Decision Tool for Groundwater Cleanup of Chlorinated Solvent Plumes at DOE Sites

Prepared for:

Legin Group, in support of the U.S. Department of Energy, as part of the DOE Monitored Natural Attenuation/Enhanced Attenuation for Chlorinated Solvents Project

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Geomatrix

TABLE OF CONTENTS

TABLES

FIGURES

Executive Summary

Background

The U.S. Department of Energy (DOE) Monitored Natural Attenuation/Enhanced Attenuation (MNA/EA) for Chlorinated Solvents Project goal was to develop cost effective and environmentally protective solutions for the challenge of large and complex groundwater plumes of chlorinated volatile organic compounds (cVOCs) at DOE sites. Over the last twenty-five years, cVOCs have been identified as one of the most common contaminants requiring remediation in groundwater at numerous sites across the U.S. and throughout the world. Site investigations have enabled delineation of the extent and concentrations of cVOCs within these plumes and active remediation systems have removed significant quantities of cVOCs. However, cVOC concentrations in groundwater remain significantly above MCLs. Thus, tools that can enhance our ability to evaluate and compare alternative remediation approaches are needed.

Decisions about the appropriate remediation approach for any given site are influenced by both technical and non-technical factors, such as economics, regulatory requirements and expectations, and stakeholder interests. Because the evaluation criteria used to compare alternatives (e.g., safety, risk, environmental impact, and cost) are complex, trade-offs must be made to select a preferred alternative.

The objective of this project was to develop and test a decision tool and process to support responsible decision-making regarding alternative remedial approaches at sites containing groundwater contaminated with cVOCs. The cVOC Remediation Decision Tool (cVOC Tool) has been designed specifically to be useful at sites with any type of ongoing treatment, and to give fair consideration of all types of alternatives, including EA and MNA.

cVOC Tool Overview

The cVOC Tool is based on a structured analytic approach for comparing alternatives, involves a well-defined process for applying that approach, and is implemented through an Excel spreadsheet that can be easily used. The analytic approach is a proven, rigorous, and technically defensible method known as multi-attribute utility analysis (MAU), which is part of the practice of Decision Analysis. To apply the process, a user (e.g., site remediation manager, regulatory agency staff, a stakeholder group, or some combination) follows these steps:

- describe the site characteristics and conditions;
- identify and specify a set of alternatives to be considered for the site;
- evaluate how well each alternative is expected to perform, using the objectives and performance metrics specified within the tool;
- compare the evaluated alternatives using different techniques (e.g., consequence tables and multi-attribute comparisons).

MAU provides a systematic and logical way to combine technical judgments about the anticipated performance of alternatives on objectives important to a decision-maker with management value judgments about the relative importance of achieving those objectives. In the cVOC Tool, alternatives are evaluated and compared using six high-level objectives. These objectives were defined to be broadly applicable for managing and remediating cVOC plumes at any site, and detailed enough to allow for consistent and logical evaluation of alternatives.

An ideal alternative would accomplish all of the following objectives:

- minimize public health and safety risks
- minimize risk to worker safety
- minimize adverse environmental impacts
- maximize regulatory responsiveness
- minimize total cost, and
- minimize time to completion.

Performance metrics are a consistent set of measurement scales used to evaluate how well a specific alternative will meet a given objective. Knowledgeable technical staff on the evaluation team can use the performance metrics in the spreadsheet to record their evaluation of how well each alternative is expected to perform. These technical judgments of anticipated performance are combined with quantified management value judgments to calculate a "utility" value for an alternative. The calculated utility value is a single metric that can be used to compare alternatives when no single alternative performs better than others on all objectives. The management value judgments reflect the relative value to a decision maker of improvements in the alternatives. In MAU, these judgments are typically elicited from the responsible decision-makers and stakeholders for a specific decision problem. To make the cVOC Tool more generally applicable, several different sets of value judgments are encoded in the Tool; the user can calculate the utility of each alternative using any (or all) of these judgments. If the value judgments encoded in the cVOC Tool are not reflective of local priorities, an option is also available for the user to define an alternative set of value judgments that better reflect local stakeholder values.

Using the cVOC Tool, a wide range of sensitivity analyses can be conducted to:

- compare the alternatives one objective at a time to see the relative value of each alternative from a single perspective;
- compare the relative value of the alternatives on all objectives combined, using the three built-in weight sets; and,
- compare the relative value of alternatives using alternative value functions or weights defined by the user.

