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ORIGINAL ARTICLE

Green and sustainable remediation practices in Federal Agency cleanup programs

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Abstract Federal agencies manage hazardous waste sites under the assumption that environmental restoration will improve the environment by returning contaminated groundwater to beneficial use, removing waste residuals from a site, treating discharges to surface water, and reducing overall risks to human health and the environment. However, the associated time-consuming and expensive operations, extensive performance monitoring, and post-closure care can lead to unanticipated environmental impacts due to both the technological nature of these cleanup activities and the related protracted timelines. These life-cycle impacts can and should be included in the evaluation of remedial alternatives. Increasingly, Federal agencies are considering these life-cycle impacts—variously referred to as "environmental footprint analysis," "sustainable remediation," "green remediation," "greener remediation," and "green and sustainable remediation"—when evaluating environmental restoration approaches. For the purposes of this paper, this concept will be referred to as "green and sustainable remediation" (GSR), with application of GSR assumed to take place across the cleanup life cycle, from the investigation phase through site closeout. This paper will discuss the history of GSR, what GSR is, who is implementing GSR, and GSR metrics. The paper will also discuss two approaches to GSR, using case studies to understand and implement it; the first will be a qualitative approach, and the second a more detailed quantitative approach.

Keywords Green remediation · Sustainability · Environmental footprint · EO 13693 · Sustainable remediation · Forum (SURF) · Green cleanups

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A brief history of green and sustainable remediation

Increasingly, concepts variously referred to as "sustainable remediation," "green remediation," "greener remediation," and "green and sustainable remediation" (hereafter referred to as "green and sustainable remediation," or GSR) are being incorporated into the investigation and remediation of contaminated sites (hereafter referred to as "environmental restoration," or ER) (Holland et al. 2011). Although the concept of GSR has great cachet today, in reality, the concept has a long pedigree.

One of the first instances of subject matter experts (SMEs) examining the impacts of site remediation over an entire project life cycle comes from a case study in Canada (Page et al. 1999). The SMEs involved with this study examined the impacts associated with excavating and disposing soil contaminated with lead, arsenic, cadmium, and polyaromatic hydrocarbons. A concept referred to as "life-cycle thinking" was used to inventory the impacts of site remediation activities in an effort to expand the consideration of environmental and human health impacts. The authors concluded that the remediation of a site resulted in life-cycle burdens that were (1) local—aquifer damage and contaminants remaining below the cleanup level; (2) regional—emissions, resource consumption, and human health; and (3) global—acid rain, global warming, and ozone depletion. The assessments indicated that the effects of operations as trivial as excavation and disposal can extend beyond the boundaries of the site itself.

Since that time, a number of other SMEs have attempted to define sustainable and green remediation concepts and to develop approaches to measure project life-cycle impacts based on the consideration of these concepts. The following are some, but not all, of the key milestones since this began:

- 2006—Sustainable Remediation Forum (SURF) formed. Its purpose is to foster the formal integration of sustainable principles, practices, and metrics in remediation projects on a national and international basis.
- 2007—Association of State and Territorial Solid Waste Management Officials (ASTSWMO) created the Green Cleanups Task Force, which advocates for "greener cleanups."
- 2008—US Environmental Protection Agency (EPA) first developed the *Green Remediation Technical Primer* and formed the EPA/State Greener Cleanup Working Groups.
- 2011—Interstate Technology Regulatory Council (ITRC) published guides on Green and Sustainable Remediation Technology Overview (GSR-1) and GSR Technical/Regulatory Guidance (GSR-2).
- 2013— and American Society of Testing and Materials (ASTM) published the standard guides *Standard Guide for Integrating Sustainable Objectives into Cleanup* (E2876-13) (ASTM 2013a) and *Standard Guide for Greener Cleanups* (E2893-13), which includes a best management practices table in Excel format (ASTM 2013b).

The timeline continues beyond 2013 with numerous references to GSR-related case studies, technical approaches for integrating GSR into decision making for remediation sites, and GSR-focused conferences and symposia, which are reported on in the literature. The SURF website contains links to numerous GSR-related publications and resources (http://www.sustainableremediation.org/remediation-resources).

What is GSR?

Whether conducted under Federal cleanup programs like the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or the Resource Conservation and Recovery Act (RCRA), as amended, or by State-directed cleanup programs, the purpose of ER activities is to remediate a site to the point where it can be beneficially used, for example, for residential development, recreational use, or industrial use. Whether the ER activities involve achieving strict cleanup standards to allow residential reuse or more lenient cleanup standards to allow industrial reuse, any environmental improvement will be accompanied by various impacts. Various organizations have developed different, but similar, definitions of sustainable remediation practices, each focusing on different aspects of the process in crafting approaches for measuring these overall impacts:

- EPA defines green remediation as "the practice of considering the environmental effects of remedy implementation and incorporating options to minimize the environmental footprint of cleanup actions" (EPA 2008, 2012).
- SURF defines sustainable remediation as "a remedy or combination of remedies whose net benefit on human health and the environment is maximized through the judicious use of limited resources" (Ellis and Haadley 2009).
- ITRC defines GSR as "the site-specific employment of products, processes, technologies, and procedures that mitigate contaminant risk to receptors while making decisions that are cognizant of balancing community goals, economic impacts, and environmental effects" (ITRC 2011).
- ASTSWMO defines green remediation as "consideration of sustainability principles in all phases of remediation in order to maximize the net environmental benefit of a cleanup" (ASTSWMO 2011).
- ASTM defines greener cleanup as "the incorporation of practices, processes, and technologies into *cleanup* activities with the goal of reducing impacts to the environment through reduced demands on natural resources and decreased *emissions* to the environment. A *greener cleanup* considers the five *core elements*, while protecting human health and the environment. In the environmental remediation industry, this term is used interchangeably with green *cleanup*, green remediation, and greener remediation" (ASTM 2013b). In this case, the five factors are: minimizing energy use; maximizing the using of renewable energy; minimizing air pollutants, GHG emissions and water use; reducing, reusing, and recycling materials; and protecting land and ecosystems.
- The US Department of Defense (DoD) defines GSR in the *Defense Environmental Restoration Manual* as follows: "Green and sustainable remediation expands on DoD's current environmental practices and employs strategies for environmental restoration that use natural resources and energy efficiently, reduce negative

impacts on the environment, minimize or eliminate pollution at its source, and reduce waste to the greatest extent possible. Green and sustainable remediation uses strategies that consider all environmental effects of remedy implementation and operation and incorporates options to maximize the overall environmental benefit of environmental response actions" (DoD 2012).

