or permanent wells rather than typical rotary methods, wherever feasible, to eliminate the need for disposal of cuttings and improve efficiency of substrate delivery into discrete vertical intervals
- Maximizing reuse of existing or new wells and boreholes for injections to avoid a range of wasted resources, and
- Using groundwater recirculation processes allowing multiple passes of groundwater through fewer wells.

Recommended practices for designing, constructing, and operating wells, such as those used for in situ injection and groundwater recirculation, are provided in: *Green Remediation Best Management Practices: Pump and Treat Technologies*.[4c] Additional practices for subsurface air delivery are provided in *Green Remediation Best Management Practices: Soil Vapor Extraction & Air Sparging*.[4d]

Project managers of land-based bioremediation systems can reduce the project footprint through BMPs such as:

- Constructing a retention pond within a bermed treatment area to store, treat, use, or release diverted stormwater
- Reclaiming clean or treated water from other site activities for use in injection slurries or as injection chase water
- Integrating a landfarm rain shield (such as a plastic tunnel) with rain barrels or a cistern to capture precipitation for potential onsite use, and
- Evaluating the need for a leachate collection system for a landfarm (along with a leachate treatment system) to fully preserve the quality of downgradient soil and groundwater.

Land disturbance during bioremediation construction, particularly at sites involving ex situ techniques, can be reduced through practices such as:

- Maintaining specific areas for different activities such as materials mixing or waste sorting, which will also avoid cross-contamination
- Covering ground surfaces of work areas with mulch to prevent soil compaction caused by activities such as front-loader application of soil amendments
- Establishing well-defined traffic patterns for onsite activities, and
- Employing rumble grates with a closed-loop graywater washing system (or an advanced, self-contained wheel-washing system) to minimize onsite and offsite trackout by delivery vehicles.

Emission of greenhouse gas (GHG) and particulate matter from mobile sources can be reduced through BMPs such as reducing engine idling, fueling heavy machinery with ultra low-sulfur diesel fuel, and retrofitting equipment with diesel oxidation catalysts or other advanced diesel technology. More practices are outlined in *Green Remediation Best Management Practices: Clean Fuel & Emission Technologies for Site Cleanup*.[4e]

Contributors to the Bioremediation Footprint at Romic East Palo Alto

	Total Estimated Footprint	Attributed to O&M
Energy	23,000 million Btu	58%
Potable water	6,800,000 gallons	100%
CO_2 equivalent	5,000,000 pounds	70%
Sulfur oxides	22,000 pounds	86%
Particulate matter	800 pounds	78%
Air toxics	200 pounds	10%

O&M activities account for much of the environmental footprint of bioremediation recently initiated at the Romic RCRA site in East Palo Alto, CA. Site investigation, remedy construction, and future decommissioning also contribute but to a lesser extent. Although onsite contributors are relatively small in comparison to offsite factors such as "upstream" materials manufacturing, they may hold greater importance to the local community.

Operating and Monitoring a System

Energy consumption and associated emissions during bioremediation O&M can be reduced by:

- Introducing biostimulation or bioaugmentation amendments to the subsurface via gravity feed in existing wells, when high-pressure injection is unnecessary to assure proper distribution in certain geologic units
- Evaluating feasibility of using pulsed rather than continuous injections when delivering air, to increase energy efficiency
- Employing portable units or trailers equipped with photovoltaic panels to generate electricity or direct power for equipment such as air blowers, and
- Investigating delivery of industrial byproducts needed in high volumes by way of rail rather than trucks.

Environmentally preferable purchasing in the context of bioremediation includes products such as:

- Tarps with recycled or biobased contents instead of virgin petroleum-based contents, for protection of ground surfaces in staging areas and coverage of soil undergoing ex situ treatment
- Soil nutrients and other treatment-related materials available in bulk quantities and packed in recyclable containers and drums, to reduce packaging waste
- Treatment liquids in concentrated form if a product is locally unavailable (and the concentration process does not involve additional energy consumption), to reduce long-distance shipping volumes and frequencies, and
- Biodegradable cleaning products effective in cold water applications, to conserve energy while avoiding introduction of toxic chemicals in environmental media.

Composting of mining waste-contaminated soil and sediment with municipal biosolids and lime along the Upper Arkansas River in Colorado resulted in 100% vegetative cover in most previously denuded areas within ten years, due to increased microbial functions combined with phytoremediation and reduced leachate.

Green remediation relies on continually improving a project's natural resource efficiencies and scouting for novel approaches. At the Distler Brickyard Superfund site in Kentucky, for example, chitin (a natural biopolymer derived from shrimp and crab shells) was injected into an aquifer as a source of volatile fatty acids to promote VOC degradation. Another example is provided at the Naval Amphibious Base Little Creek in Virginia, where bioremediation involved injection of diluted cyclodextrin (a simple sugar) that could be recycled. Information on reagent options and evaluation of related factors is provided in various demonstration reports compiled by the Environmental Security Technology Certification Program (ESTCP).[5]

Opportunities to reduce the environmental footprint of long-term actions can be further reduced through optimization of the monitoring program. Periodic reevaluation can help identify potential monitoring changes such as reduced sampling frequency, fewer sampling locations, or routine sampling of a smaller well network as a contaminant plume collapses over time.[6]

Green Remediation: A Sampling of Success Measures for a Bioremediation System

- *Reduced fuel consumption due to transport of high-bulk reagents via rail rather than trucks*
- *Reduced GHG emissions as a result of using gravity-fed injection systems rather than fuel-fed pumping*
- *Protection of nearby and downstream surface water through construction of bermed retention ponds that capture and treat contaminated stormwater runoff*
- *Beneficial use of industrial waste or surplus byproducts as bioremediation reagents*
- *Reduced soil compaction during system construction as a result of using well-defined work areas*

References [Web accessed: 2010, February 28]

[1] U.S. EPA; *Principles for Greener Cleanups;* August 27, 2009; http://www.epa.gov/oswer/greencleanups

[2] U.S. EPA; *Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites;* EPA 542-R-08-002, April 2008

[3] Interstate Technology and Regulatory Council; *In Situ Bioremediation of Chlorinated Ethene: DNAPL Source Zones*; June 2008

[4] U.S. EPA; *Green Remediation Best Management Practices:*
[a] *Site Investigation;* EPA 542-F-09-004, December 2009
[b] *Excavation and Surface Restoration;* EPA 542-F-08-012, December 2008
[c] *Pump and Treat Technologies*; EPA 542-F-09-005, December 2009
[d] *Soil Vapor Extraction & Air Sparging;* EPA 542-F-10-007, March 2010
[e] *Clean Fuel & Emission Technologies for Site Cleanup*; EPA 542-F-10-008, April 2010

[5] ESTCP Environmental Restoration Projects and Related Efforts; http://www.estcp.org/Technology/ER-Chlorinated-Solvents.cfm

[6] U.S. EPA and U.S. Army Corps of Engineers; *Roadmap to Long-Term Monitoring Optimization*; May 2005, EPA 542-R-05-003

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