Pilot Test

A pilot test of the cVOC Tool was performed at the DOE Savannah River Site, specifically for the A-Area Burning Rubble Pit/Metals Burning Pit and Miscellaneous Chemical Basin Operable Unit (OU). The site contains a one-mile long cVOC plume in the two uppermost aquifers. The OU underwent a Remedial Investigation (RI) and a Feasibility Study (FS), where sixteen alternatives were evaluated. Agreement was not reached between the site manager and the regulatory agency on the appropriate path forward. Since completion of the RI/FS, the plume has shown significant improvement in water quality and as such, some of the alternatives considered in the FS were no longer appropriate to consider. The cVOC Pilot Test considered nine alternatives, which ranged from no action or MNA to a variety of active treatments, including continuation of the ongoing interim remedial action. The results of the evaluation are presented in a consequence table, by single objectives, and as MAU values for the three built-in sets of management value judgments.

The preferred alternative (that with the best calculated utility score) varies for the different value judgments, which means that the ultimate choice of a preferred alternative will depend on the relative emphasis the decision-makers put on the time to reduce groundwater concentrations and the costs to do so. In this case, the analysis did not lead unambiguously to a single preferred solution, but it highlighted the key tradeoffs, facilitating discussions between site management and the stakeholders, including the state regulatory agency.

1.0 Background

1.1 Overview of the DOE Monitored Natural Attenuation/Enhanced Attenuation for Chlorinated Solvents Project

The U.S. Department of Energy (DOE) Office of Environmental Management (EM) authorized an Alternatives Project at the Savannah River Site (SRS) to develop cost effective and environmentally protective solutions for the challenge of large and complex groundwater plumes of chlorinated volatile organic compounds (cVOCs) at DOE sites. The DOE Monitored Natural Attenuation/Enhanced Attenuation (MNA/EA) for Chlorinated Solvents Project builds upon the U.S. Environmental Protection Agency (EPA) protocol and directive (EPA, 1998, 1999) for MNA. The DOE MNA/EA Project focuses on three major technical areas: mass balance, EA, and innovations in characterization/monitoring. The first two support the EPA directive, which calls for demonstration of plume stability, as well as attainment of maximum contaminant limits (MCLs) within a reasonable time period. By further study of the concept of mass balance and introduction of the concept of EA, the project goals include development of new tools for transitioning from active remediation to a protective, long-term monitoring state. The DOE MNA/EA Project is a departure from classical MNA in that its central theme focuses on achieving a favorable balance between the release of contaminants from sources (source loading) and processes that destroy or retard migration of contaminants in resultant plumes (attenuation capacity) through targeted intervention. The need for such intervention at each site should decrease over time, as MNA becomes the appropriate solution.

1.2 Need for Decision Tools

Over the last twenty-five years, cVOCs have been identified as one of the most common contaminants requiring remediation in groundwater at numerous sites across the U.S. and throughout the world. Most DOE sites have identified significant cVOC plumes, some of which are among the largest in the U.S. During this timeframe, site investigations have enabled delineation of the extent and concentrations of cVOCs within these plumes. In addition, active remediation systems, installed at many of these sites, have removed significant quantities of cVOCs. However, cVOC concentrations in groundwater remain significantly above MCLs, which typically represent the final remediation goals for these sites.

During the last ten years, advances in understanding of the capacity of natural systems to destroy or retard migration of these contaminants have become well recognized. However, because significant challenges related to our ability to predict engineered and natural remediation in the subsurface remain, tools that can enhance our ability to evaluate and compare alternative remediation approaches are needed.

Environmental decision-making is a significant challenge, because of competing needs and interests ranging from environmental and economic to socio-political. In many instances, comparative risk assessment and cost-benefit analyses are used in some integrated fashion to evaluate remedial alternatives. However, because the evaluation criteria (e.g., safety, risk, environmental impact, and cost) are complex, remedial alternatives cannot be easily compared to one another. Because trade-offs must be made to select a preferred alternative, comparative risk assessments and cost-benefit analyses do not always produce results satisfactory to the various stakeholder interests.

Decisions about the appropriate remediation approach for any given site are influenced by both technical and non-technical factors, such as economics, regulatory requirements and expectations, and stakeholder interests. Decisions specific to transitioning from active to a natural or EA approach are further complicated by cognitive biases that invest stakeholders in the status quo solution and make them reluctant to modify an approach that seems to be working. The lack of a formal, tested basis for determining whether, when, and how to transition to passive or attenuation-based approaches often results in active remediation being continued longer than is necessary to meet remedial objectives and goals.

