Interim Advisory for Green Remediation

Department of Toxic Substances Control

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California Environmental Protection Agency

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Executive Summary

This advisory is intended for project managers, responsible parties, and environmental consultants in performing sustainability or green remediation assessments at cleanup sites. The advisory introduces the concepts of sustainability and life-cycle thinking and shows how these concepts can be incorporated into any stage of a cleanup project, including site characterization, treatment alternative selection, remedial design implementation, long-term monitoring, operation and maintenance, and closure. This advisory also presents a simple tool, the green remediation evaluation matrix (GREM). The GREM can be used to perform qualitative comparisons of treatment alternatives. Other tools that can be used for calculating green house gas (GHG) emissions and energy consumption are referenced.

The advisory looks to the future, toward which the field of green or sustainable remediation is headed. Because this field is rapidly evolving, the advisory will be updated periodically and will include state-of-the-art quantitative and qualitative assessment techniques.

Section 1 Preface

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With the recognition of a global warming trend and significant estimated carbon dioxide (CO_2) emissions at federal Superfund sites (USEPA/OSWER, April 2008), the United States Environmental Protection Agency (USEPA), numerous state environmental regulatory agencies, and a variety of organizations are developing policies, practices, and evaluation methods aimed at reducing the environmental footprint of cleanup sites.

The (USEPA) currently defines green remediation as *"the practice of considering all environmental effects of remedy implementation and incorporating options to minimize the environmental footprints of cleanup actions."*

This advisory introduces the concepts behind the Department of Toxic Substances Control's (DTSC's) green remediation to project managers, responsible parties, environmental consultants, and the public and offers an assessment tool for evaluating remedial alternatives under consideration at cleanup sites. It also includes a list of tools and references that will be updated periodically.

The advisory applies to several phases of a cleanup project, including: investigation, feasibility study, design, implementation, long-term monitoring, operation and maintenance, and closure. The science of assessment and selection of a remedy based upon sustainability or green criteria continues to evolve. Consequently, the advisory is a living document that will periodically be revised and supplemented by new tools and case studies.

This advisory introduces green remediation (GR) principles of sustainability and life-cycle thinking that are incorporated into what is termed the life-cycle management

(LCM) approach. The LCM approach and GREM are presented in this advisory to identify key areas for reducing environmental impacts of remedial options. The impacts associated with physical, chemical, or biological stressors are evaluated for each alternative and then assembled into the GREM, a matrix of applicable environmental stress factors and their consequences, constituting a *qualitative* framework for comparing remedial options. Tools for *quantitative* assessments will be incorporated into or referenced in future updates to this advisory.

Section 2 Green Remediation

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To protect human health and the environment, policy makers, remediation practitioners, and the public should be aware of wider potential impacts of remedial options and incorporate this information into the remedy-selection process. GR employs sustainability principles and life-cycle thinking in a systematic method for documenting, displaying, and assessing a wide range of impacts from which better informed decisions can be made.

GR involves employing technologies and cleanup approaches to reduce a project's environmental footprint. The environmental footprint of a remediation activity exceeds the site physical boundary because the materials used and the energy consumed create impacts elsewhere. Typically, these offsite impacts have not been fully incorporated into the decision-making process, but their cost ultimately becomes a burden to all of society. GR assessments identify potential impacts that may have been discounted, or not included, in traditional assessments. GR assessments can illustrate impacts that occur on local, regional, and global scales, including: the direct and indirect releases of contaminants; the consumption of raw materials; and the production, collection, and disposal of wastes.

GR includes sustainability concepts, which recognize a holistic assessment in a broader scope and time horizon. In addition to looking beyond project site physical boundaries, it examines a wide range of impacts that affect overall sustainability, including the social and economic impacts of remedial decisions. Sustainability integrates many different and sometimes competing factors in planning for the future and incorporates consideration of factors that may be intangible and unquantifiable. The interaction of environmental, social, and economic factors is illustrated in Figure 2.1.

In evaluating remedial alternatives, it is important to remember that sustainability is only one of the criteria among others, such as reduction in the toxicity, mobility, or volume of the contamination, which must be considered during the remedy selection. The final selected remedy will result in a balance of criteria.

Another important aspect of GR is the incorporation of "life-cycle thinking," which considers all inputs and outputs related to processes from start to finish. Life-cycle thinking can provide information on specific environmental impacts and burdens that occur directly during site activities, as well as indirectly in support of those activities, including any environmental impacts outside the site boundaries. For example, one should consider not only the local transportation impacts, but also impacts related to the production of vehicles and fuel consumed, as well as the regional and global impacts of all the emissions produced, if the vehicle or equipment cannot be reused to remediate other sites.

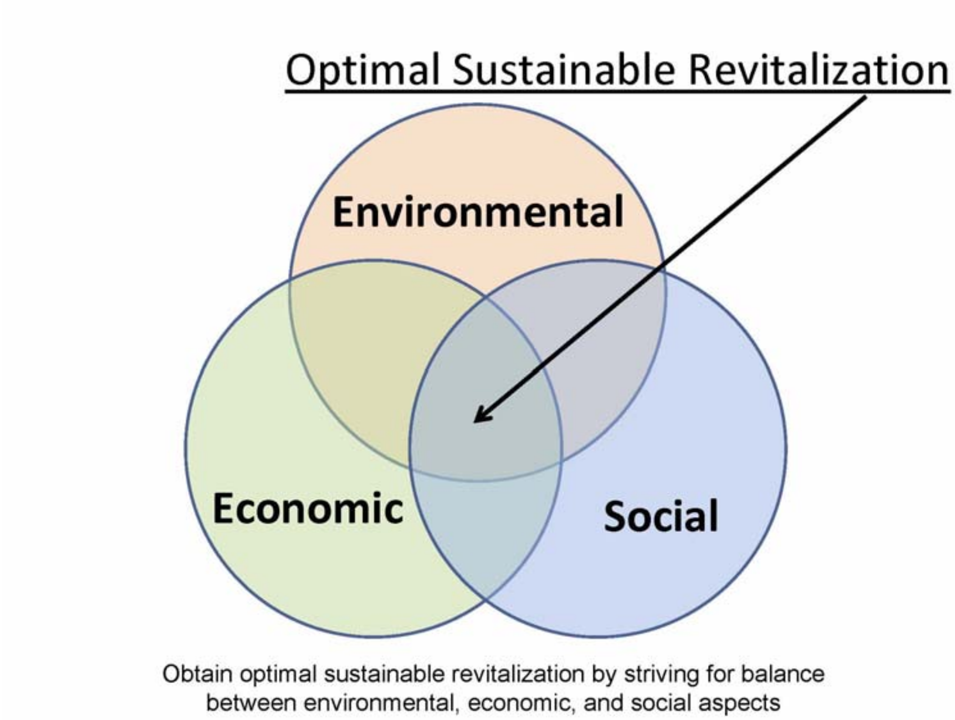
Life-cycle thinking can be applied to the assessment of remediation projects in several ways. It can provide benchmarking for existing systems and can be used retrospectively to identify opportunities to decrease impacts in future remedial actions involving similar applications, as well as to identify where specific improvements would be most advantageous. It can be used to compare different alternatives during the remedy-selection process. Life-cycle thinking provides the ability to expand current decision making to include a fuller representation of the environmental and human health impacts.

Life-cycle thinking has been formalized into the practice of life-cycle assessment (LCA), which has become an internationally standardized method (ISO 14040/44 series). LCA computes the material and energy costs associated with products or services, including extraction of natural resources; processing of resources into feedstocks; manufacture of components and finished products; development and delivery of services; and disposal of wastes. LCA can be used to compare cradle-to-grave scenarios (e.g., landfill scenarios) as well as cradle-to-cradle scenarios (e.g., recycle and reuse scenarios). Although to date LCA has been used primarily by businesses to benchmark operations or to evaluate and compare products or alternative processes, it is beginning to be employed in analyzing remediation projects. There is also increasing interest in using LCA to develop consumer information to support sustainable consumption (www.epa.gov/nrmrl/lcaccess/whylca.html). LCA helps to identify options that are more environmentally superior (i.e., less burdensome) than others. LCA methodology is attractive because it is comprehensive, inclusive, and promotes a holistic approach to minimizing overall environmental effects.

