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Green Remediation Best Management Practices: Bioremediation

A fact sheet about the concepts and tools for using best management practices to reduce the environmental footprint of activities associated with assessing and remediating contaminated sites

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The U.S. Environmental Protection Agency (EPA) *Principles for Greener Cleanups* outline the Agency's policy for evaluating and minimizing the environmental footprint of activities involved in cleaning up contaminated sites.[1] Best management practices (BMPs) of green remediation involve specific activities to address the core elements of greener cleanups:

- Reduce total energy use and increase the percentage of energy from renewable resources.
- Reduce air pollutants and greenhouse gas emissions.
- Reduce water use and preserve water quality.
- Conserve material resources and reduce waste.
- Protect land and ecosystem services.

BMPs involving use of renewable energy, green infrastructure or carbon sequestering vegetation during site cleanup and restoration also may help mitigate and adapt to ongoing climate change.

Overview

Bioremediation enhances the effects of naturally occurring biological processes that degrade contaminants in soil, sediment and groundwater. Implementation of this technology may rely on one or more biological processes designed to occur in situ or ex situ:

- Biostimulation, which involves injecting amendments into contaminated media to stimulate contaminant biodegradation by indigenous microbial populations. Amendments may include air (oxygen) by way of bioventing, oxygen-releasing compounds that maintain aerobic conditions in an aquifer, or reducing agents such as carbon-rich vegetable oil or molasses that promote growth of anaerobic microbial populations.
- Bioaugmentation, whereby native or non-native microbes are injected into a target area to aid contaminant biodegradation. At some sites, bioaugmentation is preceded by biostimulation to create conditions favorable for microbial activity.
- Bioreactors that isolate contaminated media and provide the desired aerobic or anaerobic conditions in which microorganisms can degrade contaminants. In situ bioreactors often comprise trenches filled with carbon media through which contaminated groundwater slowly flows or is recirculated, enabling the bioreactors to act as permeable reactive barriers (biobarriers). Other bioreactors treat groundwater pumped from one or more wells, often as a remediation "polishing" step taking place within at-grade beds from which accumulating sludge may need periodical removal.
- Aboveground treatment of excavated soil or sediment that is either placed in aerated surface beds; mixed with compost within a controlled system such as windrows or a dedicated building; mixed with amendments to form aerated biopiles; or mixed with water to form a slurry typically to be treated in a series of tanks.[2]

The environmental footprint of bioremediation activities typically concerns construction of wells, trenches, surface beds or a supporting aboveground infrastructure. Use of water, processed or raw materials, and fuel or other forms of energy also contribute to the footprint.

Project Planning

Incorporation of BMPs to minimize the environmental footprint of implementing bioremediation may begin early in the project, during site investigations. In situ and ex situ applications rely on thorough delineation of the contaminant source areas and plumes and development of an accurate conceptual site model to be updated over time. BMPs relevant to site investigation planning include:

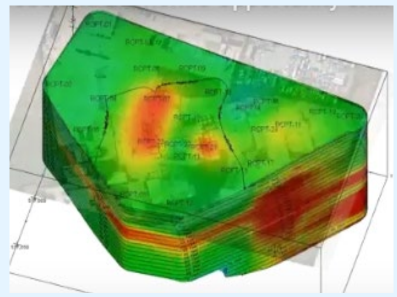
- Use direct-push technology rather than rotary drilling rigs to install boreholes and wells wherever feasible, which eliminates handling and disposal of drill cuttings, avoids use and disposal of drilling fluids, and reduces drilling duration and associated fuel usage.
- Use direct sensing equipment such as membrane interface probes, laser-induced or X-ray fluorescence sensors and cone penetrometers instead of techniques involving more land, ecosystem and subsurface disturbance and materials use.

