United States Environmental Protection Agency
Office of Land and Emergency Management (5203)
EPA 542-F-21-029 December 2021 Update

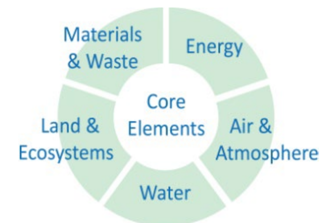
Green Remediation Best Management Practices: Pump and Treat Systems

A fact sheet about the concepts and tools for using best management practices to reduce the environmental footprint of activities associated with extracting and treating contaminated groundwater

www.clu-in.org/greenremediation

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:

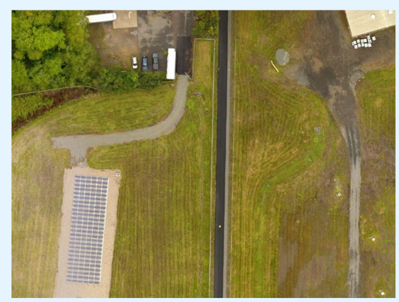
- Reduce total energy use and increase the percentage of energy from renewable resources.
- Reduce air pollutants and greenhouse gas (GHG) emissions.
- Reduce water use and preserve water quality.
- Conserve material resources and reduce waste.
- Protect land and ecosystem services.



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

Remediation of contaminated groundwater at many sites involves pump and treat (P&T) operations to restore the quality of an aquifer or prevent migration of a contaminated groundwater plume. A P&T system extracts contaminated groundwater from one or more wells and then applies treatment technologies to remove, degrade or destroy the groundwater contaminants ex situ. Under relevant state permits, the treated water is reinjected into the aquifer or discharged to nearby surface water. In some cases, the treated water is discharged to a local sewer system for additional treatment.



Design of a multi-layered cap above consolidated waste at the Solvents Recovery Service of New England Superfund site in Southington, Connecticut, included solar energy development. A 53 kilowatt solar array on the permanent cap offsets a portion of the grid electricity used for long-term extraction of the site's contaminated groundwater.[3]

More than 80 percent of the groundwater remedies selected for Superfund sites in the early 1990s included P&T systems, some of which still operate. Although selection of remedies involving P&T has since declined significantly, to about 20 percent in fiscal year 2017,[2] newer P&T systems are anticipated to similarly operate for long time periods. As a result, the most significant opportunities to minimize the environmental footprint of P&T implementation concern usage of energy and treatment materials over multiple years, in some cases decades.

Operation and maintenance (O&M) of a P&T system involves maintaining the groundwater extraction wells by activities such as removing biofilms and sediments that can clog well screens and repairing any damaged seals. O&M also involves managing treatment processes, which may include carbon adsorption, metals precipitation, neutralization, aeration, evaporation, ultraviolet exposure or ion exchange. The total footprint of P&T implementation encompasses direct contributions such as air emissions associated with onsite burning of fossil fuel, as well as indirect contributions such as air emissions associated with using electricity generated at an offsite fossil fuel-fired electricity plant.

Other major opportunities for a greener cleanup concern long-term discharge of the treated water, with aims to maximize beneficial use of the treated water in non-potable applications.[4] Reclaiming the treated water also avoids the offsite energy and material usage and waste generation associated with completing groundwater treatment at a sewage treatment plant.

Shortages of freshwater are anticipated in 40 states within the next decade. Water reuse represents a major opportunity to supplement existing water supplies with water sources such as industrial process water and stormwater.[5]

Project Planning

Incorporation of broad BMPs during project planning can help minimize the environmental footprint of a P&T project throughout its life. Relevant BMPs include:

- Integrate one or more onsite photovoltaic (PV) or wind energy systems to supply electricity for groundwater extraction and treatment equipment or for offsetting grid-supplied electricity used for this purpose. The systems may be scaled up or configured in a modular fashion to additionally meet electricity demands of ongoing site activities or anticipated site reuse.
- Identify onsite or offsite non-potable uses for the treated water, such as building operations, dust and fire suppression, plant irrigation, wetlands restoration or recreational impoundments.[6]
- Choose the nearest facilities at which to dispose of or recycle anticipated wastes.
- Use existing structures that are unused or underutilized to house remediation and monitoring equipment and supplies.
- Incorporate green requirements into applicable service and product procurements.