The overall goal of this advisory is to introduce principles of sustainability and life-cycle thinking related to green remediation and formulate them into a tool that project managers, responsible parties, and environmental consultants can use. The framework developed here includes completing a checklist for each alternative under consideration, combining them into a matrix comparative evaluation, and applying the LCM approach. The LCM approach can be used in lieu of full LCA to identify those factors likely to produce the most significant consequences. After developing a flow diagram illustrating the steps or processes involved in the cleanup and identifying or inventorying all the inputs and outputs for each process, the processes are linked to physical, chemical, or biological stressors with the potential to produce environmental, economic and/or social impacts. Each stressor and its associated impact can be ranked according to its level of concern, assuming sufficient data are available. When these assessments are prepared for each of the alternatives, the resulting checklists can be combined into a matrix of stressors and their consequential impacts—the

GREM. At the simplest level, the framework approach helps to identify key areas for improvement or opportunities for reducing impacts on remedial options.

Figure 2.1 Concept of Sustainability



Section 3 Background and Introduction to the Department of Toxic Substances Control Green Remediation Evaluation Tool

At the onset, a screening guide to aid in selecting “greener” or more sustainable remediation technologies was anticipated. After testing the concept, however, it became clear that what makes a technology “green” is related to the particular site conditions. For example, because of differences in extraction efficiencies associated with the soil type, depth to groundwater, etc, a pump-and-treat technology intended for rapid cleanup of an aquifer might consume considerably more energy during its operation and exert a more significant environmental footprint than an in-situ technology operated over a longer period. At a different site, the comparison might not be dramatically different or the opposite might be true. Consequently, it is not possible to make a blanket statement about whether a specific technology or application is “green,” as much as that might be desirable.

Rules-of-thumb or other guidelines may eventually be developed to aid in identifying or prioritizing the “greenness” of technologies for site uses with specific types of contamination, media and environmental conditions. These guidelines will likely be forthcoming only after green remediation has become more refined and includes the results from case study analysis and demonstration projects.

3.1 Sustainability as a Criterion for the Remedy Selection Process

Regulatory agencies evaluate remedies according to the nine criteria set forth in the National Contingency Plan (NCP) or equivalent criteria used for a RCRA Corrective Measures Study (CMS). Largely qualitative, the nine criteria are typically applied to a suite of remedies that have undergone at least a cursory evaluation relative to scale, duration, and cost. Sustainability is not listed as a criterion.

Notwithstanding its absence in the list of criteria, sustainability should be considered as one of several factors to be examined in evaluating the environmental impact of a remedy. Some of these factors may compete with sustainability, and trade-offs may become necessary to achieve the best approach or most acceptable solution for the stakeholders.

3.2 Green Remediation and the California Environmental Quality Act (CEQA)

As experienced remedial project managers in California know, all remediation projects must comply with CEQA. Those that do not qualify for an exemption must be subjected to an Initial Study (IS), and if the findings from the IS indicate that significant environmental impacts are likely, then an Environmental Impact Report (EIR) must be prepared. The IS process is similar to a GR analysis because both include quantifying the impacts of environmental stressors. California legislation specifically requires that

GHG emissions be quantified to the extent possible and compared with thresholds of significance, and that mitigation measures be implemented if the estimated emissions are deemed significant.

An IS differs from a GR analysis in the stage of the project during which it is performed. While the lead agency usually performs an IS late in the process, after the remedy has been tentatively chosen, it is recommended that the project manager perform the GR analysis throughout the remediation process to enable incorporating “green” approaches during site characterization; remedy selection; operation, monitoring, and maintenance; and remediation process optimization (RPO).

3.3 Green Remediation Evaluation Matrix

The general approach of life-cycle thinking has been incorporated into GR. Life-cycle thinking evolved into the concept of “Life-Cycle Framework” (LCF), which incorporates two approaches: Life-Cycle Management (LCM) and Life-Cycle Assessment (LCA). LCM is a simple, semi-quantitative approach, useful for remediation, while LCA is a more comprehensive, quantitative approach, appropriate for detailed evaluation where quantitative data on energy or natural resource use are available or specific information on potential impacts is needed. LCF is illustrated in Figure 3.1. As shown, LCF recognizes those stresses and impacts from activities associated with building and implementing a remedy. LCF considers the stresses and impacts associated with raw material extraction, product development, and other activities that take place well before, and well after, the treatment is applied.

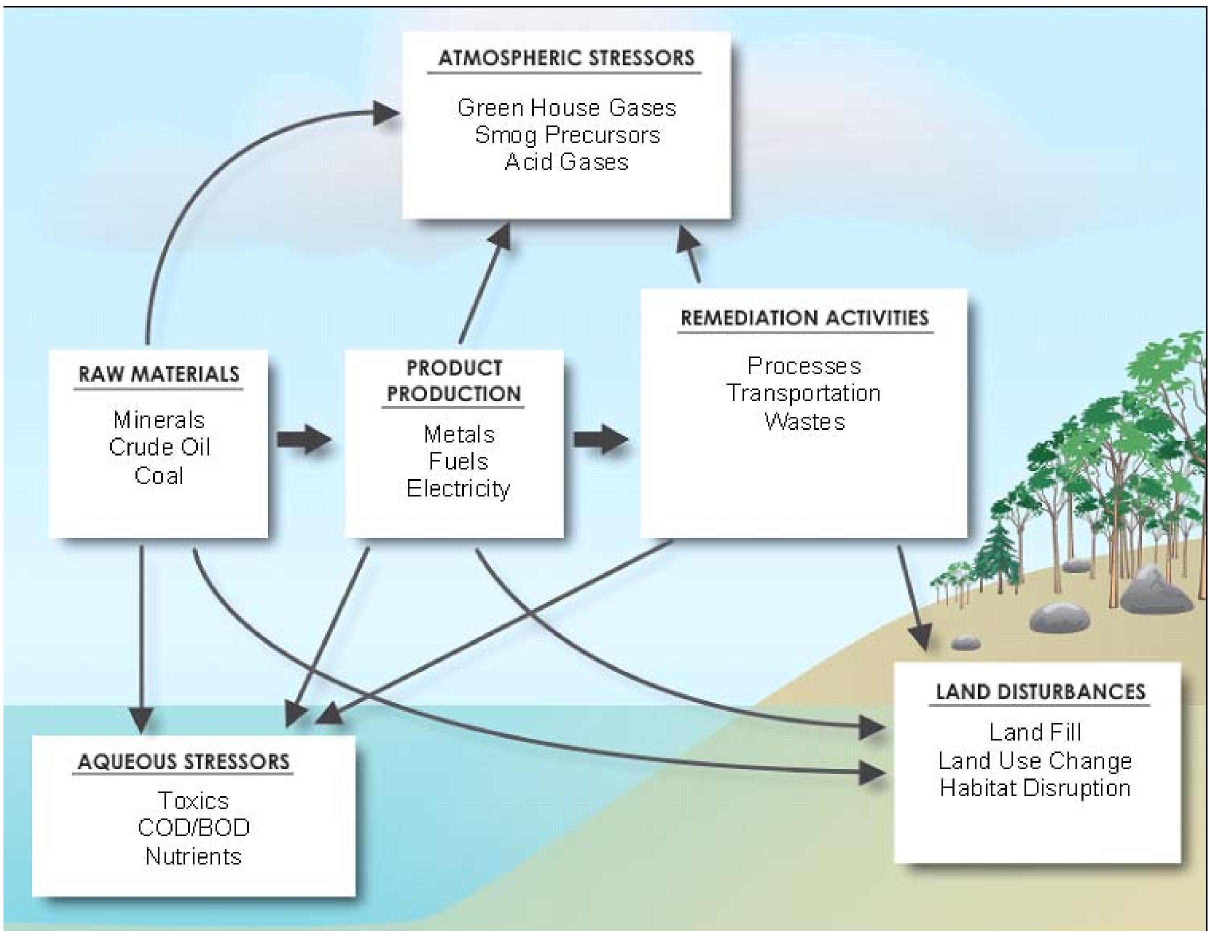
These types of impacts, those that occur either off-site or before or after remediation, are greatly suited to LCA, which lends itself to an extensive study program. LCM analysis would also consider such off-site impacts, but in an abridged manner and with a narrower focus than a full LCA.

