Integrating Green and Sustainable Remediation Metrics within the CERCLA Process during the Feasibility Study

The purpose of this guidance is to serve as a companion to the *Department of the Navy Guidance on Green and Sustainable Remediation*[1] and provide supplemental information with regard to integrating green and sustainable remediation (GSR) during the feasibility study (FS). Additional details regarding GSR concepts and implementation of GSR throughout the remedial action process can be found in the Navy GSR Guidance.[1]

The Department of the Navy (DON) is implementing GSR as part of the existing optimization program, and has included GSR in the Policy for Optimizing Remedial and Removal Actions at All DON Environmental Restoration Program Sites[2] that requires optimization and GSR evaluations at the remedy selection, design, and remedial action operation (RA-O) phases. In accordance with this policy, the *Guidance on Green and Sustainable Remediation*[1] emphasizes and promotes consideration of sustainability throughout the entire remedial process, and specifically allows for integration of GSR metrics within the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) nine criteria during the remedy evaluation and selection phase.

Remedy selection provides the greatest opportunity to lower the overall remedy footprint. While it is possible to minimize the footprint during later stages of the project, the greatest benefit can be achieved by selecting the remedy that generates the smallest footprint at the start. Selecting the most sustainable remedial option among the alternatives identified in an FS under CERCLA or Resource Conservation and Recovery Act (RCRA) corrective measure study establishes a lower remedy footprint. Most importantly, a selected remedial alternative must meet all of the applicable CERCLA threshold criteria or RCRA performance standards, including overall protectiveness of human health and the environment.

This paper focuses on Navy GSR metrics and their incorporation into the nine criteria for alternatives analysis during remedy evaluation as defined by the National Contingency Plan (40CFR300.430(e)(9)). The last section of this paper is an example of GSR being incorporated into remedy selection at Site 45, Marine Corps Recruitment Depot (MCRD), Parris Island. Background and additional information on this subject is available in the Navy Optimization Policy[2] and GSR Guidance.[1]

Navy GSR Metrics

The list of Navy GSR metrics is based on the core elements described in the Department of Defense's (DoD's) GSR memorandum,[3] Executive Orders, and by the U.S. Environmental Protection Agency (EPA) in its Green Primer.[4] The Navy metrics are listed below, and the list

[1] Department of Navy (DON). 2012. *Guidance on Green and Sustainable Remediation*. April.
[2] Department of Navy (DON). 2012. *Policy for Optimizing Remedial and Removal Actions at All DON Environmental Restoration Sites*. April 2.
[3] Department of Defense (DoD). 2009. *Consideration of GSR practices in the Defense Environmental Restoration Program*. August.
[4] United States Environmental Protection Agency (EPA). 2008. *Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites*. EPA 542-R-08-002. April.

can be expanded or reduced based on specific information regarding the site, technology, or stakeholders. Details on each of these metrics are available in the Navy GSR Guidance.[1]

- Energy Consumption
- Greenhouse Gas (GHG) Emissions
- Criteria Pollutant Emissions
- Water Impacts
- Ecological Impacts
- Resource Consumption and Waste Generation
- Worker Safety/Accident Risk
- Community Impacts

As discussed in the Navy GSR Guidance, many of the metrics listed above can be evaluated with publically available tools, including SiteWise™ and SRT™. These tools can be used to evaluate the GSR metrics in both a quantitative and qualitative manner. SiteWise™ is the Navy's preferred tool; its use is required during the remedy evaluation and selection phase of the remedial action.[5] For additional information refer to the Navy GSR Guidance[1] and SiteWise™ Version 2 User Guide.[6]

CERCLA Remedy Evaluation Criteria
CERCLA establishes nine remedial alternative evaluation criteria to be used in the detailed alternative analysis conducted as part of the FS. The detailed analysis consists of an assessment of individual alternatives against each of the nine evaluation criteria and a comparative analysis that focuses upon the relative performance of each alternative against those criteria. The nine criteria are categorized into three groups — threshold, balancing, and modifying criteria — as shown in Table 1.

GSR within the CERCLA Framework
According to DON guidance GSR[1] metrics should be considered as part of the discussion and evaluation of the CERCLA criteria during the FS phase. The DON Optimization Policy[2] requires the use of SiteWise™ for conducting the analysis of GSR metrics for this purpose. Assessment of remedial alternatives with respect to sustainability should not be considered a unique criterion within the FS; rather the GSR metrics fit easily within the nine existing CERCLA criteria. Considering GSR metrics associated with site remediation in the purview of the existing regulatory framework provides the Navy with the ability to choose more sustainable options overall, and not just green options. Table 2 demonstrates how the metrics included in a GSR assessment can be mapped into the existing CERCLA evaluation criteria.

---

[5] *The Policy for Optimizing Remedial and Removal Actions at all Department of Navy (DON) Environmental Restoration Program Sites* (2 April 2012) mandates that SiteWise™ be used for all GSR evaluations during the remedy evaluation and selection phase of work.
[6] NAVFAC. 2011. *SiteWise™ Version 2 User Guide*. UG-2092-ENV. June.