To measure GSR impacts during the life cycle of the cleanup process, metrics have been developed in EPA's *Core Sustainability Principles* (EPA 2012). The EPA definition of a metric is a project parameter for which a quantitative value may be derived mathematically, estimated through engineering details, or extracted from past project records with actual data (EPA 2012). Others view GSR evaluation through the lens of a more expansive definition of "metric." SURF documents a suite of metrics that are both qualitative and quantitative. SURF defines a metric as "the specific aspect of the parameter to be measured." Metrics are further designated as "quantifiable or qualitative" and identified as environmental, social, or economic measures" (Butler et al. 2011).

For the purposes of this paper, the expansive SURF definition of GSR and GSR metrics will be used. This definition allows a choice over a large set of potential metrics measure quantitative and qualitative environmental, social, and economic impacts to best represent site-specific characteristics of the project being analyzed and the interests of the stakeholders. Because the impacts and their relative importance to the project will be project-specific, it is expected that the metrics chosen for each project will vary.

Who are the GSR practitioners?

Both public- and private-sector organizations practice GSR. Public-sector groups include both Federal and State organizations. In some cases, public/private consortia were organized on a project-specific basis and on a programmatic basis to aid in the implementation of GSR. Federal agencies with active GSR programs include:

- EPA Headquarters and Regions,
- US Department of Energy (DOE) Cross Programmatic Work Group,
- US Department of Defense (DoD),
    - US Army Corps of Engineers (USACE),
    - US Naval Facilities Engineering Command,
    - US Air Force, and
    - US Army.

State programs include, but are not limited to, programs in:

- California,
- Massachusetts, and
- Minnesota.

Other practitioners include:

- National and international SURF members;
- ASTM;
- ITRC;
- ASTSWMO;
- Private-sector corporations such as Boeing, DuPont, Shell, and Exxon; and
- Numerous cleanup consulting firms.

This paper will focus on GSR implementation in Federal agency-related ER projects.

Why implement GSR?

The key drivers for the implementation of GSR are Federal agency requirements, policies, and guidance; and environmental, economic, and societal benefits. The agency requirements include compliance with executive orders and agency-specific policies. In addition, agencies may issue GSR guidance that, if not accompanied by an executive order or policy, encourages GSR and instructs how GSR can be implemented. The agency requirements, along with any agency policies and guidance, are discussed below. The environmental, economic, and social benefits are discussed in the following section.

Executive orders, guidance, and policy

There are no specific laws or regulations that mandate the implementation of GSR. However, there are Federal Executive Orders (EOs) that require Federal agencies to incorporate sustainability practices in agency operations. Most recently, "Planning for Federal Sustainability in the Next Decade" (EO 13693) incorporates sustainability principles and Federal leadership in environment, energy, and economic performance. In addition, "Climate Change Adaptation" (EO 13653) also addresses sustainability principles. There are also many agency-specific actions. Examples include:

- DOE Order 436.1: "Departmental Sustainability." (DOE 2011).
- DoD policy: "Consideration of GSR Practices in the Defense Environmental Restoration Program" (DoD 2009), updated in "Defense Environmental Restoration Program Management Manual 4715.20" (DoD 2012).
- US Navy policy requires GSR as part of optimization: "Policy for Optimizing Remedial and Removal Actions

at All Department of the Navy (DON) Environmental Restoration Program Sites" (DON 2012).

- US Navy: "Guidance on Green Sustainable Remediation," UG-2093-ENV, Rev. 1 (U.S. Navy 2012).
- USACE: "Decision Framework for Incorporation of Green and Sustainable Practices into Environmental Remediation Projects" (USACE 2010), updated in "Detailed Approach for Performing Green and Sustainable Remediation (GSR) Evaluations in Army Environmental Remediation" (USACE 2012a).
- US Air Force Instruction 32-7001 DOE Office of Environmental Management GSR contracting policy for cleanups.
- EPA: "Encouraging Greener Cleanup Practices through Use of ASTM International's Standard Guide for Greener Cleanups" (EPA 2013).
- EPA Regions 1 through 10: region-specific green remediation policies.

In addition to the above-noted agency-specific guidance, GSR policy and guidance have been developed by State governments, public–private partnerships, and standard-setting organizations. This guidance includes the following documents:

- California: "Interim Advisory for Green Remediation" (California DTSC 2009).
- Illinois: "Greener Cleanups Matrix" (Illinois EPA 2008).
- Minnesota: "Green and Sustainable Remediation, Petroleum Remediation Program" and "A practical GSR Framework for Federal Agencies and States" (MPCA 2011, 2012).
- New York: "Program policy, DER-31 green remediation" and "Policy for Green Remediation" (NYSDEC 2010, 2011).
- Oregon: "Green Remediation Policy Draft" (Oregon DEQ 2011).
- Wisconsin: "Green and Sustainable Remediation Manual" (Wisconsin DNR 2012).
- ASTSWMO: "Incorporating Green and Sustainable Remediation at Federal Facilities" (ASTSWMO 2010).
- ITRC: "A Practical GSR Framework for Federal Agencies and States" (ITRC 2011).
- ASTM: "Standard Guide for Integrating Sustainable Objectives into Cleanup" (E2876–13) (ASTM 2013a) and "Standard Guide for Greener Cleanups" (E2893-13) (ASTM 2013b).

Benefits of implementing GSR

GSR can help achieve the protectiveness of the cleanup remedy with a smaller environmental footprint, which has the potential to reduce costs while engaging communities in decision making. Because GSR includes consideration of resource preservation, it also has the potential to improve economic outcomes by increasing the economic value of a site (e.g., turning a brownfield into a green field and facilitating site reuse). Although not necessarily at every site, GSR implementation can achieve the following goals:

- Reduce energy consumption,
- Contribute to meeting greenhouse gas reduction goals,
- Reduce toxic air emissions,
- Reduce waste generation,
- Conserve water and natural resources,
- Reduce ecological impact,
- Reflect good environmental stewardship,
- Help gain public acceptance and build the public's confidence,
- Demonstrate performance in achieving environmental sustainability goals, and
- Reduce costs.