The potential stressors and impacts are captured in the evaluation for each technology and then expanded into the matrix presented in Table 3.1, which compares all the technologies. The GREM displays potential environmental stressors and their associated impacts, with two or more remedial alternatives, and allows a ranking or rating of the severity or significance of those impacts. Details of how the GREM will be used are presented in Chapter 4.

To date, much of the interest in GR has been focused on the emissions of GHGs (or the “carbon footprint”) associated with the energy consumed during operation of the remedy. The GREM is intended to account for all the relevant environmental, economic, and social impacts that occur before, during, and after implementation of the remediation project (through raw material extraction, production, transportation, and disposal), as well as off-site impacts.

GR is new and evolving field. Only some of the numerous remedy impacts that LCA might target are considered here and, of those, many are examined in a cursory, qualitative manner. Nonetheless, GR presents an opportunity to consider those impacts during remedy selection, design, and implementation. The simple elements of the GREM provided in Table 3.1 make available the selection of "greener" remedies by combining a range of interests and considerations into one evaluation form. More details describing how to complete the matrix are presented in Section 4.

Figure 3.1 Life Cycle Diagram – A Conceptual Diagram



Note: This diagram illustrates how the process (from raw material to product production to remediation activities) creates environmental stressors (atmospheric, aqueous, and land), which would cause impacts.

Table 3.1 Green Remediation Evaluation Matrix

Green Remediation Evaluation Matrix (GREM) *				
Stressors	**Affected Media**	**Mechanism/ Effect**	**Y/N ****	**Score**
Substance Release/Production				
Airborne NOx & SOx	Air	Acid rain & photochemical smog		
Chloro-fluorocarbon vapors	Air	Ozone depletion		
Greenhouse gas emissions	Air	Atmospheric warming		
Airborne particulates/toxic vapors/gases/Water vapor	Air	General air pollution/toxic air/humidity increase		
Liquid waste production	Water	Water toxicity/sediment toxicity/sediment		
Solid waste production	Land	Land use/toxicity		
Thermal Releases				
Warm water	Water	Habitat warming		
Warm vapor	Air	Atmospheric humidity		
Physical Disturbances/Disruptions				
Soil structure disruption	Land	Habitat destruction/ soil Infertility		
Noise/Odor/Vibration/Aesthetics	General environment	Nuisance & safety		
Traffic	Land; general environment	Nuisance & safety		
Land stagnation	Land; general environment	Remediation time; cleanup efficiency; re-development		
Resource Depletion/Gain (Recycling)				
Petroleum (energy)	Subsurface	Consumption		
Mineral	Subsurface	Consumption		
Construction materials (soil/concrete/plastic)	Land	Consumption/reuse		
Land & space	Land	Impoundment/reuse		
Surface water & groundwater	Water, land (subsidence)	Impoundment/ Sequester/reuse		
Biology resources (Ppants/trees/animals/microorganisms)	Air, water, land/forest, subsurface	Species disappearance/ diversity reduction/ regenerative ability reduction		

Notes:

* Use for evaluating one technology or remedial alternative as a checklist
Expand for alternative comparison by adding additional score columns for each alternatives

** state whether the impact applies or does not apply to the alternative and continue the evaluation

3.4 Use of GREM for Screening Proposals

The components of GREM allow collection of at least relative impact rankings from stressors associated with remedies. It is expected that proponents of a particular “green” approach will be the primary evaluators of the potential impacts of a given remedy. Many consulting firms in the remediation industry are developing tools that will accomplish this type of analysis. Such tools make use of databases that include ancillary environmental metrics (carbon dioxide emissions, energy consumption, etc associated with products and activities.

Although the assessment and selection of a remedy based upon sustainability or “green” criteria is in its infancy, the structure and elements provided in Table 3.1 nonetheless permit an evaluation and comparison, if only qualitative, of major environmental impact categories that can be associated with remediation projects.

3.5 Limitations in Applying GREM

There are limitations that must be considered when considering using GREM, such as lack of consensus about definitions and factors to be included in the analysis, as well as the nature of the types of factors and variables and their difficulty in comparison because of confounding and synergistic effects and availability of quantitative data.

3.5.1 Lack of Consensus in the Definition of GR and the Extent of the Boundary of Analysis

As GR is still evolving, general consensus throughout the regulatory and environmental communities on the definition of green remediation has not yet been achieved.

The degree to which the boundaries of a GR analysis should be extended is site- and project-specific. Small projects or those in the early phases of a feasibility study may require less extensive analyses and, hence, narrower boundaries, or they may be limited to consideration of only the most significant components of environmental impact. When the project complexity grows, or the boundary expands, so, too, do the data requirements and the likelihood that some of these data will be unavailable. For example, if a rare metal is used in an analytical instrument or remediation technology, and the boundary drawn includes the instrument in the analysis, life-cycle data on the metal may be unavailable. In this instance, however, the bearing on the analysis would probably be minimal, and the data gap could be ignored. In addition, with growing interest in the principles of deep ecology, recognition of the rights of all species to thrive in equilibrium with one another has expanded, even though the establishment of the value of habitat and species preservation remains problematic because of cultural factors, evaluator subjectivity and specificity of the organisms involved.

3.5.2 Lack of Quantitative Data

The application of the evaluation tool to the technologies under consideration requires the use of quantitative data, if the resulting scores are to be compared meaningfully. Unfortunately, with the exception of energy-related parameters, quantitative data on the impacts of certain stressors are largely nonexistent because factors have not been adequately investigated or data are inherently difficult to obtain. Where such data do exist, aggregating them in a manner that considers their frequently diverse quantification bases (e.g., tons, acres, kilowatt-hours, and so forth) presents a further challenge.

It may also be difficult to properly allocate the inputs or outputs to the different stages in the process, particularly when the system is complex or the boundaries between stages are unclear.

In addition, models for converting the outputs from the inventory phase of the analysis into inputs for the impact phase are few relative to some types of processes and products. For example, while it may be possible to quantify the production of tail-pipe emissions, determining the impact of those emissions on the particular species of plants and animals present, or to the specific elements of their habitat, may be difficult. The causal mechanisms behind observed environmental consequences may not be well known, making quantification difficult or impossible.

3.5.3 Mix of Qualitative and Quantitative Factors

Most stressors to be evaluated are more qualitative than quantitative. For example, noise is quasi-quantitative because sound level can be readily measured and quantified, yet the impact is largely associated with the perception of the receptors. Such is the case with most nuisance factors (e.g., loss of landscape view from visual impairment resulting from the remediation project or increase in traffic noise).

Some factors that have recently emerged into public consciousness and policy discussions include impacts (loss/gain) to habitat and the richness and diversity of life, including the non-human species. Other quality of life concerns associated with the concept of deep ecology (i.e., all species of plants and animals should be able to thrive, not merely survive) are becoming recognized as important. But these are only now beginning to be expressed in semi-quantifiable terms, often only as rank-order quantities. Assessing their importance in the mix relative to other criteria is difficult because of both the subjectivity involved and the nature of their characterization (e.g., ordinal, interval, or ratio variables). Finally, the effects upon some otherwise quantitative variables may be impacted (e.g., screened, diminished, or augmented) when confounding factors are present. Although an action or measure affecting quality of life in a particular way might be quantifiable, were one to conduct extensive preference surveys, its ranking might vary greatly with the age, gender, ethnic background and economic status of the individuals impacted.