Table 1. Summary of CERCLA Remedy Evaluation Criteria

Category	Criteria	Descriptions	GSR Considerations
Threshold Criteria	Overall protection of human health and the environment	Addresses whether or not a specific alternative will achieve adequate protection and describes how the contamination at the site will be eliminated, reduced, or controlled through treatment, engineering, and/or institutional controls.	In accordance with CERCLA requirements, threshold criteria must be met in order for a remediation alternative to be eligible for selection. GSR assessment should only be evaluated within the balancing and modifying criteria for those alternatives which meet both threshold criteria.
	Compliance with applicable or relevant and appropriate requirements (ARARs)	Addresses whether or not a remedial alternative meets all related federal and state environmental statutes and regulations. An alternative must comply with ARARs, or be covered by a waiver, to be acceptable.	In accordance with CERCLA requirements, threshold criteria must be met in order for a remediation alternative to be eligible for selection. GSR assessment should only be evaluated within the balancing and modifying criteria for those alternatives which meet both threshold criteria.
Balancing Criteria	Long-term effectiveness and permanence	Addresses the ability of a remedial alternative to maintain reliable protection of human health and the environment over time. It also considers the risk posed by treatment residuals and untreated materials.	Sustainability impacts related to long-term effectiveness include adverse impacts from remedial actions or residuals from remedial activities that require a long period of time to attenuate. GSR metrics which may be evaluated under this criterion include GHG and criteria pollutant emissions, as well as water and ecological impacts, and resource consumption.
	Reduction in toxicity, mobility, or volume through treatment	Addresses the preference for remedial actions that use treatment technologies that permanently and significantly reduce toxicity, mobility, and/or volume of contaminants.	GSR metrics are not tied to the reduction in toxicity, mobility, or volume because this criterion evaluates the ability of the treatment alternative to permanently reduce toxicity, mobility, or volume of the hazardous substances.
	Short-term effectiveness	Addresses the period of time needed to implement the remedy and any adverse impacts that workers, the community and the environment may be subjected to during construction and operation of the remedy.	All of the GSR metrics can be considered when evaluating short-term effectiveness. This includes environmental impacts from remedy implementation associated with air emissions and resource consumption, as well as any impacts to ecological resources, worker safety and the surrounding community.

Table 1. Summary of CERCLA Remedy Evaluation Criteria (Continued)

Category	Criteria	Descriptions	GSR Considerations
	Implementability	Addresses the technical and administrative feasibility of implementing a remedial alternative from design through construction and operation. Factors such as availability of services, materials, and operational reliability are considered.	GSR metrics are not tied to the implementability of a remedial alternative, as this criterion evaluates the technical and administrative feasibility of implementing an alternative and the availability of various services and materials required during its implementation.
	Cost	Addresses the total cost of a remedial alternative, including consideration of the capital costs, annual operation and maintenance costs, and net present value of these costs.	Several GSR metrics can be considered under the cost criterion, including energy consumption, water impacts/use, resource consumption, and worker safety. Each can affect the overall cost of the remedy depending on the amount of energy consumption, water use, resource consumption, mitigation needed to address safety concerns, and potential for worker accidents and lost time worked. Developing appropriate optimization strategies helps to not only reduce these costs associated with the remedy, but also improve the sustainability of the remedial action.
Modifying Criteria	State acceptance	Addresses the acceptability of a remedial alternative to state regulatory agencies.	All of the GSR metrics can be evaluated as part of the state acceptance criterion, as all of these sustainability issues are of concern to the regulatory agencies which oversee the remediation projects in order to ensure overall protection of human health and the environment.
	Community acceptance	Addresses the acceptability of a remedial alternative to the public.	All of the GSR metrics can be evaluated as part of the community acceptance criterion, as all of these sustainability issues ultimately impact the surrounding community members.

4

Table 2. Mapping GSR Metrics with CERCLA Remedy Evaluation Criteria

SUSTAINABILITY METRICS	BALANCING CRITERIA					MODIFYING CRITERIA	
	LONG-TERM EFFECTIVENESS	REDUCTION IN TOXICITY, MOBILITY, OR VOLUME	SHORT-TERM EFFECTIVENESS	IMPLEMENTABILITY	COST	STATE ACCEPTANCE	COMMUNITY ACCEPTANCE
Energy Consumption			X		X	X	X
GHG Emissions	X		X			X	X
Criteria Pollutant Emissions	X		X			X	X
Water Impacts/Use	X		X		X	X	X
Ecological Impacts	X		X			X	X
Resource Consumption	X		X		X	X	X
Worker Safety			X		X	X	X
Community Impacts			X			X	X

As indicated in the DON Guidance, EPA's *Principles for Greener Cleanups*[7] states that greener cleanup should be considered during any phase of work, including site investigations, evaluation of cleanup options, and optimization of the design, implementation and operation of new or existing cleanups. The EPA principles further state that environmental footprint assessments should include, at a minimum, energy use, air emissions, water impacts, material use, and land and ecosystem protection. Each of these elements is covered by the list of Navy GSR metrics discussed above.