- Deploy portable gas chromatography/mass spectrometry equipment for analyzing petroleum compounds and volatile organic compounds (VOCs) in soil and groundwater, to minimize the need for sample packaging and shipment to offsite laboratories.
- Use phytoforensics to screen for subsurface contaminants and aid mapping of source areas and plumes, which avoids the land and ecosystem disturbance and fuel use associated with drilling equipment.[3]
- Use high-resolution, three-dimensional imaging techniques to optimize placement of boreholes.

Activities involved in site investigations are further addressed in a companion BMP fact sheet. The BMP fact sheet series also addresses remediation technologies sometimes used in conjunction with bioremediation, such as soil vapor extraction or groundwater pump and treat systems.[4]

Bench-scale treatability tests can be used to design and implement bioremediation projects that efficiently use natural resources and minimize deployment of field machinery and crews throughout the project lifecycle. Treatability tests help:

- Determine the onsite mass of contaminant parent and daughter products, other metabolic products and existing microbial populations.
- Demonstrate specific biodegradation mechanisms of potential microbial cultures, chemical substrates or amendments.
- Select the most suitable reagents or amendments and their optimal concentrations or proportions.
- Evaluate potential delivery methods and dispersion characteristics under simulated aquifer conditions.
- Determine if supplemental technologies are needed to destroy contaminants in hot spots or areas anticipated to involve lengthy periods of microbial acclimation.



High-resolution, three-dimensional imagery helps guide bioremediation implementation at the Bay Road Holdings LLC (formerly Romic) site in East Palo Alto, California. The project involves injections of amendments providing a food source for naturally occurring microorganisms capable of degrading contaminants in an anaerobic environment.

Delivery of the amendments through horizontal instead of vertical wells optimizes placement and dispersion of substrates within the target zones while avoiding disruption of ongoing site redevelopment. The delivery system is fully automated and includes piping that enables subsurface recirculation of the groundwater. A non-toxic, biodegradable surfactant is used to aid emulsification of light non-aqueous phase liquids in the vadose zone.

Following initial use of cheese whey and molasses amendments, the enhanced injections now underway deliver food-grade sugars, vitamin B and other nutrients.[6]

Pertinent local, state and federal regulatory requirements might affect options for reducing the footprint of biostimulation or bioaugmentation activities. Permits for underground injections, for example, vary among state regulatory requirements.[5]

Stimulation of microbial degradation in contaminated soil typically requires use of carbon-rich solid materials as well as amendments that restore soil geochemistry. BMPs concerning amendment selection include those focused on making beneficial use of locally generated industrial byproducts or waste instead of virgin materials. For example, plan to:

- Use forestry byproducts such as wood chips or sawdust and agricultural byproducts such as straw or cottonseed hulls as long-term sources of carbon.
- Use manure compost supplied by agricultural producers, which provides essential carbon as well as various enzymes depending on the particular feedstock and maturity.
- Use biosolids from a municipal wastewater treatment facility.
- Obtain pesticide-free compost from mushroom producers, which contains beneficial fungi as well as nutrients such as nitrogen, phosphorous and potassium.
- Integrate chitin, which is derived from seafood waste, as a source of nitrogen to counteract nitrogen losses commonly encountered in petroleum-contaminated soil.

Selection of carbon-rich substrates, soil nutrients and other amendments to be administered in liquid form, such as lactate, food-grade molasses or anhydrous ammonia, may benefit from evaluation of the material lifecycles.

The U.S. EPA Spreadsheets for Environmental Footprint Analysis (SEFA) are available to evaluate the environmental footprint of implementing cleanup technologies such as bioremediation at a detailed level.[7]

Construction and Startup of Bioremediation Systems

The environmental footprint of field activities involved in constructing subsurface or aboveground components of a bioremediation system and preparing for system startup can be reduced by BMPs such as:

- Choose biodegradable hydraulic fluids to operate equipment such as drill rigs. Selection of suitable biobased products may consider variables such as biomaterial sourcing, percentages of accompanying petroleum-based ingredients and shelf life.[8]
- Minimize engine idling through techniques such as manual or automated shutdown of machinery not actively engaged for a predetermined time period.
- Lay absorbent matting on ground surfaces of staging and work areas to avoid release or seepage of toxic materials into soil and groundwater or the local sewer system, and properly dispose of the spent absorbents.