3.5.4 Consideration of Social or Environmental Justice

Environmental justice has become recognized as worthy of consideration, at least on a local level, but global equity, with few exceptions, has yet to be factored into most formulations of sustainability presently under discussion. With the growing awareness of human interconnectedness, those concerns will ultimately have to be addressed.

GREM attempts to include some of these social factors by recognizing, for example, the importance to the local community of jobs created by the remediation project. But the extent to which such social factors should be included and the means by which they should be evaluated, along with other criteria, is still to be explored.

3.5.5 Long-Term Impacts and Synergistic Effects

There is uncertainty regarding long-term impacts and the synergistic effects of multiple stressors. As the sciences advance, the full extent of the long-term environmental impacts resulting from the use of certain materials and the consumption of natural resources will become more apparent. Analysts have greater confidence in the predicted impacts for projects with relatively short operational horizons than they do for those operating over longer terms. Factors resulting in directly observable impacts will eventually be reduced, as will those with secondary, cumulative, or synergistic effects.

As GREM becomes more sophisticated, the view of long-term impacts will likely reach greater resolution and the synergistic effects will be better identified, but in the meantime the tool remains an imprecise metric device capable of making a generalized prediction of the future. It is important to acknowledge that GREM is primarily a qualitative evaluation technique that will probably never become more than a quasi-quantitative instrument for comparing two or more alternatives, which will preclude falsely adopting a simple, reductionist view and will encourage maintaining a balanced vision that covers all the factors that impact a project and possible alternatives for consideration.

3.5.6 General Limitations

Conducting a full LCA can be cost- and time-prohibitive because of limitations on available data, particularly when such data are proprietary. Advanced and costly models may be required to assess resource depletion and impacts. Calibration and sensitivity analyses of these models or uncertainty analyses of the modeling results may not yet have been performed.

Section 4 Applying the Green Remediation Evaluation Matrix in Green Remediation

The purpose of the GREM is to assess whether there is a likelihood of a significant environmental, social, or economic impact resulting from implementation of the remedial technology/activity. The assessment is based on a site-specific life-cycle framework that defines the boundary of evaluation and considers potential inputs and outputs from those remedial technologies and activities under consideration.

When constructing a GREM, for each alternative, generate a flow diagram that includes resource inputs and project outputs; determine the stressors produced and assess the significance of the impacts, either qualitatively or quantitatively; combine the completed checklists into the summary GREM; adjust the scores as necessary; and finally review and compare the scores between the alternatives to make a final decision in selecting the alternative.

4.1 Generating a Life-Cycle Framework (LCF) Flow Diagram — Inventory of Inputs and Outputs

Begin by identifying the overall remedial objectives of the project and available trade-offs, such as remedial time vs. high capital/fast return and land use control vs. unrestricted criteria. For each alternative, define the evaluation boundary, considering system, temporal, and geographic elements, and generate a LCF flow diagram, similar to Figure 4.1, depicting the relationship between site remediation life-cycle stages and affected environmental media (soil, water, and air). Then perform an inventory of all the inputs and outputs across and within that boundary. The process is similar to constructing a conceptual site model for remediation.

When undertaking a sustainability assessment, attempt to account for all the inputs and outputs across the site boundary during the investigation, implementation and operational phases of the remedial project, and transformations and conversions that occur within the boundary. Include not only the more obvious inputs such as energy and any natural resources (e.g., water, soil, metals, and so forth) consumed, but also human resources (e.g., labor) expended.

Expanding the evaluation boundary outside the remediation project site’s physical boundary is encouraged, but within reasonable efforts to conduct such an evaluation. To make the GR evaluation more manageable, it may be appropriate to simplify the manufacturing impacts associated with the more common materials that go into a remediation project, such as piping and excavation equipment, by relying on the purchasing or renting costs as an indicator of the overall manufacturing life-cycle cost rather than performing a full manufacturing life-cycle assessment of those materials and equipment. In addition, specialized remedial materials such as nano-sized zero valent iron used for in-situ chemical remediation, or the equipment required to manufacture it, may need to be analyzed separately.

4.2 Determining the Environmental Stressors within Impact Categories

Next, account for the various environmental stressors (e.g., GHGs; other priority air pollutants; solid and liquid wastes produced; thermal releases; noise, soil, and habitat disruption; and so forth) that result from project implementation or that are associated with the inputs and outputs. As shown in Table 4.1, the stressors are grouped into four major impact categories: substance production and release, thermal releases, physical disturbances/disruptions, and resource depletion or gain through recycling and/or reuse. The table illustrates the typical components to consider within each major category that result from remediation activities. Additional site and technology-specific stressors not appearing in this list, however, should be included whenever appropriate. These stressors then act on their environmental targets, singly or synergistically, to generate their impacts.

The potential impacts include mineral resource depletion, acid rain, ozone depletion, smog production, global temperature change, and local economic effects. Secondary effects might include deforestation; flooding and sea level rise; storm frequency and intensity increase; and species migration, reproductive depression, numerical reduction or extinction of species or habitats. Account for other outputs, whether as useful outcomes (e.g., contaminant reduction) or beneficial byproducts, in a similar manner.