At this point in time, there is no EPA requirement for performing sustainability evaluations during the FS, or any other phase of the cleanup. However, EPA has developed a methodology[8] for conducting this evaluation. The goal of the EPA methodology is the same as that of SiteWise™, to quantify environmental impacts due to implementation of remedial activities. Some metrics evaluated by the EPA methodology are different compared to those identified by Navy, but the metrics in both the EPA methodology and the Navy GSR Guidance comprise the principle elements recommended by EPA in the *Principles for Greener Cleanups*.[7]

---

[7] United States Environmental Protection Agency (EPA). 2009. *Principles for Greener Cleanups*. Office of Solid Waste and Emergency Response. 27 August 2009.
[8] United States Environmental Protection Agency (EPA). 2012. *Methodology for Understanding and Reducing a Project's Environmental Footprint*. EPA 542-R-12-002. February.

The draft EPA guidance also notes that results of a footprint analysis during the development of remedy alternatives may be subject to substantial uncertainty due to limited specific remedy information available and the absence of actual data or engineering design estimates. This is an important note to consider when conducting the GSR evaluation during the FS. As appropriate, assumptions related to GSR input values should be consistent between each of the alternatives being evaluated. For example, the volume of media to be remediated (i.e., each target treatment zone) should be consistent among all alternatives, and distances and frequency of travel should be consistent among those alternatives, which include personnel travel or material transportation/disposal. This will help to ensure a fair comparison of GSR metrics between remedial options to address each target treatment zone at the FS phase. However, there are instances when different land use controls (LUCs) are being evaluated, which can impact the target treatment zones. In those cases, the remedies with LUCs may have a lower footprint for many metrics than those remedies with unrestricted use. This can be accounted for in the analysis by including ecological impacts and community impacts as metrics.

Short- and long-term effectiveness, as well as cost and state and community acceptance, is the criteria under which most of the GSR metrics can be incorporated during the FS remedy evaluation. A discussion of how GSR metrics can be incorporated into each of these CERCLA criteria is provided below. Although remedial alternatives developed with GSR in mind may vary in their implementability, the GSR metrics themselves do not contribute to understanding the implementability of a remedial alternative, as this criterion evaluates the technical and administrative feasibility of implementing an alternative and the availability of various services and materials required during its implementation. GSR metrics also do no impact the reduction in toxicity, mobility, or volume because this criterion evaluates the ability of the treatment alternative to permanently reduce toxicity, mobility, or volume of the hazardous substances.

Note that the GSR assessment should only be evaluated with the CERCLA criteria for alternatives which meet both threshold criteria: overall protection of human health and the environment, as well as compliance with all ARARs. This is in accordance with CERCLA requirements under 40 CFR 300.430, which state that the threshold requirements must be met in order for a remediation alternative to be eligible for selection.

Short-Term Effectiveness

The short-term effectiveness criterion is based on an evaluation of impacts on the workers, community, and the environment due to implementation and operation of a remedy. All of the metrics developed by the Navy such as energy consumption, criteria pollutant emissions, water impacts/use, ecological impacts, resource consumption, worker safety, and community impacts can potentially influence the relative ranking of an alternative’s short-term effectiveness. For example, energy, water and resource consumption would result in short-term impacts through the consumption of these resources which would not otherwise be used if not for implementation of the remedy. In addition, the emission of air pollutants from the use of heavy equipment or generators can also have a negative short-term impact during remedy implementation. Short-term ecological impacts may result from remedy implementation if sensitive ecological habitats or species are negatively affected by the remedy implementation, and worker safety and community impacts may be negatively affected through hazards associated with implementation of the remedy or increased traffic, odors, or noise from construction and operation activities.

Long-Term Effectiveness

Long-term effectiveness addresses the ability of a remedial alternative to maintain reliable protection of human health and the environment over time, and considers the risk posed by treatment residuals and untreated materials. GHG and criteria pollutant emissions can also be mapped onto the long-term effectiveness because these residuals of remedial activity do not attenuate in the atmosphere for a long period of time. Similarly, water and ecological impacts, as well as resource consumption, can also be mapped to long-term effectiveness due to the long period of attenuation that may be required to reverse any adverse impacts and the finite amount of resources that are available.