How does one go about implementing GSR at a site?

Much of the ER work done for Federal agencies is performed by contractors; therefore, the first step in implementing GSR is often to include GSR as part of procurement actions to create the contractual mechanisms for vendors to perform GSR during the remediation. Including the work as part of the procurement actions impacts the second step: to determine the level of GSR that will be performed during the remediation process and the method that will be used to incorporate GSR. Section "How does one go about implementing GSR at a site?" A. of this paper addresses the contracting/procurement practices specifically. Section "How does one go about implementing GSR at a site?" B. describes the GSR implementation methods that can be used.

A. Contracting/procurement practices

The initial inclusion of GSR in the procurement process consists of a paragraph or section in the statement of work (SOW) that commits the contractor to using GSR to the maximum extent feasible and practical during all phases of the project. For example, the SOW could require the contractor to prepare a characterization, remediation, monitoring, or waste management plan that includes GSR activities and a follow-up report that documents the GSR activities implemented. In addition, the SOW could require ongoing communication between the contractor and the project team (e.g., inclusion of GSR in the progress reports and monthly meetings to update the project team on the progress of GSR implementation and to allow project team members to provide input during the GSR implementation process). Finally, and potentially most importantly, the contract can include incentives for the contractor to use GSR practices with measurable goals to achieve results and cost benefits. Resources that can be used for crafting contract language and incentives include the following:

- DOE GSR contract and incentive language: DOE memo "Green and Sustainable Remediation Contract Language," distributed to DOE field sites in September 2013 directs field sites to include GSR contract language (DOE 2013).
- US Army GSR study contract language examples can be found at http://www.fedcenter.gov/Documents/index.cfm?id=22322&pge_prg_id=27392 (see Appendix A, Attachment A-2) (USACE 2012b).
- *EPA Greener Remediation Contracting Toolkit* (EPA 2015).
- Air Force Instruction (AFI) 32-7020 (US Air Force 2014).
- Air Force Instruction (AFI) 32-7001 (US Air Force 2011).

B. Implementation approaches

In addition to developing the SOW, there should be an initial consideration of the method(s) used for implementing GSR. The GSR practitioners mentioned above have developed several methods to do this. The EPA advocates the method outlined in the ASTM *Standard Guide for Greener Cleanups* (E 2893-13) (ASTM 2013a) across all of its cleanup programs (*Encouraging Greener Cleanup Practices through Use of ASTM International's Standard Guide for Greener Cleanups* (EPA 2013).

The EPA's recommended method tends to focus on environmental considerations. In contrast, other Federal agencies tend to look at a broader scope of impacts, including social, economic, and environmental considerations (ITRC 2011). For this broader scope of impacts, the methods outlined in either the ASTM *Standard Guide for Integrating Sustainable Objectives into Cleanup* (E2876-13) (ASTM 2013a) or the US Navy and Army agency-specific guidance documents or decision frameworks are available. See, for example, the following documents:

- US Navy: *Guidance on Green Sustainable Remediation*, UG-2093-ENV, Rev. 1 (U.S. Navy 2012).
- USACE: *Decision Framework for Incorporation of Green and Sustainable Practices into Environmental Remediation Projects* (USACE 2010), updated in *Detailed Approach for Performing Green and Sustainable Remediation (GSR) Evaluations in Army Environmental Remediation* (USACE 2012a).

In addition, several states have GSR policies and related GSR methods (see section "Why implement GSR?"). Because the method selected will depend on the customer (DoD agency, EPA, State, or other) and the interests of the stakeholders, including regulators, consultation with the stakeholders and incorporation of their input is encouraged while developing the SOW and during GSR implementation.

Although the terminology and definitions that refer to and define GSR vary and multiple public-sector, private-sector, and public/private entities have crafted methods for evaluating GSR practices, these methods can generally be condensed into two approaches:

- Approach 1 is a *qualitative* way to identify and implement commonsense GSR-related best management practices (BMPs).
- Approach 2 is a *quantitative* assessment and evaluation of a remedy footprint using GSR metrics associated with any given set of BMPs, with a quantitative comparison between and among the remedial options and remedy components as applied to a given remedy or suite of remedies. This approach can be used to measure the footprint reductions gained from the BMPs selected and implemented.

Using one approach does not preclude using the other. For example, ASTM's *Standard Guide for Greener Cleanups* (E 2893-13) provides a framework to identify and incorporate BMPs into site cleanup with the option to quantitatively measure BMPs during the cleanup process (for more insight, see ASTM's 2014 webinar at http://www.clu-in.org/conf/tio/gcsg_042514).

Table 1 summarizes the key features of both approaches. Included in Table 1 are descriptions of each approach and the associated time commitment and cost. Also included is a summary of when to intervene during the cleanup process. The table also provides a sample application of each approach. It is anticipated that the effort needed to research and select appropriate BMPs for a given project (Approach 1) would be minimal and could be accomplished in 2–24 h. In contrast, the effort needed to perform a detailed quantitative footprint evaluation (Approach 2) would likely require a much more significant effort involving from 40 to 100 h of effort. The costs noted are the anticipated costs for either identifying the BMPs or performing the quantitative evaluation, and *not* the costs for implementing the BMPs.