Figure 4.1 Life-Cycle Evaluation Framework

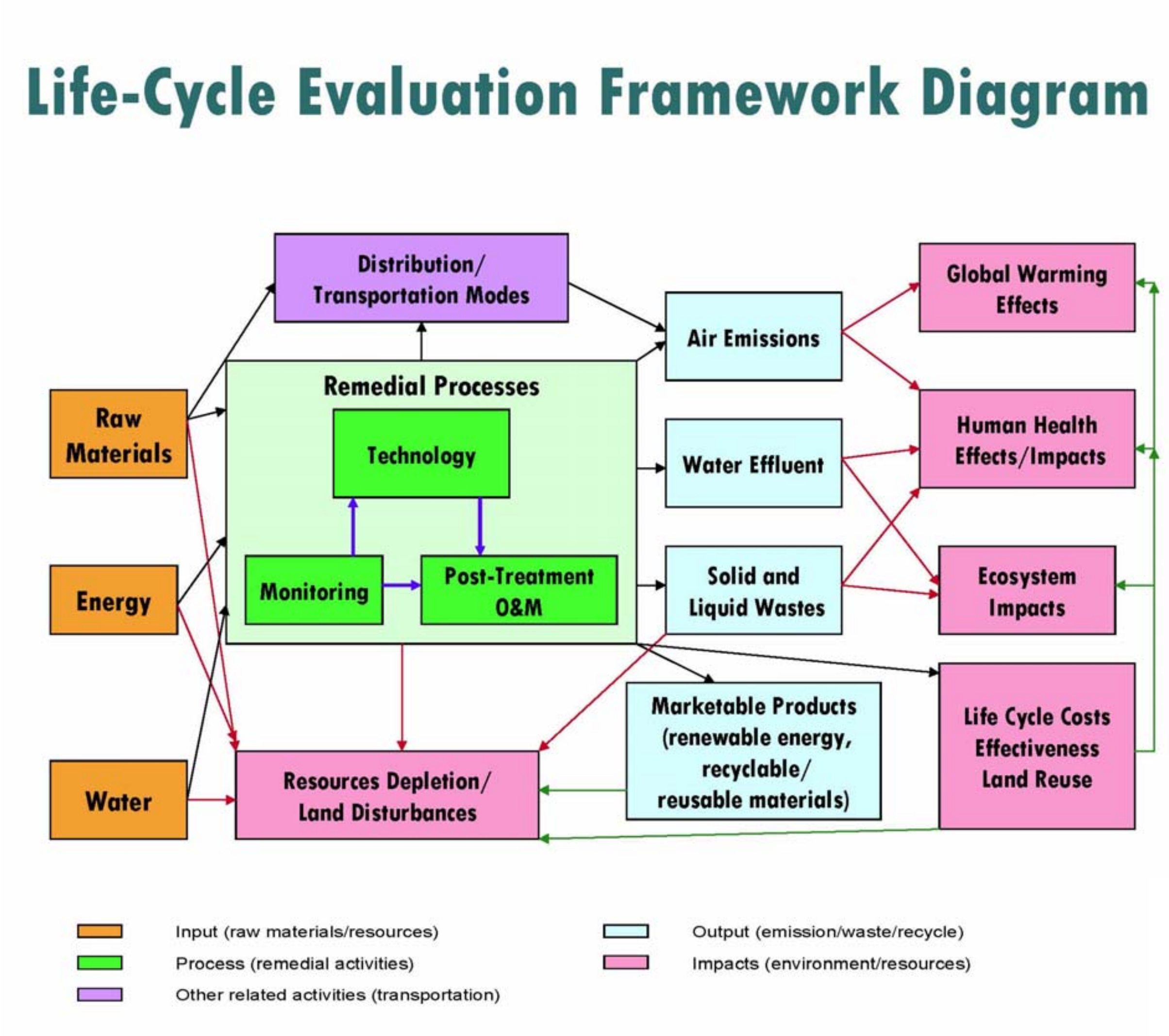


Table 4.1 Impact Category/Stressor in Green Remediation Evaluation Matrix (GREM)				
Stressors		**Examples of Components to Consider**	**Affected Media**	**Mechanism/ Effect**
Substance Release/Production				
	Airborne NOx & SOx	• <u>Emissions from:</u> o Transportation to and from the site (trucking, sample shipping, etc.) o On-site construction equipment (excavators, etc.) o Remedial technology (thermal oxidizer, supplemental fuel, off-site carbon regeneration, fugitive emissions from other operating equipment, etc.) o Special remedial material/equipment manufacturing • Electric power generation (power grid: remote impacts; auxiliary power)	Air	Acid rain & photochemical smog
	Chlorofluorocarbon vapors (e.g. CFCs, HCFCs)	• Freon for the refrigerant unit • Freon used for equipment cleaning • Freon used for special remedial material/equipment manufacturing	Air	Ozone depletion

Table 4.1
Impact Category/Stressor
in
Green Remediation Evaluation Matrix (GREM)
(continued)

	Stressors	Examples of Components to Consider	Affected Media	Mechanism/ Effect
	Greenhouse gas emissions (e.g. HFCs, PFCs, CO_2, CH_4, NO_x, SF_6)	• Emissions from: o Transportation to and from the site (trucking, sample shipping, etc.) o On-site construction equipment (excavators, etc.) o Remedial technology (thermal oxidizer, supplemental fuel, off-site carbon regeneration, fugitive emissions from other operating equipment, etc.) o Special remedial material/equipment manufacturing • Electric power generation (power grid: remote impacts; auxiliary power) • Consider cleaner fuels, less traveling and heavy equipment use	Air	Atmospheric warming (radioactive forcing-biospheric warming)
	Airborne particulates (PM_{10}/$PM_{2.5}$)/toxic vapors ("priority pollutants"), VOCs or gases/water vapor	• Emissions from: o Transportation to and from the site (trucking, sample shipping, etc.) o On-site construction equipment (excavators, etc.) o Remedial technology (thermal oxidizer, supplemental fuel, off-site carbon regeneration, fugitive emissions from other operating equipment, etc.)	Air	General air pollution Toxic air Humidity increase

Table 4.1
Impact Category/Stressor
in
Green Remediation Evaluation Matrix (GREM)
(continued)

	Stressors	**Examples of Components to Consider**	**Affected Media**	**Mechanism/ Effect**
		o Special remedial material/equipment manufacturing. • Electric power generation (power grid: remote impacts; auxiliary power) Minimize dust with engineering control		
	Liquid waste production	• Wastewater/sludge generated from: o On-site construction equipment and activities (decontamination water, stormwater, treated or untreated groundwater/condensate, etc.) o Remedial technology (in-situ and ex-situ groundwater treatment system, etc.) o Special remedial material/equipment manufacturing • Minimize sediments and nutrient loading through source control	Water	Water toxicity Sediment toxicity Secondary effects thru volatilization
	Solid waste production	• Solid waste from: o On-site construction activities (construction debris, PPE, etc.) o Remedial technology (contaminated soil from dig-and-haul, disposal of solids from filter cake and particulate filters, non-regenerable adsorption filter materials, sludge, etc.) o Special remedial material/equipment manufacturing	Land	Land use/ toxicity

Table 4.1 Impact Category/Stressor in Green Remediation Evaluation Matrix (GREM) (continued)				
Stressors		**Examples of Components to Consider**	**Affected Media**	**Mechanism/ Effect**
Thermal Releases				
	Warm water	• Warm water from: o Remedial technology (scrubber blowdown from thermal oxidizer, steam condensate for in-situ remediation, cooling water blowdown, etc.) o Special remedial material/equipment manufacturing	Water	Habitat warming
	Warm vapor	• Warm vapor from: o Remedial technology (scrubber from thermal oxidizer, steam for in-situ remediation, steam from cooling water, etc.) o Special remedial material/equipment manufacturing	Air	Atmospheric humidity increase
Physical Disturbances/Disruptions				
	Soil structure disruption	• Excavation and backfill • In-situ remedial action (in-situ bioremediation, in-situ chemical oxidation, barrier wall, cut-off wall, in-situ fixation, in-situ thermal, etc.) • Groundwater Pump-&-Treat and Vapor Extraction System (extraction/injection well installation)	Land	Habitat destruction Geophysical/ geochemical changes Soil Infertility

Table 4.1 Impact Category/Stressor in Green Remediation Evaluation Matrix (GREM) (continued)				
Stressors		**Examples of Components to Consider**	**Affected Media**	**Mechanism/ Effect**
	Noise/Odor/Vibration/ Aesthetics	• Noise/Odor/Vibration from: o Transportation to and from the site (trucking, sample shipping, etc.) o On-site construction equipment (excavators, drilling rig, etc.) o Remedial technology (blower for soil vapor extraction, pump for groundwater extraction, alarm/indicating sounds and lights, etc.) o Special remedial material/equipment manufacturing • Other visual impairment from remedial activity	General environment	Nuisance and safety
	Traffic	• Traffic from transit to and from the site (materials and equipment shipping, debris and waste hauling, sample shipment, construction and O&M crew commuting, etc.)	Land General environment	Nuisance and safety
	Land stagnation	• Land use control (capping, groundwater restriction until beneficial use goal achieved, temporary or permanent loss of space for/during remedy implementation, etc) • Loss of use or production during remediation	Land General environment	Remediation time Cleanup efficiency Re-development

Table 4.1 **Impact Category/Stressor** **in** **Green Remediation Evaluation Matrix (GREM)** **(continued)**				
Stressors		**Examples of Components to Consider**	**Affected Media**	**Mechanism/ Effect**
Resource Depletion/Gain (Recycling)				
	Petroleum (energy)	• Fuel for: o Transportation to and from the site (trucking, sample shipping, etc.) o On-site construction equipment (excavators, etc.) o Remedial technology (thermal oxidizer, supplemental fuel, off-site carbon regeneration, etc.) o Special remedial material/equipment manufacturing o Electricity generation • Fuel includes petroleum-based and natural gas-based (renewable energy will be considered as credit for reuse)	Subsurface	Consumption
	Mineral	• Minerals ore (iron, copper, nickel, chromium, aluminum, etc) for piping, structure, remedial equipment, etc • Exotic and rare metals (platinum, palladium, rhodium, etc) for catalyst • Chemicals for remediation (coagulants, ORP chemicals, general minerals for nutrients, etc.)	Subsurface or surface	Consumption