- ♦ Reclaim uncontaminated graywater or treated water from other site activities for use in preparing injection slurries, administering chase water, converting excavated soil or sediment into a treatable slurry, or irrigating land-based systems.
- ♦ Consolidate shipping and delivery of incoming materials to minimize the number of truck trips and associated fuel consumption and offsite air emissions. For example, a single shipment could supply the volume of wood chips to be placed in a biobarrier as well as the amount needed for site restoration.
- ♦ Deliver large quantities of materials by way of barges supported by tugboats and cargo vehicles equipped with clean diesel technology, rather than delivery trucks emitting more greenhouse gas.
- ♦ Cover material loads hauled by trucks or trains, to avoid aerial deposition of loose materials and improve fuel economy.

Additional BMPs applying to construction and field testing of bioremediation systems include:

- ♦ Reuse existing wells for injection points, to avoid unnecessary surface disturbance and a range of resources associated with machinery and personnel deployment.
- ♦ Choose surfactants that are non-toxic and biodegradable.
- ♦ Administer injectants via gravity feed rather than active pumping whenever high-pressure injection is unnecessary, to minimize equipment deployment and associated fuel usage.
- ♦ Install renewable energy systems such as photovoltaic arrays or transportable wind turbines to power equipment such as groundwater recirculation pumps.
- ♦ Use energy-saving pulsed rather than continuous modes when possible to deliver or withdraw air for bioventing or biosparging applications.
- ♦ Conduct any excavation in a surgical manner to avoid unnecessary damage to adjacent ground surfaces and vegetation.
- ♦ Use a continuous one-pass trencher rather than a hydraulic excavator to construct a biobarrier. This machinery enables simultaneous installation of the trench and placement of reactive material into the fresh trench, thereby avoiding the need for two separate field passes of fuel-intensive machinery and the existence of temporarily open trenches.
- ♦ Cover ground surfaces of work areas with mulch to prevent soil compaction caused by activities such as front-loader application of soil amendments.

Construction and initial operation of a bioremediation system may involve periodic redeployment of heavy machinery or utility vehicles and a dedicated aboveground infrastructure. Relevant BMPs may include:

- ♦ Confine vehicle and machinery traffic within defined corridors to avoid widespread soil compaction and vegetation damage.
- ♦ Deploy machinery and trucks equipped with new or rebuilt engines meeting cleaner emission standards and advanced technologies treating engine exhaust.
- ♦ Employ rumble grates with a closed-loop graywater washing system or a self-contained wheel-washing system to minimize vehicle trackout.
- ♦ Use existing buildings to store materials and equipment or conduct activities requiring tight controls, in lieu of building new structures.
- ♦ Capture rainwater through structures such as rain barrels or a cistern as a source of water for onsite purposes such as dust control.
- ♦ Quantify and mitigate noise impacts that may disturb sensitive animal species.
- ♦ Limit use of artificial lighting that may disturb sensitive animal species.

Other BMPs apply to procurement of environmentally preferable products for either in situ or ex situ bioremediation systems. For example:

- ♦ Purchase soil amendments and treatment materials that are available in bulk quantities and packed in recyclable containers.
- ♦ Use liquid treatment materials that are available in concentrated form from local suppliers, to minimize long-distance shipping volumes and frequencies.
- ♦ Choose all-purpose utility tarps made of recycled or biobased materials rather than virgin or petroleum-based materials.
- ♦ Use biodegradable cleaning products that are effective in a wide range of temperatures, to avoiding introduction of toxic chemicals in environmental media while minimizing need for heated wash water.

At Site 93 of the Camp Lejeune Military Reservation in North Carolina, a photovoltaic array powers a pump that recirculates contaminated groundwater through a subsurface biogeochemical reactor. Construction of the bioreactor involved injecting 220 gallons of crude soybean oil into a mulch and gravel substrate placed in a 25- by 25-foot cell about 6 feet deep. Approximately 45 cubic yards of uncontaminated excavation soil was used as backfill to minimize import of clean fill.