The features of the approaches detailed in Table 1 can be used to help select the approach most appropriate for an individual project, with the selection process interfacing

Table 1 GSR approaches

Parameter	Approach 1 Use of BMPs	Approach 2 Footprint quantitative evaluation
Description	Enhance the remedial project by incorporating sustainable methods—this involves identifying and implementing BMPs	A quantitative decision takes a holistic view of the remedy or a portion of the remedy. Using specially designed GSR software, this approach considers the project design, metric evaluation, and life-cycle cost in selecting the preferred alternative
Time commitment[a]	2–24 h	40–60 h: BMPs with footprint evaluation 80–100 h: BMPs with a full life-cycle assessment (LCA)
Cost[b]	\$1 K–\$5 K	\$10 K–\$15 K
When to intervene	Anytime during the cleanup or closure process	Most often during the remedy design, construction, and remedy operation. Less likely in investigations
Example	This BMP can be as simple as replacing diesel fuel with low-sulfur diesel or biodiesel blend for trucks and heavy equipment	Using quantitative analysis to determine the use of in situ remediation technique instead of pump-and-treat technologies reduces energy requirements and GHGs and enables achievement of cleanup metrics in a shorter amount of time at lower cost

[a] Information from Silver et al. (2015); this does not include GSR implementation and documentation

[b] From the 2012 Army GSR Study (USACE 2012b). These costs will vary depending on the complexity of the site

across the preparation of the SOW and award of contract. One consideration is the overall size of the project and related environmental footprint. For small projects, the decreases in environmental footprint may not merit the level of effort of a quantitative evaluation. For example, the environmental footprint within the investigative phase is usually low relative to the footprints considered in the remedy selection and implementation phases. Therefore, Approach 1 (BMP evaluation only) may be sufficient for a project in the investigative phase. Similarly, for a project of small size or duration in any of the remedial phases, a BMP evaluation without quantification may be the best choice. However, all the methods developed by the agencies, as discussed earlier, recommend a BMP evaluation on all projects because of the relatively low level of effort compared to the potential for footprint and related cost reductions.

The next section discusses the process used in Approach 1 and illustrates this process through a case study.

C. Approach 1: qualitative bmp selection process and case study

Approach 1 can be performed ad hoc by researching and identifying BMPs that are likely to result in minimizing the impacts of remediation activities based on professional judgment and experience. However, a formalized framework and a comprehensive list of BMPs can be used to implement Approach 1 to increase the potential of BMP implementation and related footprint reduction. An example of a more formalized method for Approach 1 is depicted in Fig. 1, which is taken from ASTM's *Standard Guide for Greener Cleanups* (E 2893-13) (ASTM 2013b).

A key step in this sequence (or in an ad hoc selection strategy) is the identification of applicable BMPs. A number of resources provide comprehensive BMP lists; the following are some of these resources

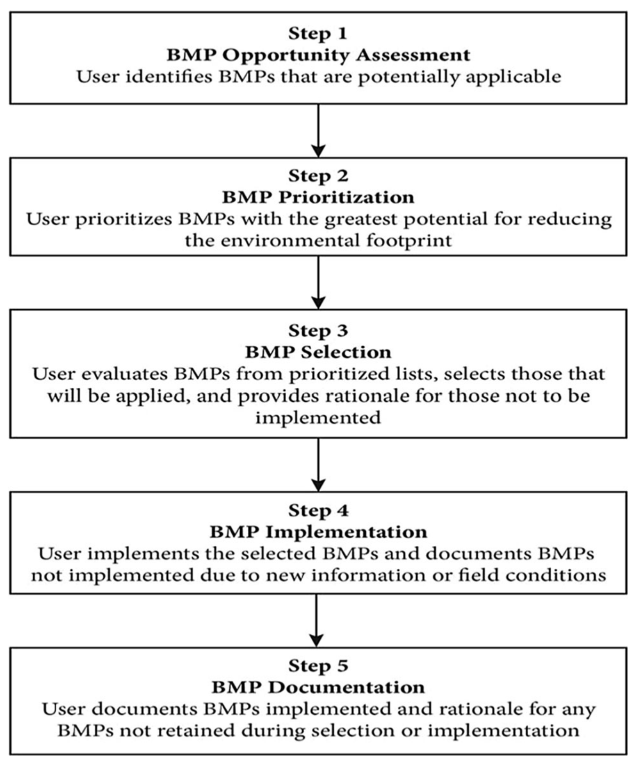

Fig. 1 ASTM flowchart for selecting qualitative BMPs (reprinted, with permission, from E 2893-13, *Standard Guide for Greener Cleanups*, copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428. A copy of the complete standard may be obtained from ASTM: www.astm.org.)

Table 2 Case study illustrating Approach 1 BMP process

Best management practice	Step 1—check if applicable or explain if not	Step 2—priority	Step 3—check if selected or explain if not	Step 4—indicate if BMP was implemented or explain if not
BMP 1—buy carbon offset credits	✔	Low	Agency policy does not allow	N/A[a]
BMP 2—reclaim uncontaminated soil for reuse	Soil remediation was not required	N/A	N/A	N/A
BMP 3—use byproducts/waste/less-refined materials from local sources	✔	Medium	✔	Substitute substrate–substrate unavailable at time of remediation
BMP 4—switch to a less energy-intensive technology for remediation polishing	✔	High	✔	Decision to switch to monitored natural attenuation (MNA) deferred until more monitoring
BMP 5—use regenerated granular activated carbon in carbon beds	No extracted groundwater	N/A	N/A	N/A
BMP 6—use local staff to minimize resource use	✔	Low	✔	Implemented
BMP 7—conduct pilot tracer tests to optimize hydraulic delivery of reagents	✔	High	✔	Implemented

[a] N/A = BMP is not applicable

- EPA Technology-Specific BMPs http://www.cluin.org/greenremediation
- ASTM Standard Guide BMP lists contained in the following:
    - *Integrating Sustainable Objectives into Cleanups* (E2876-13).
    - *Standard Guide for Greener Cleanups* (E2893-13).
    - For a nominal fee, writable versions of the BMP Excel tables from ASTM can be obtained and used in a similar fashion to show the identification, selection, implementation, and documentation process.
    - The BMP Excel table from ASTM lists 160 BMPs.
    - PDF-writable technical summary.

- DoD agency BMP lists:
    - USACE, *Evaluation of Considerations and Incorporation of Green and Sustainable Remediation Practices in Army Environmental Remediation*, which includes BMPs and checklists (see http://www.fedcenter.gov/Documents/index.cfm?id=22322&pge_prg_id=27392).
    - *Navy Phase-Specific Footprint Reduction Methods Checklists* in the Navy GSR Guidance, found at www.navfac.navy.mil/go/erb.

To illustrate the Approach 1 process, we provide a BMP case study of a Federal agency site with groundwater contaminated with chlorinated solvents. The record of decision specifies the use of an in situ groundwater injection technology with monitored natural attenuation for polishing after injections have sufficiently lowered the chlorinated solvent concentrations. Although soil at the site is contaminated, the contamination is below screening levels and does not require remediation. Table 2 demonstrates the results of the ASTM process described in Fig. 1.