Table 4.1 Impact Category/Stressor in Green Remediation Evaluation Matrix (GREM) (continued)				
Stressors		**Examples of Components to Consider**	**Affected Media**	**Mechanism/ Effect**
		• Petroleum products (polymer, plastic, etc. for chemicals and materials)		
	Construction materials (soil/concrete/plastic/ wood)	• Soil and gravel for excavation backfill and grading • Concrete for remedial system construction (pavement, capping, structure, etc) • Plastic for piping, membrane, structure • Lumber for construction • Location and resource of construction materials	Land Forests	Consumption Recycle or reuse
	Land and space	• Land/space required for special remedial materials, installation of renewable energy generators (wind or solar energy farm) • Land/space loss at landfills and waste disposal facilities • Loss of use of topsoil through excavation, land use control, or other remedial action	Land	Impoundment Loss of use Reuse
	Surface water and groundwater	• Water used during remedial construction and activities (dust control, chemical mixing, soil washing, washdown, decontamination and rinse water, etc.) • Water used for special remedial material manufacturing.	Water, land (subsidence)	Impoundment Sequester Recycle or reuse

Table 4.1 Impact Category/Stressor in Green Remediation Evaluation Matrix (GREM) (continued)				
Stressors		**Examples of Components to Consider**	**Affected Media**	**Mechanism/ Effect**
	Biological resources (plants/trees/animals/ microorganisms)	• Disturbance during remedial construction and activities (noise, space intrusion, food chain changes, etc.) • Wet land or forest changes from remedial activities	Air, water, land/forest, subsurface	Species reduction or disappearance Diversity reduction Regenerative ability reduction

CFCs: Chlorofluorocarbons
HCFCs: Hydrochlorofluorocarbons
HFCs: Hydrofluorocarbons,
NO_x: Oxides of Nitrogen (NO, N_2O, NO_2)
PFCs: Perfluorinated compounds
SO_x: Oxides of Sulfur (SO, SO_2, SO_3 etc.)
VOCs: Volatile Organic Compounds

4.3 Evaluating the Significance of the Impacts

For each remedial alternative being considered, estimate the significance of the potential impacts from each stressor identified during the inventory phase and designate its significance on the checklist. The Y/N check box in the GREM can be used during the initial inventory stage to determine whether certain stressors could be eliminated from further evaluation or combined with other stressors. This approach takes into account site-specific conditions. Additional stressors could also be added to the GREM, if site conditions warrant. Scores, either qualitative or quantitative, should be assigned for each impact category/stressor and recorded in the last column of the GREM. Whenever possible and when data are readily available, each score should be based on a quantitative calculation, using available tools (see Appendix B) to generate a value that includes the units of measure (e.g. kilowatt-hours for electrical energy use or metric tons CO_2 equiv for GHG emissions). Otherwise, estimate the effect qualitatively. If the stressor is deemed to be insignificant, it can be eliminated from the checklist.

To compare the overall impact of one remedial alternative with the other on the GREM, one of several scoring methods, described below, may be used.

4.3.1 Qualitative Scoring

Qualitative scoring is based on the relative impacts, using a qualitative index/symbol, such as ☺ 😐 ☹, ● ⦿ ○, good/bad/worst, or a relative numerical score ranging from 1 to 10, with the highest score given to the remedial alternative with the lowest adverse impact. The remedial alternative with the highest total score (or most ☺ or ●) should be considered the "greenest" remedial alternative.

Qualitative scoring is less time-consuming than using a quantitative method but relies on the evaluator's subjective judgment. Compared with many quantitative methods, qualitative scoring offers less consistent resolution, however, it may be most practical approach at this time.

4.3.2 Quantitative Scoring

Quantitative scoring is usually performed by expressing a computed estimate of an impact as a standardized value or converting it to an equivalent or a life-cycle cost. For example, stack emissions from equipment or certain fugitive VOC vapors from contaminated soil, such as methane, may be expressed in metric tons of CO_2 equivalents, or "MT-CO2-e." Quantitative values may sometimes be further expressed in terms of cost equivalency. The expression of emissions equivalents in terms of cost, using the current price of CO_2 in the carbon trading market serves as an example. Although calculation tools and programs for estimating the GHG and other air emissions, resource depletion, and energy consumption are available, tools to quantify the impacts from other stressors are not widely accessible. Other stressors, whose impacts are subjective, can best be assessed qualitatively.

Although adding the overall costs from each impact will provide a more comprehensive cost/benefit evaluation, the assignment of costs to an intangible impact from stressors, such as loss of land use benefit, will ultimately be judgmental and subject to uncertainty. Nevertheless, life-cycle costs are widely used in currently available tools for alternative comparison.

4.3.3 Normalized Scoring

Normalized scoring is a quantitative method that expresses the estimated impact in terms of an index against a related threshold value. For example, the magnitude of GHG emissions can be divided by the GHG emission threshold established by a local air resource management district or agency and expressed as a non-dimensional number.

This method normalizes the impact against the selected threshold. Thus, the lowest overall total value in the GREM represents the lowest impact. Proper selection of the threshold value, however, can be also judgmental and subject to uncertainty. For example, the GHG threshold will be specific to project location and size.

4.3.4 Weighted Scoring

A weighted scoring method can be applied to qualitative, quantitative, or normalized scoring. This method assigns an evaluation weight factor to each stressor before adding the total score, enabling the evaluator to modify the relative importance of the various stressors, and may be an essential process, depending on site conditions. For example, the importance of traffic impacts in a remote area, relative to other concerns, may need to be assigned a lesser weight value before calculating the total score.

Decision tools are available to facilitate weighted scoring and provide sensitivity analysis. In addition, some of the uncertainty mentioned in the previous scoring methods may be reduced by using a lower weighting factor for unimportant stressors. Because the weight value assigned to each stressor will be judgmental, it is critical to obtain the input of all the stakeholders on weight value during the weight selection process. Significant coordination and sensitivity analysis should be expected when using this approach

4.3.5 Compiling the Scores

Compile the total scores for each remedial alternative into the GREM, which will serve as a summary table to provide a relative ranking of all the remedial alternatives evaluated. In addition, through GREM evaluation, the significant impact of certain stressors may be quickly identified. Focused evaluation on those stressors for all the remedial alternatives being considered could optimize the remedial alternatives or further streamline the use of GREM for a particular site. While GREM provides the project manager with a tool for comparing the relative greenness of the remedial options, there may be overriding factors at a site that could lead to selecting a remedial alternative that might not be as “green” as other options.

Section 5 Using Green Remediation Evaluation Matrix in the Remedial Process.

In addition to assisting in selecting a remedial alternative, GREM may be used to reevaluate an existing remedial action after its implementation, such as for a five-year performance review. With GREM, claims made by a responsible party, consultant, or manufacturer that their product or action is “green” may also be evaluated.

5.1 Using GREM to Evaluate Alternatives

Regardless of the stage of a remedial project, GREM can be used to evaluate alternatives, even for remedial investigation methods. Any evaluation will likely involve identifying baseline impacts, comparing alternatives with other options or with the baseline, and evaluating ways to reduce impacts.

Figure 5.1 illustrates how GREM can be deployed over the process of a typical remedial project. It is important to note that GREM can be used during the remedy assembly and selection process by altering the components of each alternative to optimize the alternatives to achieve a “greener” approach.

5.2 Using GREM to Evaluate Existing Systems for Continued Process Optimization and Improvement

Although GR evaluation can be deployed at any time during the remedial process, this section specifically discusses the use of the green remediation evaluation after the remedy is in place. This evaluation can occur at any time after implementation or over the five-year review period for a typical CERCLA remedial action or a post RCRA corrective action evaluation.

The systematic evaluation of the remediation once the remedy is in place is often referred to as “remediation process optimization” (RPO) (ITRC, 2004). The key elements of RPO will include: proper use of a conceptual site model; reevaluating the remedial action objectives and decision logic; revisiting the exit strategy; evaluating existing remedy performance and cost efficiency; developing remedy optimization and cost-benefit analysis; implementing; and tracking.