Other BMPs can be incorporated into detailed design of a P&T system, such as:

- Maximize automation of mechanical and electronic equipment to minimize in-person monitoring.
- Implement a telemetry system to reduce frequency of site visits and responses to non-critical alarms.
- Use multi-port sampling systems rather than well clusters to collect groundwater samples from multiple depths, which minimizes the number of monitoring wells needing to be installed.
- Rely on gravity flow where feasible to minimize the number of pumps required for groundwater transfer or effluent discharge.
- Use closed-loop rather than open-loop treatment processes to reduce the need for fresh water and raw materials and potentially improve treatment system efficiency.
- Reclaim uncontaminated byproducts for potential recycling, such as precipitated metals solids and spent activated carbon.

Lifecycles and environmental tradeoffs within and among P&T projects may vary considerably. Considerations might include aspects such as:

- The natural resources used to manufacture or process chemicals and other treatment materials.
- Fuel usage and air emissions associated with transporting goods or wastes and commuting workers.
- Coinciding increases in energy efficiency and energy demand associated with pre-heating extracted groundwater prior to treatment.
- The potential for treatment chemicals or treatment byproducts to exist in the treatment system effluent.

Project teams can use the U.S. EPA *Spreadsheets for Environmental Footprint Analysis* (SEFA) to quantify onsite and offsite contributions to the environmental footprint of P&T implementation and accordingly adjust project parameters and activities.[8]

Up to 33 percent of the effluent from two groundwater treatment plants at the former Nebraska Ordnance Plant in Mead, Nebraska, is used to irrigate onsite or adjacent field crops and replenish fishponds. The remainder is discharged to a nearby creek. Associated outfall piping also enables emergency use of the treated water for fire suppression.[7]

Operation of three onsite, grid-tied wind turbines offsets about 60 percent of the electricity used to extract contaminated groundwater at the 183-acre Continental Steel Corp. site in Kokomo, Indiana. The extraction system utilizes 16 wells from which water is continuously extracted at a rate of up to 266 gallons per minute. Additional renewable energy is produced onsite by a 7.2 megawatt solar farm, which generates $36,000 in annual revenue for the City of Kokomo.[9]

Construction of P&T Systems

BMPs to minimize fuel usage, air emissions and waste generation associated with constructing a P&T system include:

- Equip diesel machinery with emission control technologies such as diesel oxidation catalysts, diesel particulate filters and approved fuel additives.[10,11]
- Fuel off-road machinery with biodiesel blends, which typically emit less particulate matter.
- Implement an engine idle reduction plan to avoid fuel use when machinery is not actively engaged. Options include manual shutdown after a specified time or engagement of automatic shutdown devices.

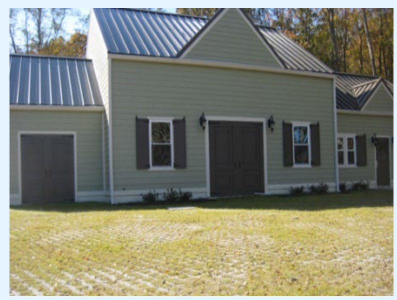
- Use biobased rather than petroleum-based lubricants to operate machinery, vehicles and equipment. Selection of suitable biobased products may consider variables such as biomaterial sourcing, percentages of accompanying petroleum-based ingredients, and shelf life.[12]
- Deploy direct-push drilling rigs instead of rotary drilling rigs when feasible, which can reduce drilling duration by as much as 50-60% while generating less drill cuttings requiring disposal.