As depicted in Table 2, a suite of BMPs was selected for evaluation. For example, one could select from the ASTM guide all of those BMPs potentially applicable for the remediation of groundwater, soil, staffing selection, purchasing energy offset credits, and so forth. There are more than 160 ASTM BMPs, which focus on various potential components of cleanup projects including buildings, vehicles, wastewater, air emissions, energy, and other components. Not all BMPs will be applicable to each project. As suggested by the ASTM guide, in Step 1 the practitioner then determines which BMPs are applicable or documents the rationale for not selecting a BMP. For example, although BMP 5 is applicable for the treatment of groundwater using active treatment technologies (e.g., pump and treat), the BMP is not applicable because groundwater is being treated in situ.

In Step 2 the practitioner subjectively ranks BMPs as low, medium, or high in order to prioritize which BMPs will be implemented. As noted in Table 2, BMPs 4 and 7 have been ranked high because greater impacts and related largest potentials for footprint reduction appear to be associated with those remediation activities.

Subsequently in Step 3, the practitioner would select those BMPs that are going to be implemented or otherwise

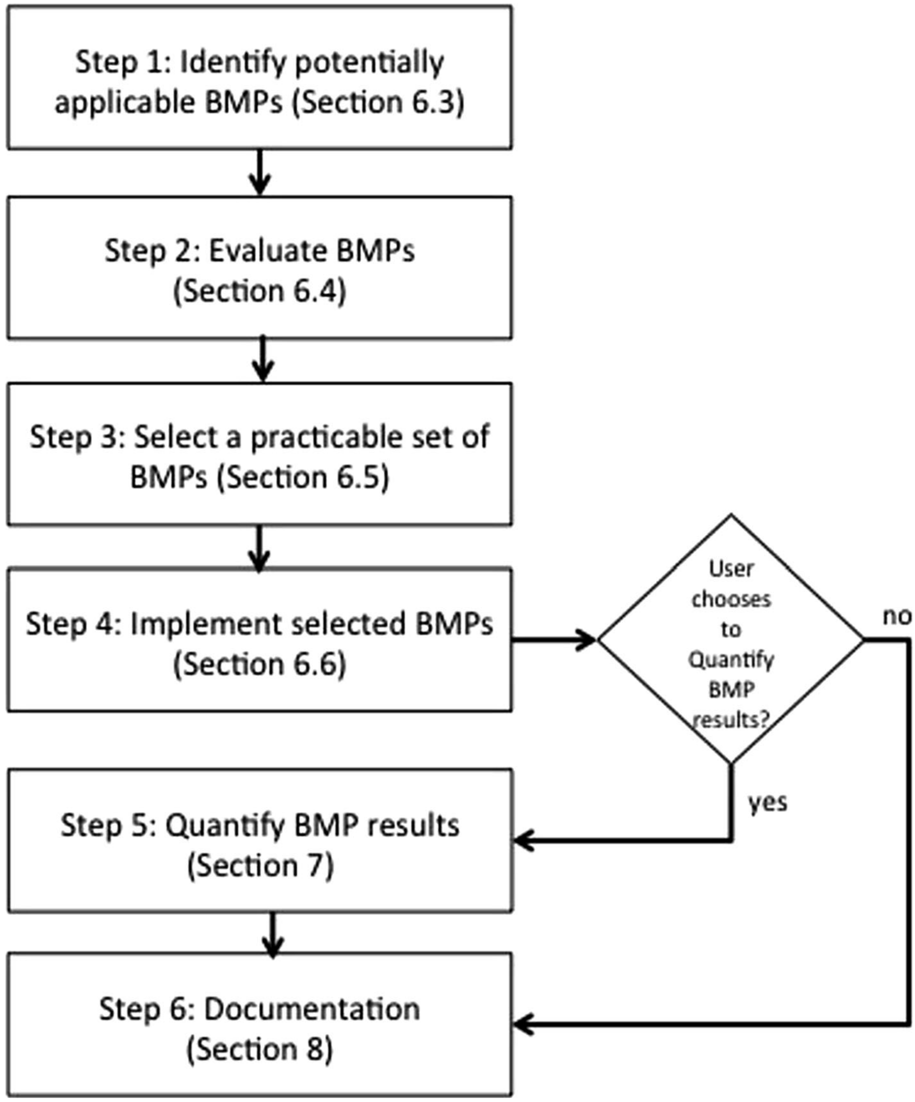

Fig. 2 ASTM flowchart for evaluating best management practices (reprinted, with permission, from E 2876-13, *Standard Guide for Integrating Sustainable Objectives into Cleanup*, copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428. A copy of the complete standard may be obtained from ASTM, www.astm.org.)

explain why the BMP was not selected. For example, BMP 1 was not selected because, in this case, the Federal agency does not allow the purchase of carbon offset credits. Finally, in Step 4 the whole process is documented. Table 2 then both represents Approach 1 and documents the results of the approach's BMP qualitative selection process.

D. Approach 2: quantitative selection process and case study

Approach 2 flows from Approach 1 and includes the additional step of a quantitative evaluation of the remedial options represented by the BMPs. Both ASTM and ITRC have created a comprehensive framework that leads the practitioner through a quantitative evaluation of GSR metrics. The ITRC framework consists of the following six steps:

- Step 1—Define study goals and scope.
- Step 2—Define the functional unit (what, how much, how well, and for how long).
- Step 3—Establish system boundaries.
- Step 4—Establish project metrics.
- Step 5—Compile inputs and outputs and assess impacts.
- Step 6—Analyze sensitivity, uncertainty and interpret impact assessment results.

The ASTM's *Standard Guide for Integrating Sustainable Objectives into Cleanup* (E2876-13) contains another representation of the overall Approach 2 process. The decision flowchart from ASTM E2876-13 is included in Fig. 2. Here the BMP evaluation in Approach 1 is followed by quantification of the GSR options identified in the BMP evaluation.

The first step in Approach 2 is to perform the process in Approach 1, which is to identify, select, and implement BMPs. Once the BMPs are implemented, the footprint reduction from the BMP implementation is quantified.