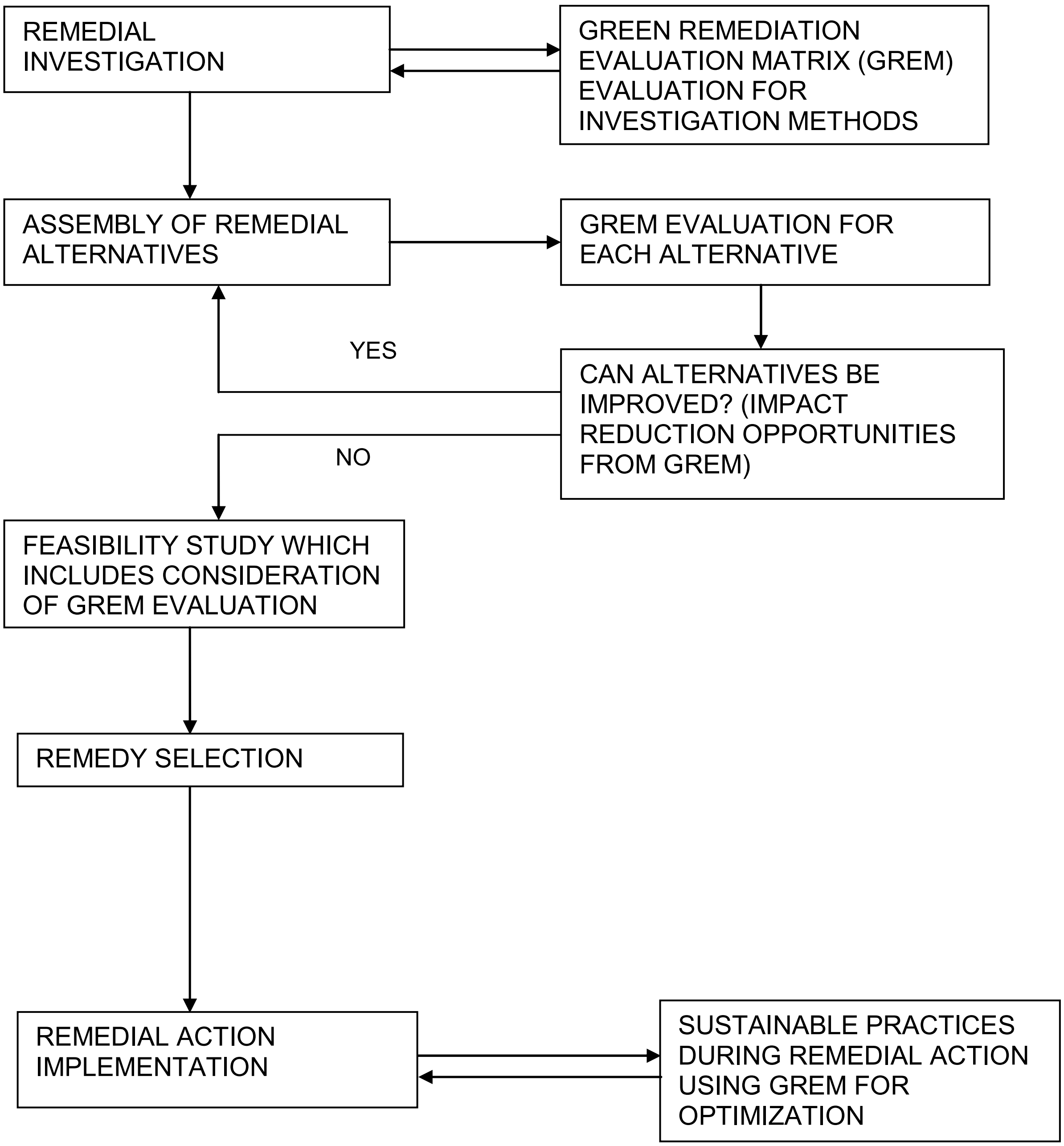
During RPO, the actual remediation information, such as treatment effectiveness and efficiency, operation and maintenance costs, the timeline to reach the remedial goals, and the stakeholder concerns, will be collected and evaluated. Based on the evaluation, an optimization approach with measurable milestones will be developed to improve the performance. The RPO will be tracked for its implementation as iterative to consider the inherited uncertainties or emerging regulatory and technology challenges in a typical remediation project.

Like the remedy selection stage, RPO involves selecting alternatives to optimize the existing remedy in place. Therefore, GR evaluation should be used for each optimization approach. While GR evaluation during the remedy selection only estimates energy and material usage for the existing remedy, GR evaluation during RPO uses actual site information.

Once available, such site information as electricity bills, truck usage logs, and contaminants removal and treatment rates, should be used to develop the baseline condition, for example, GHG generation, for GR evaluation. The baseline could be used to compare optimization alternatives for GR and evaluate other improvements (in equipment or technology).

Additional site information collected from the existing remedy action will be used to update the conceptual site model for RPO. This updated conceptual site model and operational experience of the existing remedy will help to better define the elements in the flow diagram for LCF analysis.

Figure 5.1 GREM in Remediation Process



Section 6 What's to Come

Looking forward, the challenges facing broader implementation of GR, include the need for clear terminology, development of statutory as well as regulatory guidelines and policy, standardized assessment metrics and methodologies, and a need for incentives. These challenges, some of which are discussed below, will be addressed as the green remediation concept and implementation evolves.

6.1 Challenges

The application of GR must be kept within the context of other potential mitigating factors when selecting a new remedy or evaluating an ongoing action. The "greenest" alternative may not always be the best solution for a particular remediation project. Important local factors, such as development issues, local air quality in non-attainment zones, and other extenuating factors, may justify a less "green" remedial alternative. Uncertainty surrounds how to consider social and economic equity concepts.

Similarly, the application of GR is assessed by the type and scale of the proposed activity and impacted populations. A one-size-fits-all approach will fail, and sustainability considerations should be site-specific. Performance indicators and cost review are integral components for evaluating the success of any GR project. The development of tools for greener remediation will be an iterative process.

6.2 Stakeholder and Policy Issues — Looking Ahead

An important step in the process is to clearly define what constitutes "green" or sustainable as applied to a particular remedial project. Although these terms have been defined within this advisory document, they are not yet universally accepted. Until such definitions are agreed on by impacted stakeholders, it will be difficult to apply them uniformly and consistently for either selecting "green" or sustainable remedial alternatives or for reliably evaluating their performance.

There is broad consensus on the need for sustainability metrics and standards in assessing the "greenness" of projects. There are diverse opinions, however, regarding whether metrics or standards should be qualitative or quantitative and whether detailed estimates are prudent, given the complexity and effort required to complete them, especially for small sites. The American Society for Testing and Materials (ASTM, Committee E50.04) and the USEPA (the Green Cleanup Standard Initiative), intend to address such concerns as the need for uniform definitions, consistent methods, mutual expectations, and common goals; streamlined adoption by all state and federal cleanup programs without modification to current policy, guidance, or regulation; a consistent approach that overlays the various regulatory frameworks; a framework for developing new tools that evaluate cleanup impacts ; implementation ease for the regulated community; added incentives to responsible parties and to state and local governments for participating in green cleanups.

A related need is more clearly defined policies and statutory and regulatory guidelines at state and federal levels. Although there is lack of consensus about whether sustainability assessments should be required for cleanup projects, USEPA, headquarters and regional offices are currently developing and implementing policies at federal Superfund sites. Nevertheless, threshold criteria for protectiveness and site-specific cleanup objectives should not be compromised while implementing GR.

6.3 Incentives

To encourage the assessment and application of "green" or "greener" remediation, regulatory incentives should be explored and implemented. Economic and statutory incentives and social impacts, including good land stewardship and environmental justice issues, should be reviewed. Incentives could include pilot programs, fast-track permitting, and reduced permit cost.