After three years of operation, the bioreactor substrate was replenished to enhance reductive dechlorination of contaminants. Replenishment was accomplished by injecting 100 gallons of emulsified vegetable oil and 4 liters of bioaugmentation culture through existing piping.

Ongoing use of passive rather than low-flow devices to periodically sample relevant monitoring wells avoids generation of purge water. This sampling approach also reduces use of fuel and other resources associated with field activities required for long-term monitored natural attenuation at Site 93. Additional BMPs identified through use of the ASTM *Standard Guide for Greener Cleanups* (E2893-16) are implemented at Site 93 and elsewhere at Camp Lejeune.[9]

System O&M and Monitoring

Green remediation strategies rely on a flexible operational framework that enables continual improvements in a project's use of natural, manufactured or other resources as cleanup progresses. Operation and maintenance (O&M) activities for bioremediation systems vary considerably. For example, substrates could be injected into a few wells during a single round at some sites, while other sites may require multiple injection rounds in numerous wells. Potentially relevant BMPs applying to long-term O&M of a bioremediation system include:

- Use fewer injection wells as a contaminant plume shrinks over time.
- Use alternate amendments with smaller lifecycle footprints to remediate portions of a site showing marginal biodegradation progress.
- Add passive air flow-control devices within wells to supply more air for aerobic biological processes.
- Integrate an onsite source of renewable energy to power blowers that may be needed to additionally aerate wells, surface beds or biopiles.
- Evaluate potential effects of a changing climate on the system, which may include different temperature, precipitation or wind conditions when compared to those determined during project design. Effects could include greater or less evaporation, photodegradation of exposed substrates, or generation of leachate.

BMPs concerning energy and material usage during remediation monitoring include:

- Use field test kits or analyze only indicator compounds when possible, to minimize sample packaging and shipping to an offsite laboratory.
- Choose local laboratories with courier delivery whenever possible.
- Reuse materials that can be dedicated to selected purposes, such as the tubing needed for multiple rounds of fluid sampling.
- Use solar power packs to operate equipment with low energy demands, such as security lighting and system telemetry.
- Maximize automation through use of equipment such as electronic pressure transducers and thermocouples with an automatic data logger to record data at frequent intervals.

Optimization of a groundwater extraction and treatment system that had operated for 14 years at the Re-Solve, Inc. Superfund site in North Dartmouth, Massachusetts, included installing an anaerobic bioreactor. The bioreactor consists of two partially raised beds containing peat and sand.

The groundwater treatment plant process water is routed to the bottom of the bioreactor via gravity. Fermentation of the peat facilitates reductive dechlorination process that breaks down VOCs remaining in the groundwater. Integration of the bioreactor facilitated shutdown of the groundwater treatment system's energy- and material-intensive air stripping and catalytic oxidation processes. Onsite photovoltaic arrays power the groundwater treatment system.[10]

Potential BMPs also may apply to resource efficiencies gained by integrating remedial operations with current or future site use:

- Repurpose buildings no longer needed for remedial activities.
- Use a suitable mix of trees, shrubs, grasses and broad-leaved herbaceous plants during site restoration to preserve or improve biodiversity and ecosystem services and sequester atmospheric carbon. A survey of native plants and resident or migratory animals in surrounding areas can help guide replanting and habitat restoration.
- Incorporate green infrastructure components such as bioswales and tree canopy to manage the site's stormwater.

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This fact sheet provides an update on information compiled in the March 2010 "Green Remediation Best Management Practices: Bioremediation" fact sheet (EPA 542-F-10-006), in collaboration with the Greener Cleanups Subcommittee of the U.S. EPA Technical Support Project's Engineering Forum.

To view BMP fact sheets on other topics, visit CLU-IN Green Remediation Focus: www.clu-in.org/greenremediation.