A number of evaluation tools are available to quantify footprint reductions. Selection of a tool will depend on a variety of considerations, including cost, ease of use, input parameters required, and tool output. There are several public-domain sustainable evaluation tools available at no cost. These tools, and the relevant websites where more information about these tools can be obtained, are as follows:

- SiteWise™: http://www.sustainableremediation.org/tools.
- Spreadsheet for Environmental Footprint Analysis (SEFA) (developed by EPA): http://www.sustainableremediation.org/tools.

In addition, private-domain sustainable evaluation tools are available that can be obtained for a fee. Two of the commonly used fee-based tools include:

- SimaPro Life-Cycle Analysis tools.
- Envision tools (designed and endorsed by American Society of Civil Engineers and Harvard University).

These fee-based tools require a license for operation, maintenance, and updating. In addition, as illustrated in Table 1, working with the LCA tools requires a higher level of effort to perform the quantification than do the public-domain sustainable evaluation SiteWise™ and SEFA.

Approach 2 using the ASTM E2876-13 process is illustrated by a case study where the resource savings of implemented BMPs were quantified using the GSR evaluation tool SiteWise™ (Version 2). The cleanup site is referred to as "Site 5." This 10-acre parcel was used for the disposal of waste and debris from 1957 until 1965. A GSR evaluation was used to compare the environmental footprint for a CERCLA Interim Removal Action (IRA) with and without GSR BMPs. The quantitative assessment was based on the following metrics:

- Greenhouse gas emissions (GHGs),
- Energy usage,
- Electricity usage from renewable and nonrenewable sources,
- Criteria air pollutants (including sulfur oxides [SO_x], oxides of nitrogen [NO_x], and particulate matter [PM_{10}]),
- Water usage,
- Resource consumption, and
- Injury or fatality accident risk (Bhargava and Sirabian 2013).

The IRA consisted of excavating surface debris, subsurface waste, and soil; mechanically screening and separating waste streams; and confirmation inspection, sampling, and site grading. A number of BMPs were identified for the IRA, which included use of onsite soil (rather than imported soil) in grading, recycling of scrap metal, and recycling of concrete. Figures 3 and 4 show the comparison of the metrics representing environmental impact for Alternative 1 (BMPs included) and Alternative 2 (BMPs not included). Figures 3, 4, 5, and 6 depict output plots for GHG emissions, total energy used, nonhazardous waste landfill space, and NO_x emissions (the impact of

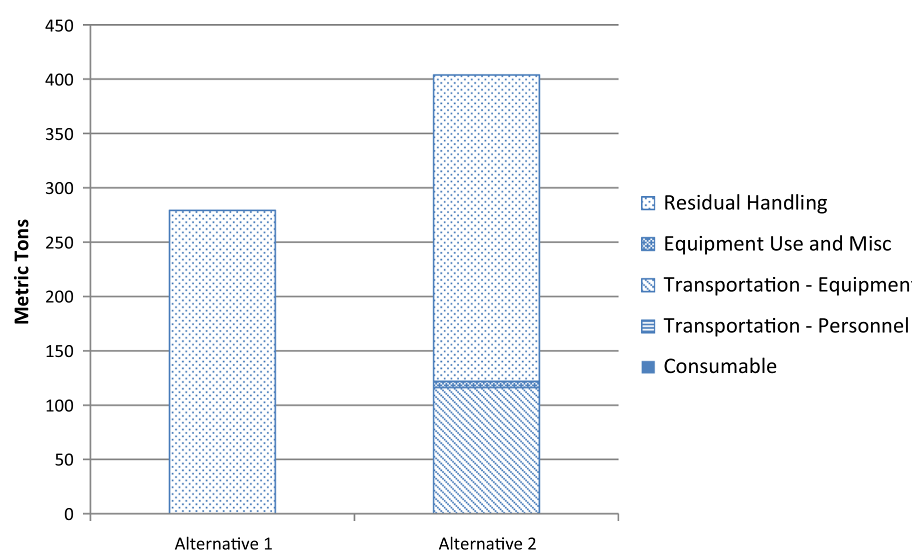

Fig. 3 GHG emissions for removal action with (Alternative 1) and without (Alternative 2) BMPs

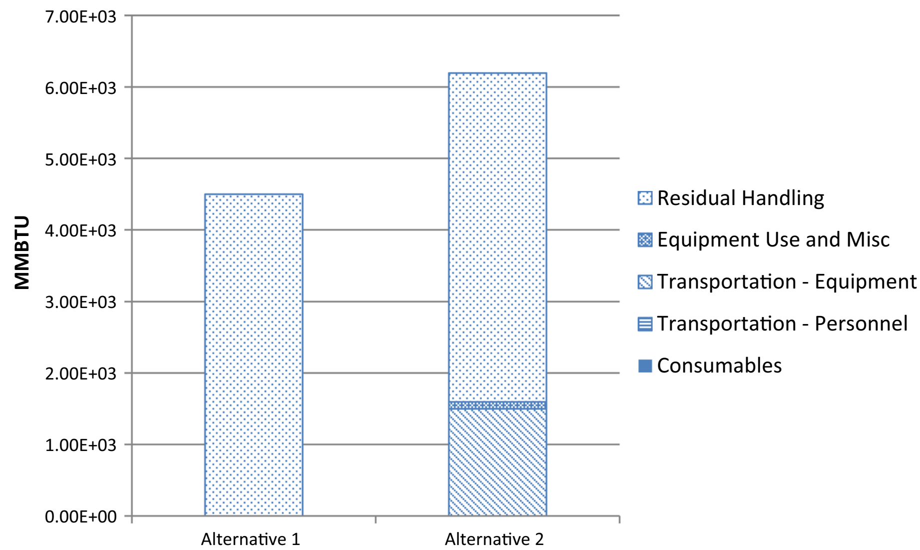

Fig. 4 Total energy used for removal action with (Alternative 1) and without (Alternative 2) BMPs

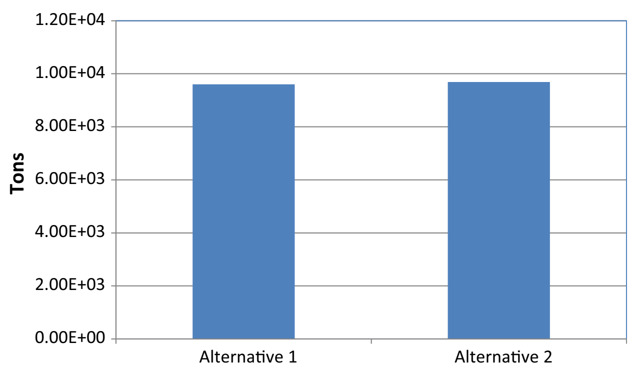

Fig. 5 Nonhazardous landfill space for removal action with (Alternative 1) and without (Alternative 2) BMPs

consumables are measureable but negligible). Figures 6, 7, 8, 9, and 10 depict output plots for SO_x emissions, PM_{10} emissions, accident risk of fatality, and accident risk of injury.