The amount of external power required for ex situ treatment of contaminated groundwater greatly varies, depending on site-specific factors such as the target rate of process flow and the selected treatment technology(s). In addition to transfer pumps, a treatment process may require operating other energy-intensive equipment such as boilers and chillers. Use of electricity, natural gas and other fuels to operate such equipment may be minimized through BMPs such as:

- Size pumps to meet the most frequent rather than the highest expected load level, to avoid excessive pumping and associated efficiency loss.
- Size electric motors for their intended uses; a partially loaded motor is significantly less efficient than one operating at 75 percent or higher capacity. The National Electrical Manufacturers Association offers a standard regarding use of high efficiency motors.[13]
- Choose boilers, fans and other equipment with energy efficiency ratings certified by Energy Star.[14]
- Choose furnaces, chillers and boilers fired by recycled petroleum- or vegetable-based oil or by biomass sources such as agricultural and forestry residues.
- Install variable frequency drives (VFDs) to set pumping flow rates rather than using valves to throttle the flows. A VFD could reduce a pump's energy demand as much as 50 percent while avoiding damage to connected mechanical equipment.
- Install waste heat recovery equipment such as heat exchangers, ground or water source heat pumps and mobile waste-to-heat generators. Such units can transfer heat among liquids, supply heated or cooled air, or convert waste heat to useable electricity.
- Insulate pipes and equipment tied to treatment steps that require heat.
- Integrate smart energy technologies and distributed energy resources to allow energy demand flexibility, optimize energy usage, and provide resilience to weather-related grid outages. Examples include advanced metering infrastructure, automated feeder switches, and voltage regulators combined with onsite solar and wind energy systems.

P&T systems typically need small housings or sheds to protect equipment exposed to outdoor elements or to store supplies. At some sites, one or more large buildings may be needed to implement multi-step or expansive treatment processes. Building construction or retrofitting can take advantage of green building approaches,[15] which include material- and energy-related BMPs such as:

- Use concrete mixes containing recycled material such as crushed waste glass.
- Install skylights or solar tubes to provide direct or indirect natural light in work and storage areas. More efficiency can be gained by using an integrated daylighting system that automates electric light dimming.[16]
- Insulate structural walls, ceilings and floors with green materials such as spray-on cellulose fiber, vegetable oil-based foam or mycelium panels.
- Integrate a solar thermal system to supply or supplement hot water needed for building operation or selected treatment processes.
- Integrate a geothermal system, which draws naturally heated or cooled air from the ground or a nearby water source.
- Use condensing water heaters or boilers to provide process or building heat, which are typically 15 percent more efficient than conventional natural gas-fired boilers.[17]
- Install air source heat pumps that can generate hot and cold water for radiant floor heating or cooling.
- Install energy recovery ventilators to allow incoming fresh air while capturing energy from outgoing, conditioned air.
- Integrate a natural gas- or cleaner diesel-fired combined heat and power system to capture waste heat from equipment such as boilers and beneficially use the heat for purposes such as pre-heating treatment process influent or conditioning air inside a building.



Design and construction of an offsite groundwater treatment plant near the Lawrence Aviation Industries site in Port Jefferson Station, New York, included installation of:

- A geothermal energy system to condition interior air.
- A cool roof made of reflective metal with a high solar reflectance index value of 29.
- Low-maintenance, insect- and weather-resistant composite siding made of sustainable materials.
- Exterior wall insulation made of soybeans and through processes involving no formaldehyde, fiberglass or petroleum.
- Ceiling tiles made of rapidly renewable resources and recycled materials (45 and 23 percent, respectively).
- Pervious pavement in parking and access areas.

The building's exterior was designed to fit the community's architectural style, thereby enhancing its aesthetic and future reuse options.[18]

Whole-building energy efficiencies can be evaluated through use of EnergyPlus,™ an energy simulation program developed by the U.S. Department of Energy (DOE).[19] The tool can model energy consumption associated with heating, cooling, ventilation, lighting and plug-and-process loads as well as water use within a building.

Areas used for groundwater treatment often contain impervious surfaces that prevent infiltration of rainwater or snowmelt, which increases the potential for stormwater runoff and associated soil erosion. Stormwater runoff carries trash, bacteria, heavy metals and other contaminants and is a significant cause of water pollution. During heavy rains, high flows of stormwater also can cause flooding and damage habitat and infrastructure.

BMPs to facilitate infiltration or potentially capture and beneficially use stormwater involve green infrastructure components, many of which can also aid sequestration of atmospheric carbon.[20] For example:

- Integrate vegetated roofing systems above onsite structures.
- Use permeable pavement to surface parking areas and walkways.
- Construct one or more rain gardens and planter boxes.
- Install rain barrels or cisterns.
- Construct a detention or retention pond that can filter pollutants carried by stormwater, prevent flooding, and store stormwater for onsite or community use. Periodic release of stormwater from a detention pond to downgradient surface water can be optimized by automating associated valves or weirs and integrating a telecommunication system and auxiliary electronic equipment to create a smart pond that can be remotely managed.
- Choose no/low maintenance native plants to vegetate swales or stormwater retention structures.