Cost

The cost criterion addresses the total cost of a remedial alternative, including consideration of the capital costs, annual operation and maintenance costs, and net present value of these costs. Some of the metrics such as energy consumption, water impacts/use, resource consumption, and worker safety can affect the overall cost of the remedy. As energy consumption, water use, and resource consumption increase, the remedial alternative costs increase as well. Alternatives with greater worker safety concerns will have greater costs associated with mitigating those safety concerns and increased risk of accidents and lost time worked. Developing appropriate performance objectives and exit strategies can help to improve sustainability of the remedial alternatives and reduce overall life cycle costs. Employing these strategies to optimize a remedy will reduce energy and resource consumption over the life of the remedy, increasing sustainability and having the potential to reduce the remedy costs. Similarly, reducing water usage and impacts will also increase sustainability and reduce remedy implementation costs. For worker safety, engineering measures are often incorporated into remedy implementation for protection of workers against hazards encountered during remedy construction and operation activities. These measures may increase the cost of a remedy, but also improve the sustainability by increasing worker safety.

State and Community Acceptance

The state and community acceptance criteria address the acceptability of a remedial alternative to the state regulatory agencies and the public. All of the GSR metrics can be mapped to the balancing criteria of state and community acceptance, as all of the GSR metrics resulting from a remedial action ultimately impact the surrounding community members, and are also of concern to the regulatory agencies who oversee the remediation projects to ensure overall protection of human health and the environment. For example, GSR metrics related to increased truck traffic or local air quality impacts from remediation activities may be of concern to the community. The state and community acceptance criteria are also relevant to the discussion of other less tangible impacts from remedial alternatives, such as lost resources value. Restricting future land use to commercial/industrial or groundwater extraction in an area where water resources are scarce may result in lost resources associated with those remedial alternatives.

Applying GSR Metrics to Optimize Alternatives

When evaluating optimization or footprint reduction strategies for a remedy, the tradeoff of various GSR metrics should be considered. A potential modification to an existing remedy may increase the values for some metrics and decrease the values for others. For example a bioremediation remedy using water from the public supply results in significant use of public water resources, but relatively minimal criteria air emissions because a generator or other equipment is not needed to provided power for extracting groundwater.[6] Potentially modifying the remedy to use extracted groundwater will decrease or eliminate the use of public water resources, but may increase the criteria air emissions from a generator that provide the power for groundwater extraction. Different site teams and different stakeholders may favor one option over another depending on their prioritization of green remediation parameters, cost, and other factors.

Example of GSR Incorporation within the FS Phase

Reporting of GSR evaluation results should be completed in two stages during the FS. First, an appendix to the FS shall be prepared to present the results and discussion of GSR with respect to each alternative. Once this is done, the results of the GSR evaluation should be incorporated into the discussion of the nine CERCLA criteria during the detailed and comparative analysis preformed as part of the FS.

A GSR evaluation was conducted to evaluate implementation of soil and groundwater remedial alternatives at Site 45, MCRD, Parris Island.[1] Site 45 is a former dry cleaning facility where polynuclear aromatic hydrocarbons (PAHs), arsenic and chlorinated solvents were identified in soil, and chlorinated solvents were also identified in groundwater.

The area of contaminated soil requiring treatment was estimated as the area with contaminants of concern (COCs) greater than cleanup levels in the unsaturated zone above the water table (approximately 4-ft deep). Based on soil concentrations, excavated soil would be considered hazardous waste and require treatment offsite prior to disposal in order to meet land disposal restrictions. The area of groundwater contamination requiring treatment was estimated as the area with tetrachloroethene and trichloroethene above maximum contaminant levels in the shallow aquifer (approximately 4 to 18 ft below ground surface [bgs]). The conceptual design for groundwater remediation identified the high concentration areas (COCs greater than 1,000 μg/L) for active treatment, with monitored natural attenuation (MNA) selected for treatment of the lesser contaminated groundwater areas. The alternatives evaluated included the following:

- **Enhanced Bioremediation:** in-situ enhanced bioremediation (for high concentration groundwater areas), shallow excavation with off-site disposal (for shallow soil), and MNA with LUCs (for lesser contaminated groundwater areas);
- **In-situ Chemical Oxidation (ISCO):** ISCO (for high concentration groundwater areas), shallow excavation with off-site disposal (for shallow soil), and MNA with LUCs (for lesser contaminated groundwater areas);
- **Emulsified Zero Valent Iron (ZVI):** in-situ chemical reduction (EZVI) (for high concentration groundwater areas), shallow excavation with off-site disposal (for shallow soil), and MNA with LUCs (for lesser contaminated groundwater areas);
- **Electrical Resistive Heating (ERH):** ERH to volatilize COCs and capture the volatilized COCs using soil vapor extraction and vapor-phase activated carbon (for high concentration groundwater areas and shallow soil), and MNA with LUCs (for lesser contaminated groundwater areas); and

- **Excavation:** full excavation with off-site disposal (for shallow soil and entire high concentration groundwater area, down to 20 ft bgs), and MNA with LUCs.

Figure 1 and Table 3 summarize results from the GSR evaluation, and Table 4 is an example of how the GSR evaluation can be incorporated as part of the nine CERCLA criteria discussion within the FS report (bold-italicized text is used to show the GSR-related discussion).