As depicted in Figs. 3, 4, 5, 6, 7, 8, 9, and 10, all environmental metrics are lower for Alternative 1 than for Alternative 2. Table 3 shows the quantified footprint reductions for the selected metrics of GHGs, energy consumption, landfill space, and clean soil resources. The cost impacts resulting from implementation and quantification of the BMPs, all of which contributed to cost avoidance, are shown in Table 4. Finally, the project stakeholders were involved in and agreed with the remediation incorporating the BMPs. Therefore, this GSR case study inclu-

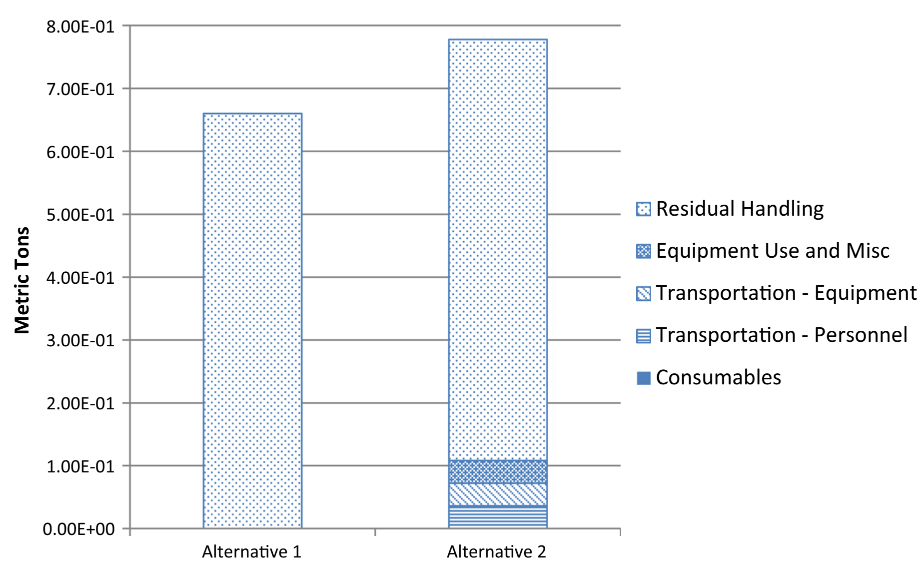

Fig. 6 NO_x emissions for removal action with (Alternative 1) and without (Alternative 2) BMPs

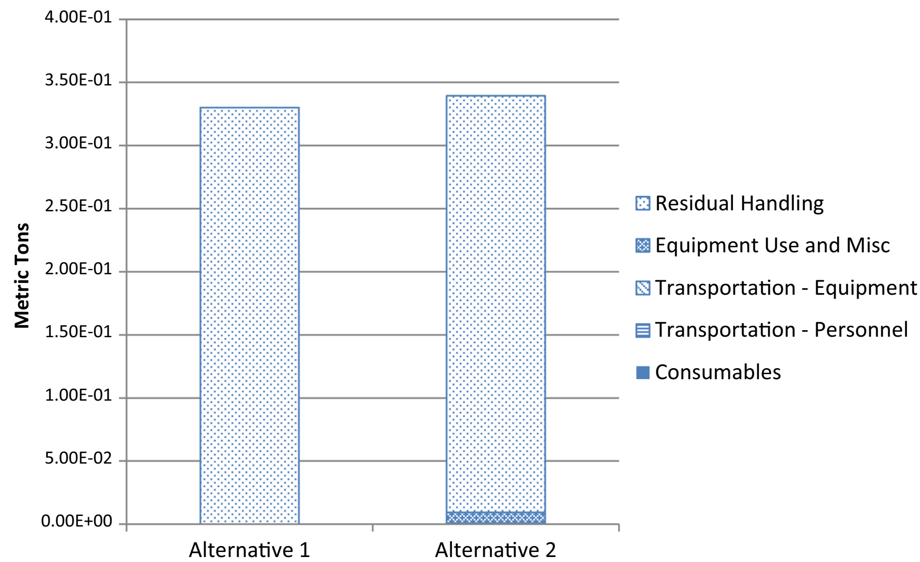

Fig. 7 SO_x emissions for removal action with (Alternative 1) and without (Alternative 2) BMPs

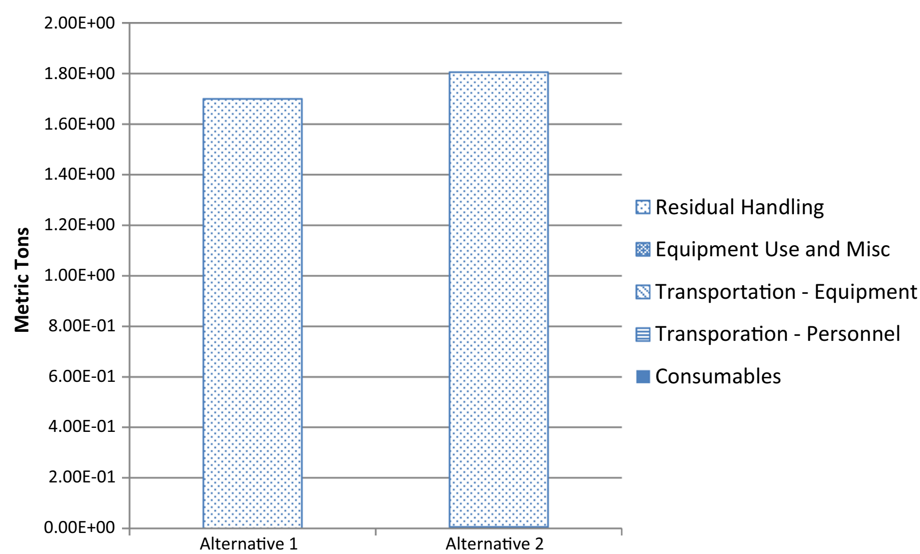

Fig. 8 PM_{10} emissions for removal action with (Alternative 1) and without (Alternative 2) BMPs