Green infrastructure elements such as planter boxes were incorporated into cleanup at the Curtis Bay Coast Guard Yard in Baltimore, Maryland. The tiered planting system filters stormwater and reduces stormwater runoff entering the sewer system.[21]

System O&M and Long-Term Monitoring

Minimizing the environmental footprint of operating a groundwater extraction and treatment system can involve general BMPs such as:

- Use real-time measurement technologies such as sensors, probes and meters equipped with program alarms to notify operators of a system or component failure.
- Install off-grid PV modules to power exterior lighting and other equipment with low energy demands.
- Employ an electronics stewardship plan that ensures purchases of sustainable electronics such as computers and displays and recycling or reuse of expended electronic equipment.[22]
- Conduct manufacturer-recommended preventative maintenance of all processing and building equipment on schedule and quickly complete any needed repairs.
- Use an onsite rather than offsite laboratory for routine sample analysis, to minimize sample packaging and shipping.
- Use electronic systems rather than hard-copy materials to document and convey information such as monthly operational reports and routine invoices.
- Compress schedules for routine or periodic work involving site visits.

Detailed BMPs concerning water pumping efficiency and associated energy usage throughout O&M include:

- Use pulsed rather than continuous rates of groundwater pumping if continuous pumping is not needed to contain a plume or reach the required rate of groundwater transfer and treatment.
- Conduct pumping during off-peak utility periods, which reduces demand on the electricity provider during on-peak periods while potentially decreasing the cost of purchasing electricity.
- Use electric instead of air-operated pumps that are typically less efficient.
- Trim or change impellers on centrifugal pumps that become oversized over time.
- Replace worn throat bushings, wear rings, impellers and pump bowls.
- Replace aged pumps with newer ones meeting the latest energy conservation standard set by the U.S. DOE.[23]

Optimization of a P&T system operating at the Frontier Fertilizer Superfund site in Davis, California, since 1995 has included energy efficiency measures such as:

- Offsetting 100 percent of the treatment process demand for grid electricity by adding ground- and rooftop-mounted PV modules.
- Equipping the groundwater extraction pumps with variable frequency drives.
- Switching from a 10-horsepower pumping system to a gravity-feed pipe system for discharge of the treated water.

Each year, the use of renewable energy avoids an estimated 147,500 pounds in carbon dioxide (equivalent) emissions.[24]

The U.S. DOE Better Buildings® initiative has compiled information about software tools and additional practices to help improve efficiency of pumping and other systems potentially involved in groundwater treatment.[25] For example:

- Replace pressure-reducing valves with backpressure turbogenerators in steam systems.
- Stabilize pressures in compressed air systems by installing pressure/flow controllers or adding dedicated compressors.
- Use chillers equipped with adiabatic (wet pad) systems that pre-cool incoming air.
- Replace standard V-belts with cogged belts in fans used for ventilation.
- Audit a treatment plant's lighting systems every five years to take advantage of quickly-evolving lighting technologies and controls. Opportunities might include new incentives offered by local utilities.

BMPs concerning materials usage and waste generation during the groundwater treatment process include:

- Use filters that can be backwashed rather than disposable filters when running process water or air through adsorption media.
- Choose product manufacturers that use renewable energy-sourced electricity or maintain zero-carbon emission policies.
- Purchase materials in bulk to reduce packaging waste and minimize the fuel and air emissions associated with onsite deliveries and offsite purchases.
- Choose materials with biobased rather than petroleum-based content, such as coconut-based granular activated carbon for adsorption processes.[26] The U.S. Department of Agriculture's BioPreferred® Program Catalog describes biobased products used for other purposes such as general operation and maintenance, custodial service, and grounds maintenance.[27]

Protective housing of groundwater treatment equipment may be minimal at sites located in mild climates. However, the environmental footprint of using large equipment and process or storage tanks in outdoor settings at any site may be reduced by BMPs such as:

- Emplace containment devices on surfaces used for chemical mixing or batched processing, to prevent spillage from entering the soil, groundwater or stormwater runoff.
- Inspect the integrity of concrete slabs on a frequent basis and promptly make any needed repairs.
- Use non-toxic, biodegradable cleaning solutions and weed suppressants.
- Install silencers on noisy equipment such as air compressors.
- Limit use of artificial lighting that may disturb sensitive animal species.