Ecological impacts were not quantified in Table 3 for this evaluation because SiteWise^{TM} and other GSR tools do not currently quantify these impacts. However, a qualitative ecological impact evaluation can be completed, which includes assessing the changes to the land use and the resulting alteration to the ecosystem's goods and services. When evaluating potential ecological impacts, ecosystem changes derived from each potential remedial technology should consider how the land use categories will be impacted at the site for the short and long term. For example, short-term infrastructure (with excavation and ERH) will degrade current ecological goods and services production, but the long-term impact of an aggressive remedial technology may improve the ecological goods and services production. Therefore, consideration of each goods and services category for each land use type should be discussed. In the case of Site 45 at MCRD Parris Island, the site has one land use category (developed area covered with grass) and contributes to several goods and services categories (flood protection, useable water, and climate) through the soil stability offered by the vegetation. Short-term impacts could include increased urban run-off from the site which impacts surface water contamination and management. Depending on the long-term plans for the site, future developments could provide cultural aspects for the community such as a park. The advantages and limitations to the short-term impacts and the timeframe for realizing the long-term benefits would need to be weighed by the stakeholders. The evaluation could be included in the overall GSR analysis.

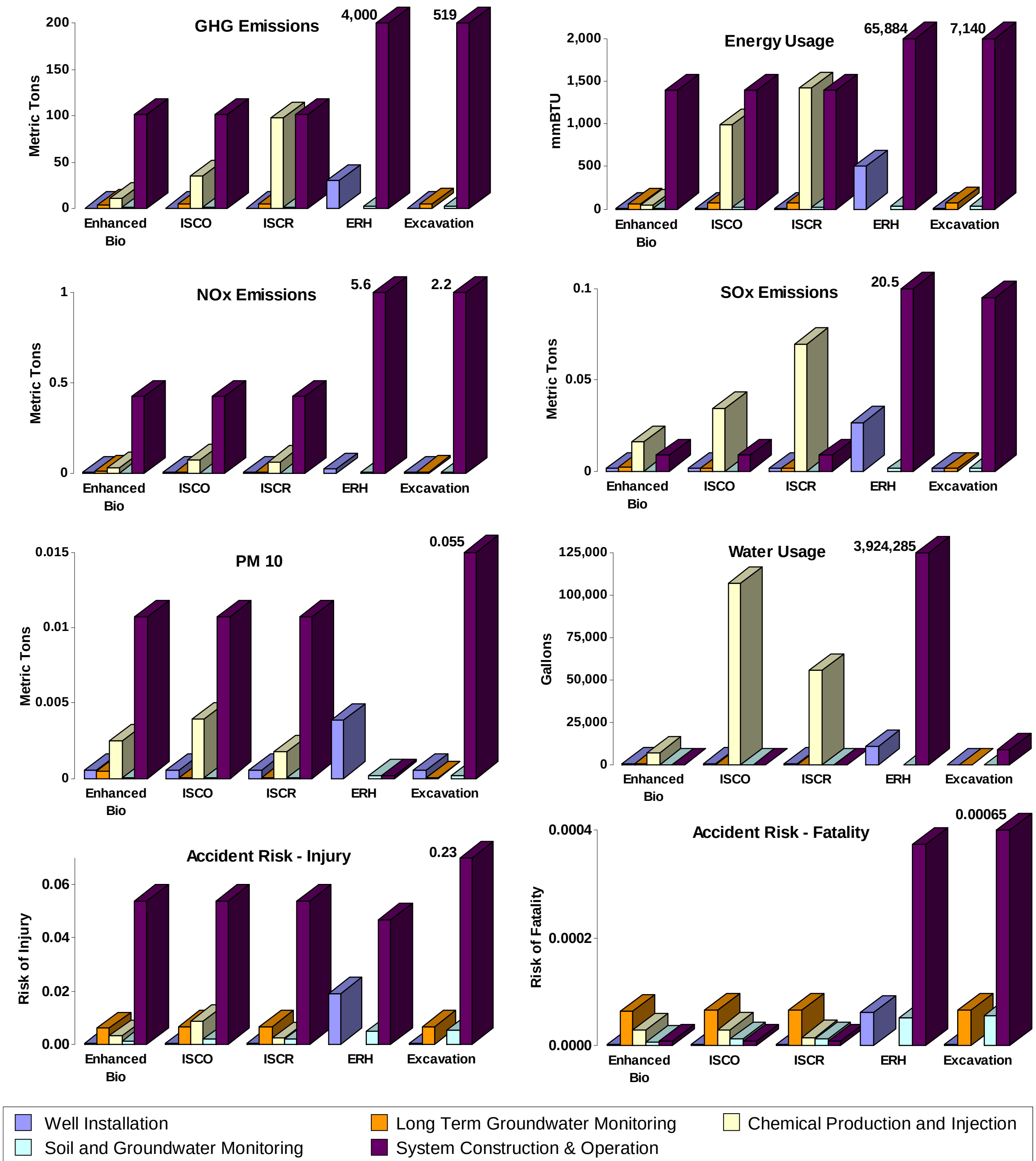

Figure 1. Comparative Analysis of GSR Metrics

Table 3. Impact Analysis based on Sustainability Metrics

Alternative	Impact Assessment	GHG Emissions	Energy Usage	Air Emissions	Collateral Risk	Community Impacts	Resources Lost	Water Usage
Enhanced Bioremediation	Relative Impact	**Low**	**Low**	**Low**	**Low**	**Medium**	**Low**	**Medium**