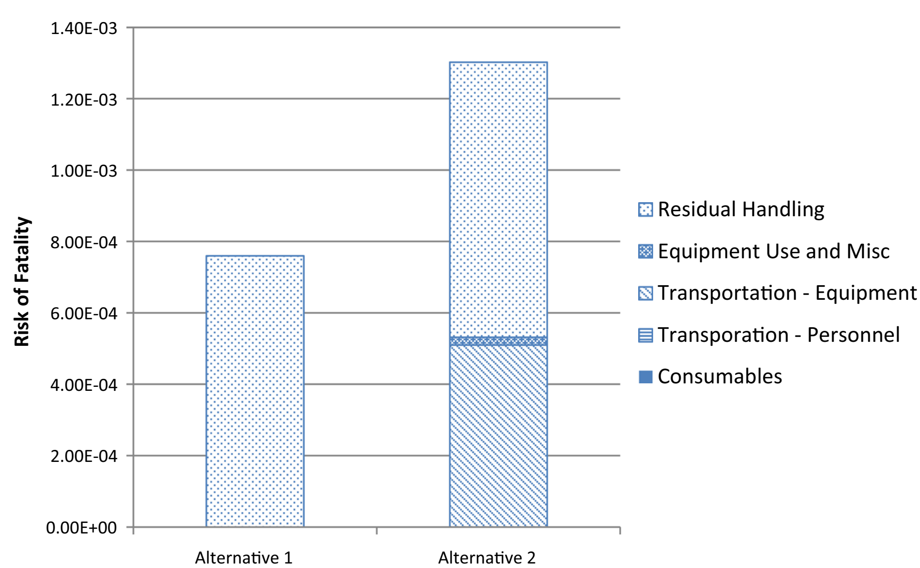

Fig. 9 Accident risk—fatality for removal action with (Alternative 1) and without (Alternative 2) BMPs

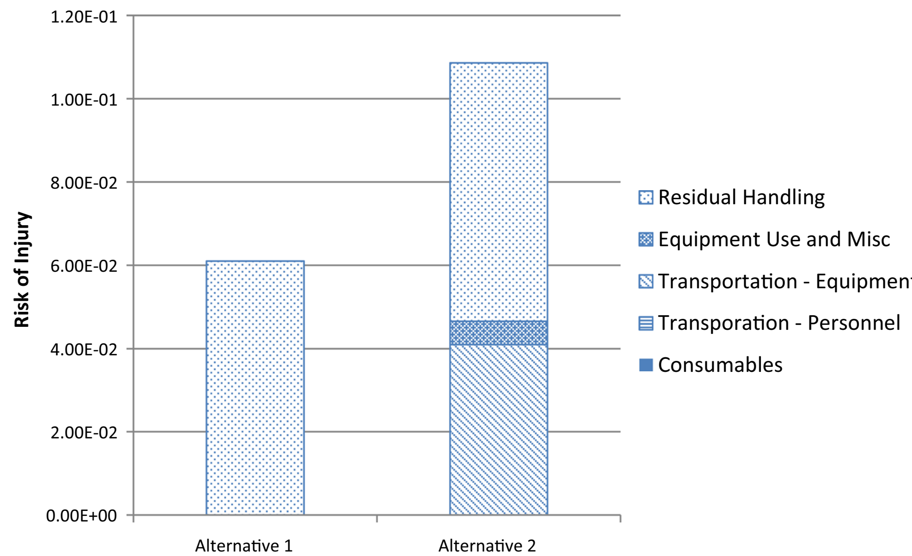

Fig. 10 Accident risk—injury for removal action with (Alternative 1) and without (Alternative 2) BMPs

Table 3 Metric evaluated and impact of footprint reduction methods

Metric evaluated	Combined impact of footprint reduction methods
Greenhouse gas emissions	224.1 metric tons
Energy consumption	1650 MMBTU
Landfill space	94 tons of waste (equivalent to waste generated by 100 people in 1 year)
Clean soil resource	9600 tons

Table 4 Footprint reduction method and associated cost avoidance

Footprint reduction method	Associated cost avoidance
8000 cubic yards of on-site soil (vs. imported) used for grading	$300,000
Recycling of scrap metal	$11,826 recycling credit
	$3200 landfill disposal cost
Recycling of 38.66 tons of concrete	$1400 landfill disposal cost
Total monetary savings associated with GSR practices	$316,400

ded the triple bottom-line environmental, economic, and social considerations, all of which were favorable with respect to the outcome of the IRA incorporating the BMPs.

Summary

This paper has covered the definition of GSR as well as the development and practice of GSR, with specific emphasis on GSR in Federal agencies. The Federal agency and State drivers for GSR consideration and implementation—policy, guidance, and expected benefits—have been described. Metrics that are used to represent and measure the environmental, social, and economic aspects of environmental remediation have been defined and explained. Two approaches to reducing project environmental footprints have been described: a qualitative approach using GSR BMPs, and a quantitative approach that uses GSR metrics to quantify environmental footprint reductions. Case studies have illustrated both approaches. The case studies have also illustrated the potential benefits in terms of reduced energy requirements and resource use, reduced emissions, cost avoidance, and community concurrence that can be obtained through application of GSR in environmental remediation. Additional examples of integrating GSR-related practices and principles into remediation projects can be found at both Federal and private-sector facilities. In general, remediation activities typically result in near-term improved environmental and societal conditions. Nonetheless, it is important to recognize that there can also be both near-term and long-term environmental impacts associated with the remediation activities. One way to assess the full life cycle of the impact of environmental remediation activities is by incorporating GSR practices and principles into project planning, management, and decision making.

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