BMPs concerning sampling and analysis of groundwater in the monitoring wells include:

- Use passive sampling techniques, which involve no well purging, where appropriate.
- Use environmentally friendly additives such as ascorbic acid to preserve or stabilize collected samples, if compatible with target analytes and anticipated analytical methods.
- Minimize the need for disposable single-use items such as plastic bags and gloves.
- Use portable solar-powered battery packs to charge small electronic devices or equipment.
- Emplace mulch on ground surfaces frequently used by workers, to minimize soil compaction, potential erosion and weed growth.
- Use hybrid and electric vehicles to transport workers, portable equipment and supplies.

More than 700 monitoring, extraction and injection wells are used to remediate 23 contaminated groundwater sites at Travis Air Force Base in California. The groundwater is extracted and treated at three on-base plants. Implementation of phytotechnology and subgrade biogeochemical reactors (SBGRs) helps reduce the site's P&T burden.

BMPs to minimize the environmental footprint of remedy implementation were prioritized by applying the ASTM *Standard Guide for Greener Cleanups* (E2893). Improved project outcomes attributed to the BMPs include:

- Reduced the annual energy demand at one groundwater treatment plant by about 158,000 kilowatt hours (kWh), by modifying the extraction method or treatment technology in three areas where contaminant concentrations had significantly decreased.
- Reduced the need for raw materials to construct each of three SBGRs by using waste materials such as restaurant waste oil (800 pounds) and recycled drywall (20 cubic yards) as reactive substrates.
- Avoiding use of about 70,000 kWh of electricity each year by using PV arrays that directly power pumps recirculating groundwater through the SBGRs.
- Enhancing water infiltration in the root zone of trees in the phytoremediation area by using recirculating water supplied by an adjoining SBGR. An additional PV array powers two submersible pumps that extend the groundwater recirculation zone.
- Beneficially using the water treated at one site to replenish water levels in a small, on-base recreational lake.[28]

Frequent review of an operating P&T system's performance and efficiencies will help identify approaches to optimize the system as groundwater remediation progresses over time. Optimization opportunities might involve modifications such as:

- Eliminate redundant or otherwise unnecessary sampling.
- Downsize selected equipment.
- Suspend operation of one or more extraction pumps.
- Take certain treatment equipment offline and repurpose the equipment.
- Eliminate one or more portions of a treatment train.
- Conduct periodic bench-scale testing of alternative chemicals or new products, which could result in using materials and processes involving a smaller environmental footprint.
- Integrate other remediation technologies such as bioremediation, in situ chemical oxidation or low-temperature thermal heating to serve as a remediation polishing step or further address source areas.
- Evaluate expansion or integration of renewable energy sources as new financial incentives become available, particularly when combined with ongoing use or redevelopment of the site.

Performance-based goals and BMPs for minimizing environmental footprints of P&T implementation may be documented in site management plans, quality assurance project plans, and product or service purchasing agreements. For example, remediation service agreements could specify:

- Laboratory use of EPA analytical methods involving procedures that generate little waste, such as solid phase micro extraction.
- Onsite renewable energy generation to meet the full electricity demand of the groundwater treatment system.
- Beneficial use of the treated water to meet non-potable water demands of onsite administrative buildings.