	Impact Drivers	Biostimulant Production, transportation & equip use during shallow excavation	Biostimulant Production and transportation and equip use during shallow excavation	Biostimulant Production and transportation and equip use during shallow excavation	Transportation related to long term groundwater monitoring and transportation and equip use during shallow excavation	Disturbance due to increased traffic during shallow excavation	Landfill space for soil disposal	Biostimulant Production
ISCO	Relative Impact	**Low**	**Low**	**Low**	**Low**	**Medium**	**Low**	**Medium**
	Impact Drivers	Oxidant Prod,, transportation, & equip use during shallow excavation	Oxidant Prod., transportation & equip use during shallow excavation	Oxidant Prod., transportation & equip use during shallow excavation	Transportation & equip use during shallow excavation	Disturbance due to increased traffic during shallow excavation	Landfill space for shallow excavation	Chemical Oxidant Production
ISCR	Relative Impact	**Low to Medium**	**Low to Medium**	**Low**	**Low**	**Medium**	**Low**	**Medium**
	Impact Drivers	ZVI production, transportation, & equip use during shallow excavation	ZVI Production, transportation & equip use during shallow excavation	ZVI Production, transportation & equip use during shallow excavation	Transportation & equip use during shallow excavation	Disturbance due to increased traffic during shallow excavation	Landfill space for shallow excavation	ZVI Production
ERH	Relative Impact	**High**	**High**	**High**	**Medium**	**Low**	**Low**	**High**
	Impact Drivers	Electrical Usage	Electrical Usage	Electrical Usage	System Construction and Operation	Land Use Controls during the period of application	Lost groundwater	Electrical Production
Excavation	Relative Impact	**Medium**	**Low to Medium**	**Medium**	**High**	**High**	**High**	**Low**
	Impact Drivers	Transportation & Disposal	Transportation & Disposal	Transportation & Disposal	Excavation to 20 ft	Disturbance due to increased traffic	Landfill Space and lost groundwater	Production of PVC for wells and GAC for water treatment