The Greener Cleanups Task Force of the Association of State and Territorial Solid Waste Management Officials (ASTSWMO) recently released *Incentives for Greener Cleanups* (June 2009). The document identifies the need for loans and grants, greater publicity, contract incentives, and consultant education and accreditation as the top measures to best stimulate GR adoption. Although the State of California Public Utilities Commission (CPUC) makes rebates available for self-generated electricity from renewable energy systems under 5 MW in capacity, a further expanded program may be needed as an incentive to promote GR.

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ACRONYMS AND ABBREVIATIONS

AFCEE	Air Force Center for Engineering and the Environment
ASTM	American Society for Testing and Materials
CALEPA	California Environmental Protection Agency
CEQA	California Environmental Quality Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1986
CMS	Corrective Measures Study
CPUC	California Public Utilities Commission
ELCD	European Reference Life-Cycle Data System
EIR	Environmental Impact Report
EUROPA	European Commission's information hub (website)
GHG	Green House Gas
GREM	Green Remediation Evaluation Matrix
GR	Green Remediation
IS	Initial Study, CEQA
LEED	Leadership in Energy and Environmental Design
LCA	life-cycle assessment
LCF	life-cycle framework
LCIA	life-cycle impact assessment
LCM	life-cycle management
NCP	National Contingency Plan
NR	Canadian National Railroad
OPR	Governor's Office of Planning and Research, State of California
RCRA	Resource Conservation and Recovery Act
RPO	Remediation Process Optimization
SETAC	Society of Environmental Toxicology and Chemistry
SRT	AFCEE Sustainable Remediation Tool
SuRF	Sustainable Remediation Forum
USEPA	United States Environmental Protection Agency

Appendix A - DTSC Green Remediation Team Members and Sponsors

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Appendix B - Calculation Tool Box

This appendix provides a general discussion of certain tools currently available to potentially evaluate green remediation alternatives. These tools are included for reference only. Each tool has its applicability and limitations and may be site-specific. A given tool may be more suitable for one site than another. This appendix will be expanded as new tools are developed in the future.

Over ten years ago, a team at the University of Toronto, headed by Dr. Miriam Diamond, developed an approach to sustainable remediation based on the Life-Cycle Framework (LCF). LCF became the backbone of GREM.

Books and technical papers are available through the Society of Environmental Toxicology and Chemistry (SETAC). The website at the European Commission's information hub (website) "EUROPA" contains "European Reference Life-Cycle Data System" (ELCD), v 1.0.1., as well as a list of LCA and software and related links. The terminology and methodology for performing LCAs are standardized and encapsulated in ISO 14040 and ISO 14044, which together describe the principles, framework, requirements, and guidelines for LCA. These also include the definition of the goal and scope of the LCA, the life-cycle inventory analysis (LCI) phase, the life-cycle impact assessment (LCIA) phase, the life-cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, the relationship between the LCA phases, and conditions for use of value choices and optional elements (see the International Organization for Standardization, http://www.iso.org).

DTSC currently uses the LCA program GaBi 4 (PE International) to perform life-cycle assessments. GaBi 4 complies with ISO 14040/44, incorporates a comprehensive database within a modular design, and employs process visualization tools to assist the user in modeling complex process relationships.

The U.S. and the World Green Building Councils offer builders and developers one of the early tools for assessing sustainability factors with their Leadership in Energy and Environmental Design (LEED) Green Building Rating System. It is a quantitative tool for the building industry that considers water and energy usage, sustainability of the site, site reclamation/reuse potential, resource depletion, indoor air quality, and other factors. The U.S. Building Council, the Natural Resources Defense Council, and the Congress for New Urbanism have recently extended the concept by jointly developing the LEED Neighborhood Development Rating System, released as a pilot version in 2007. Among other factors, the neighborhood rating system offers credits for such practices as construction activity pollution prevention, building reuse and adaptive reuse, minimizing site disturbance during design and construction, contaminant reduction in brownfields remediation, heat-island reduction, solar orientation, and on-site energy generation.

The Environmental Sustainability Index, which is intended for making country-by-country "sustainability" comparisons, considers such factors on a much larger scale, where scalar rating systems can be used (area in cultivation, area forested, population density, species diversity indices, and so forth).

Specific to site remediation is a tool used by the Canadian National Railroad (NR). Through its consultant, Golder Associates, the NR has developed what it refers to as a “semi-quantitative screening tool for sustainable site remediation,” based on concepts taken from the work done by Boussole Bernoise of Berne, Switzerland (“Sustainable Development Analysis for Projects” and the Global Reporting Initiative).
The tool uses a grid of 14 environmental indicators, 10 social indicators, and 11 economic indicators, each of which is assigned a weighting factor. The evaluator assigns a numerical score (1 to 100) to each indicator, and the weighted scores are summed under each of the three indicator categories.

DuPont Corporation has developed a Remedial Selection Matrix, in which one of the eight factors for consideration is sustainability. The tool considers GHG production, as measured in CO_2 equivalents; natural resource consumption; energy; and occupational risk as factors within a remedy’s “environmental footprint.”

The Air Force Center for Engineering and the Environment (AFCEE) has developed a “Sustainable Remediation Tool” (SRT, Revision 1, May 2009) to facilitate sustainability planning and evaluation. SRT is an easy-to-use tool based on a Microsoft Excel spreadsheet to estimate sustainability metrics relative to specific technologies for soil and groundwater remediation. The current technology modules included in the SRT are excavation, soil vapor extraction, pump and treat, and enhanced bioremediation. A revision to the tool will be available to the public.

Numerous resources are available at USEPA’s Hazardous Waste Cleanup Information website under the Green Remediation tab (see references).

Appendix C Case Studies

C.1 USEPA has compiled a list of over 25 project case studies on their website http://www.clu-in.org/greenremediation/tab_d.cfm. Each case study includes a description of the green remediation strategy, the cleanup objectives, results, the property end use, and the point of contact, as well as photos and slides describing aspects of the project.

C.1.1 Case Study - Romic Environmental Technologies Site

USEPA Region IX is conducting a green remediation pilot study at Romic Environmental Technologies, a former hazardous waste management facility, in East Palo Alto, California. During an earlier evaluation, a matrix similar to GREM was developed, as shown below, for alternative comparison and decision making.

Applying results to our decision-making

	Alternative 2 Hybrid	Alternative 3 Bioremediation	Alternative 4 Pump and Treat
Materials			
PVC Pipe (lbs)	11,000	9,000	20,000
Cement (ft3)	70	70	70
Molasses (gallons)	140,000	220,000	0
Water (gallons)	4,500,000	6,800,000	0
Energy			
Diesel Fuel (gallons)	20,000	11,000	40,000
Gasoline (gallons)	8,000	8,000	4,000
Electricity (kWh)	10,000,000	20,000	42,000,000
Waste Generation			
Spent Carbon (lbs)	1,200,000	0	3,900,000
Wastewater (gallons)	1,600,000,000	0	5,300,000,000
Air Emissions			
CO_2 (tons)	5,000	200	19,000
Other			
Road Distance (miles)	300,000	200,000	300,000
Remediation Time (years)	16	11	21

- Use a qualitative approach to balance the various aspects of each alternative.
- Remember that the "quantitative" results are estimates.
- Balance local effects with global effects.
- Balance effects of disparate items:
  - environmental contamination
  - natural resource depletion
  - worker safety
  - time to complete remedy

relatively high impact (yellow)
relatively low impact (green)
impacts similar (same order of magnitude) (light blue)

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(Source: Romic Remediation — Looking for Green Alternatives in a Corrective Action Remedy, a presentation by Karen Scheuermann, USEPA Region IX, September 25, 2008)

The most current developments of the Romic green remediation pilot study can be found at the web site of USEPA Region IX: http://www.epa.gov/region09/waste/romic-eastpaloalto/#greenpilot

C.2 DTSC is currently participating in case studies using GREM. As results from these case studies become available, they will be described in future updates to this document.