References

1 U.S. EPA. Greener Cleanups. Principles for Greener Cleanups. https://www.epa.gov/greenercleanups
2 U.S. EPA. Superfund Remedy Report. 16th Edition. EPA-542-R-20-001. July 2020. https://www.epa.gov/remedytech/superfund-remedy-report
3 U.S. EPA CLU-IN Green Remediation Profile: Solvents Recovery Service of New England, Inc. Superfund Site. https://clu-in.org/greenremediation/profiles/srsne
4 U.S. EPA. Water Reuse Activities and Resources. https://www.epa.gov/waterreuse/water-reuse-activities-and-resources
5 U.S. EPA. National Water Reuse Action Plan: Collaborative Implementation (Version 1). Federal Register notice of availability. 84 FR 48612. September 16, 2019. https://www.federalregister.gov/documents/2020/03/03/2020-04353/national-water-reuse-action-plan-collaborative-implementation-version-1
6 U.S. DOE. Federal Energy Management Program. Water-Efficient Technology Opportunity: On-site Wastewater Treatment Systems. https://www.energy.gov/eere/femp/water-efficient-technology-opportunity-site-wastewater-treatment-systems
7 U.S. EPA. CLU-IN Green Remediation Profile: Former Nebraska Ordnance Plant. https://clu-in.org/greenremediation/profiles/formernop
8 U.S. EPA. Spreadsheets for Environmental Footprint Analysis. https://clu-in.org/greenremediation/SEFA/
9 U.S. EPA CLU-IN Green Remediation Profile: Continental Steel Corp. https://clu-in.org/greenremediation/profiles/continentalsteel
10 U.S. EPA. Verified Technologies for SmartWay and Clean Diesel. https://www.epa.gov/verified-diesel-tech
11 California Air Resources Board. Verification Procedure – Currently Verified. https://ww2.arb.ca.gov/verification-procedure-currently-verified
12 U.S. Department of Agriculture. BioPreferred Program Catalog: Intermediates – Lubricant Components. https://www.biopreferred.gov/BioPreferred/faces/catalog/Catalog.xhtml
13 National Electrical Manufacturers Association. General Specification for Consultants, Industrial and Municipal: NEMA Premium® Efficiency Electric Motors. https://www.nema.org/standards/view/General-Specification-for-Consultants-Industrial-and-Municipal-NEMA-Premium-Efficiency-Electric-Motors
14 U.S. EPA and U.S. DOE. Energy Star. All Certified Products. https://www.energystar.gov/products/certified-products/detail
15 U.S. Green Building Council. LEED rating system. https://www.usgbc.org/leed
16 U.S. General Services Administration. Integrated Daylighting Systems. https://www.gsa.gov/governmentwide-initiatives/sustainability/emerging-building-technologies/published-findings/lighting/integrated-daylighting-systems
17 U.S. General Services Administration. Condensing Boilers. https://www.gsa.gov/governmentwide-initiatives/sustainability/emerging-building-technologies/published-findings/hvac/condensing-boilers
18 U.S. EPA CLU-IN Green Remediation Profile: Lawrence Aviation Industries. https://clu-in.org/greenremediation/profiles/lawrenceaviation
19 U.S. DOE. Energy Plus. https://energyplus.net/
20 U.S. EPA. What Is Green Infrastructure. https://www.epa.gov/green-infrastructure/what-green-infrastructure
21 U.S. EPA. CLU-IN Green Remediation Profile: Curtis Bay Coast Guard Yard. https://clu-in.org/greenremediation/profiles/curtisbaycgyard
22 Global Electronics Council. EPEAT Registry. https://epeat.net/
23 Hydraulic Institute. HI Energy Rating. http://er.pumps.org/ratings/home
24 U.S. EPA. CLU-IN Green Remediation Profile: Frontier Fertilizer Superfund Site. https://clu-in.org/greenremediation/profiles/frontierfertilizer
25 U.S. DOE. Better Buildings. Technology Focus Areas. https://betterbuildingssolutioncenter.energy.gov/better-plants/technology-focus-areas
26 Environmental Technology & Innovation. Valorization of coconut waste for facile treatment of contaminated water: a comprehensive review (2010-2021). Anina James and Deepika Yadav. Volume 24, November 2021. https://www.sciencedirect.com/science/article/pii/S2352186421007239
27 U.S. Department of Agriculture. BioPreferred Program Catalog. https://www.biopreferred.gov/BioPreferred/faces/catalog/Catalog.xhtml
28 U.S. EPA. CLU-IN Green Remediation Profile: Travis Air Force Base. https://clu-in.org/greenremediation/profiles/travisafb

This fact sheet provides an update on information compiled in the December 2009 "Best Management Practices: Pump and Treat Technologies" fact sheet (EPA 542-F-09-005), 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.