Table 4. Example GSR Evaluation within the CERCLA Remedy Evaluation Criteria

Evaluation Criteria	No Action	Enhanced Bioremediation	ISCO	EZVI	ERH	Excavation
Overall Protection of Human Health and Environment	Would not be protective of human health and the environment because no action would occur. Migration of COCs would continue and remain undetected.	Would be slightly less protective of human health and the environment than other alternatives because it has a longer remediation time, although it would provide active treatment of the high-concentrations areas. LUCs would prevent exposure to the balance of the plume.	Would be as protective of human health and the environment as EZVI and ERH because it would provide active treatment of the high-concentration areas. Would be slightly more protective than enhanced bioremediation because of shorter remediation time. LUCs would prevent exposure to the balance of the plume.	Would be as protective of human health and the environment as ISCO and ERH because it would provide active treatment of the high-concentration areas. Would be slightly more protective than enhanced bioremediation because of shorter remediation time. LUCs would prevent exposure to the balance of the plume.	Would be as protective of human health and the environment as ISCO and EZVI because it would provide active treatment of the high-concentration areas. Would be slightly more protective than enhanced bioremediation because of shorter remediation time. LUCs would prevent exposure to the balance of the plume.	Would be less protective of human health and the environment than the other alternatives because there would be no active treatment of the high-concentration areas in groundwater and because this alternative has the highest remediation time. LUCs would prevent exposure to the plume
Compliance with ARARs and TBCs	Would not comply.	Would comply.	Would comply.	Would comply.	Would comply.	Would comply.
Long-Term Effectiveness and Permanence	Would have very limited long-term effectiveness and permanence because no action would occur. Contaminant reduction or migration would remain undetected because no monitoring would occur.	Would be as permanent as and slightly less effective than ISCO, EZVI and ERH because it has a longer remediation time. Biodegradation would reduce COCs in high-concentration areas, and LUCs would prevent exposure elsewhere. ***The resources lost, such as landfill space and groundwater during the remedial action, are similar for enhanced bioremediation, ISCO, and ISCR. GHG emissions are smallest for the enhanced bioremediation alternative.***	Would be as permanent and effective as EZVI and ERH. Would be slightly more effective than enhanced bioremediation because of shorter remediation time. ISCO would reduce COCs in high-concentration areas, and LUCs would prevent exposure elsewhere. ***The resources lost, such as landfill space and groundwater during the remedial action, are similar for enhanced bioremediation, ISCO, and ISCR. GHG emissions are greater for ISCO than enhanced bioremediation, but less than that for EZVI. GHG emissions for this alternative are largely attributed to production of the oxidant.***	Would be as permanent and effective as ISCO and ERH. Would be slightly more effective than enhanced bioremediation because of shorter remediation time. EZVI would reduce COCs in high-concentration areas, and LUCs would prevent exposure elsewhere. ***The resources lost, such as landfill space and groundwater during the remedial action, are similar for enhanced bioremediation, ISCO, and ISCR. GHG emissions are greater for EZVI than enhanced bioremediation and ISCO. GHG emissions for this alternative are largely attributed to production of the EZVI material.***	Would be as permanent and effective for groundwater as ISCO and EZVI. Would be slightly more effective than enhanced bioremediation because of shorter remediation time. ERH would reduce COCs in high-concentration areas, and LUCs would prevent exposure elsewhere. Would be less effective than other alternatives for soil, because only some PAHs would be removed and all arsenic would remain. ***ERH has the greatest potential for lost groundwater due to vaporization because of high subsurface temperatures almost near the boiling point of water. If the vaporized groundwater is not condensed, treated and re-injected into the aquifer or otherwise beneficially used, then this would be considered a lost resource. Implementation of ERH also results in the greatest amount of GHG emissions.***	Would be less permanent and effective than other alternatives because of the long remediation time. LUCs would be required to prevent exposure throughout the plume. ***Excavation requires the most landfill space due to full excavation of the site and dewatering would likely result in high volumes of lost groundwater unless this can be treated and re-injected or beneficially used. The excavation alternative results in less GHG emissions than ERH, but more than the other alternatives with in-situ groundwater treatment.***
Reduction of Toxicity, Mobility, or Volume through Treatment	Would not reduce toxicity, mobility, or volume through treatment because no treatment would occur.	Would irreversibly and permanently reduce toxicity, mobility, and volume by removing an estimated 238 pounds of COCs in groundwater through enhanced bioremediation treatment. Would also remove approximately 14 pounds of volatile organic compounds (VOCs) in soil and destroy 12 pounds of VOCs through off-site soil treatment. PAHs and arsenic would be removed from the site and disposed offsite.	Would irreversibly and permanently reduce toxicity, mobility, and volume by removing an estimated 238 pounds of COCs in groundwater through ISCO treatment. Would also remove approximately 14 pounds of VOCs in soil and destroy 12 pounds of VOCs through off-site soil treatment. PAHs and arsenic would be removed from the site and disposed offsite.	Would irreversibly and permanently reduce toxicity, mobility, and volume by removing an estimated 238 pounds of COCs in groundwater through EZVI treatment. Would also remove approximately 14 pounds of VOCs in soil and destroy 12 pounds of VOCs through off-site soil treatment. PAHs and arsenic would be removed from the site and disposed offsite.	Would irreversibly and permanently reduce toxicity, mobility, and volume of COCs in groundwater by removing an estimated 252 pounds of COCs through ERH treatment and off-site disposal of spent activated carbon. Would reduce less COC volume in soil because some PAHs and all arsenic would remain on site.	Would irreversibly and permanently reduce toxicity, mobility, and volume by removing an uncertain mass of COCs in groundwater through biological and abiotic MNA processes. Would also remove and destroy VOCs through excavation and off-site soil treatment. PAHs and arsenic would be removed from the site and disposed offsite.

Table 4. Example GSR Evaluation within the CERCLA Remedy Evaluation Criteria (Continued)

Evaluation Criteria	No Action	Enhanced Bioremediation	ISCO	EZVI	ERH	Excavation
Short-Term Effectiveness	Would not result in any short-term risk to site workers or adversely impact the surrounding community or environment because no action would occur. The remedial action objectives (RAOs) would never be achieved.	Would result in a possibility of exposing site workers to contaminated soil during excavation and contaminated groundwater during the injection of the electron donor and monitoring activities. These risks would be reduced through compliance with appropriate site-specific health and safety procedures. There would be a slight risk to the surrounding community and environment from transport of contaminated soil. Groundwater RAO Nos. 1 and 2 would be achieved immediately upon implementation of LUCs and monitoring. Over 100 years would be required to meet groundwater RAO No. 3 and cleanup goals. ***Application of enhanced bioremediation, ISCO, or EZVI as the remedial approach at this site result in similar quantities of criteria pollutant emissions. The energy usage by the three remedial alternatives is also very similar, as well as the collateral risk to workers.***	Would result in a possibility of exposing site workers to contaminated soil during excavation and contaminated groundwater during the injection of oxidizers and monitoring activities. These risks would be reduced through compliance with appropriate site-specific health and safety procedures. There would be a slight risk to the surrounding community and environment from transport of contaminated soil. Groundwater RAO Nos. 1 and 2 would be achieved immediately upon implementation of LUCs and monitoring. Over 100 years would be required to meet groundwater RAO No. 3 and cleanup goals. ***Application of enhanced bioremediation, ISCO, or EZVI as the remedial approach at this site result in similar quantities of criteria pollutant emissions. The energy usage by the three remedial alternatives is also very similar, as well as the collateral risk to workers.***	Would result in a possibility of exposing site workers to contaminated soil during excavation and contaminated groundwater during the injection of EZVI and monitoring activities. These risks would be reduced through compliance with appropriate site-specific health and safety procedures. There would be a slight risk to the surrounding community and environment from transport of contaminated soil. Groundwater RAO Nos. 1 and 2 would be achieved immediately upon implementation of LUCs and monitoring. Over 100 years would be required to meet groundwater RAO No. 3 and cleanup goals. ***Application of enhanced bioremediation, ISCO, or EZVI as the remedial approach at this site result in similar quantities of criteria pollutant emissions. The energy usage by the three remedial alternatives is also very similar, as well as the collateral risk to workers.***	Would result in a possibility of exposing site workers to contaminated groundwater during electrode installation, operation and maintenance, and monitoring activities. This risk would be reduced through compliance with appropriate site-specific health and safety procedures. There would be a slight risk to the community from transport of condensate and spent activated carbon. Groundwater RAO Nos. 1 and 2 would be achieved immediately upon implementation of LUCs and monitoring. Over 100 years would be required to meet groundwater RAO No. 3 and cleanup goals. ***Energy use and criteria air emissions are greatest with implementation of the ERH alternative. Collateral risk to workers is greater for ERH than the other in-situ groundwater remedies, but less than the excavation alternative.***	Would result in a possibility of exposing site workers to contaminated soil during excavation and contaminated groundwater during monitoring activities. These risks would be reduced through compliance with appropriate site-specific health and safety procedures. There would be a slight risk to the surrounding community and environment from transport of contaminated soil. Groundwater RAO Nos. 1 and 2 would be achieved immediately upon implementation of LUCs and monitoring. Over 300 years would be required to meet groundwater RAO No. 3 and cleanup goals. ***The excavation alternative results in less criteria air emissions than ERH, but more than the other alternatives with in-situ groundwater treatment. Collateral risk to workers is highest for implementation of the excavation alternative due to the increased amount of transportation required.***
Implementability	Technical and administrative implementation would be extremely simple because there would be no action to implement.	Technical implementability of enhanced bioremediation would be similar to ISCO and easier than EZVI and ERH. Pilot-scale treatability testing would be required. Technical implementability of groundwater monitoring would be simple. Administrative implementation of LUCs would be simple.	Technical implementability of ISCO would be similar to enhanced bioremediation and easier than EZVI and ERH. Pilot-scale treatability testing would be required. Technical implementability of groundwater monitoring would be simple. Administrative implementation of LUCs would be simple.	Technical implementability of EZVI would be similar to ERH and more difficult than enhanced bioremediation and ISCO. Pilot-scale treatability testing would be required. Technical implementability of groundwater monitoring would be simple. Administrative implementation of LUCs would be simple.	Technical implementability of ERH would be similar to EZVI and more difficult than enhanced bioremediation and ISCO. Pilot-scale treatability testing would be required. Technical implementability of groundwater monitoring would be simple. Site use would be impacted for about 1 year during treatment. Administrative implementation of LUCs would be simple.	Would be the technically easiest alternative to implement. Administrative implementation of LUCs would be simple.
Costs	$0	$3.1M (30-Year)	$3.5M (30-Year)	$5.1M (30-Year)	$6.6M (30-Year)	$1.8M (30-Year)
State and Community Acceptance	No impacts would result because no action would be taken.	***Community impacts due to increased traffic volume associated with the remedial action was qualitatively evaluated. Excavation of shallow soil will have an impact on day to day activities of the base due to an increase in traffic and noise for the work undertaken in this alternative. However, this impact will be similar to almost all of the groundwater remedial alternatives except ERH.***	***Community impacts due to increased traffic volume associated with the remedial action was qualitatively evaluated. Excavation of shallow soil will have an impact on day to day activities of the base due to an increase in traffic and noise for the work undertaken in this alternative. However, this impact will be similar to almost all of the groundwater remedial alternatives except ERH.***	***Community impacts due to increased traffic volume associated with the remedial action was qualitatively evaluated. Excavation of shallow soil will have an impact on day to day activities of the base due to an increase in traffic and noise for the work undertaken in this alternative. However, this impact will be similar to almost all of the groundwater remedial alternatives except ERH.***	***Community impacts due to ERH implementation will be greater than enhanced bioremediation, ISCO, and EZVI, but less than the full excavation alternative. Community impacts include transportation of condensate and spent activated carbon from the site, as well as longer term on-going site activities (up to 12 months).***	***Community impact due to full excavation of the site will be large in comparison to all the other remedial alternatives.***

Note: ***Bold-italicized*** text is used to show how the GSR discussion can be incorporated in the alternative evaluation matrix.