The EPA MNA policy directive (EPA, 1999) recommended evaluation and comparison of MNA to other viable remediation methods during the study phases leading to remedy selection, early in the life of a project. However, a similar evaluation may be useful after some time of operation of the active remedial alternative, when it is time to consider other more passive or attenuation-based alternatives, to be used alone or in combination with active systems, as potential solutions.

1.3 Project Objective

The objective of this project is to develop and test a decision tool and process to support responsible decision-making regarding alternative remedial approaches at sites containing groundwater contaminated with cVOCs. The cVOC Remediation Decision Tool (cVOC Tool) has been designed specifically to be useful at sites with any type of ongoing treatment, and to give fair consideration to EA and MNA alternatives.

1.4 Potential Applications of the cVOC Tool

The primary application for this tool is to support evaluation, comparison, and discussion of alternatives when an existing active remedy is believed to no longer be effective or efficient, and when it may be desirable to transition to a more passive treatment approach. The cVOC Tool, however, can be applied to a wide variety of situations at any time in the evolution of a cVOC plume. Several potential applications are described in sidebars throughout this report.

The cVOC Tool can be used as a stand-alone decision aid or it can supplement other evaluation methods. It can be used relatively early in the life of a project during the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Feasibility Study (FS) or Resource Conservation and Recovery Act (RCRA) Corrective Measures Study (CMS) phase, or it can be used later in the life-cycle during assessment of the performance of the existing remedial system, such as during a CERCLA 5-year Record of Decision (ROD) review. Section 4 describes the steps required to apply the cVOC Tool to the evaluation of alternatives at a site. A sidebar in Section 3 describes how the cVOC Tool could be used to support a CERCLA FS.

The cVOC Tool was pilot tested at a site where a CERCLA FS had been performed (Section 5); however, consensus on the appropriate path forward was not reached. Because the site was being transferred to RCRA authority, there was an opportunity to utilize the cVOC Tool to perform another evaluation of alternatives, beginning a dialogue with the new regulatory staff.

The cVOC Tool could also be used by DOE Legacy Management staff during the long-term monitoring phase of a project to enable periodic assessment of the condition of the plume and its ability to meet requirements for MNA or EA.

EXAMPLE: USING THE CVOC TOOL TO SUPPORT A DECISION ABOUT WHETHER AND WHEN TO TRANSITION FROM ONE TREATMENT APPROACH TO ANOTHER

Sites with long-term, ongoing active treatment systems often face decisions regarding whether continued operation of the active system is the best remediation strategy. Such questions frequently arise when an active treatment system is no longer removing significant quantities of contaminants, yet costs of operation and maintenance remain high. An example of such a situation might be a site with significant chlorinated solvents in the vadose zone, for which a soil vapor extraction system has been operating for some period of time. Typically, a significant mass of contaminants is removed early on in the life of the system, after which contaminant concentrations decline asymptotically. The question becomes when should the site be transitioned to an alternative approach, which could involve a more passive soil vapor extraction system or MNA?

That transition should be made if and when there is an alternative available that is preferable to continuing the status quo. The cVOC Tool can provide a practical answer to the question of what a “preferable” alternative is: it is an alternative that better meets and balances the objectives included in the cVOC Tool. Suggestions of transitioning a site to a less active approach, such as EA or MNA often meet public and regulatory skepticism and concern. The cVOC Tool may help focus stakeholder discussions on the end goals for the site and the best way to achieve those goals, while providing a venue for dialogue among the various parties.

If, in an initial evaluation of remedial alternatives for a site, the evaluation team develops alternatives with a long-term vision, they can (and perhaps should) define and include alternatives that explicitly include a transition from more to less active treatment at some point in the future. The cVOC Tool can help identify “when” in the future the transition should be conducted, where “when” may be defined in terms of calendar time or in terms of site conditions – e.g., in 3 years, or when an SVE system has removed X% of the total mass, or when the system is operating at Y% of its peak efficiency. The most important step in using the cVOC Tool to facilitate this decision is the alternatives definition step: if the user carefully defines a range of alternatives that include possible transition strategies and times, evaluation of those alternatives will lead to selection of the alternative with the best transition strategy.

If an active treatment system is in place and operating without a transition plan, and the site manager or other stakeholders believe continued operation of the system is no longer the best strategy for the site, the cVOC Tool can be used to compare the continued operation of the existing system (the “status quo” alternative) with other alternatives identified by the evaluation team as potentially preferable. The Pilot Test application described in Section 5 included consideration of the status quo alternative in comparison with both more and less active options.

- When using the cVOC Tool for a site undergoing possible transition from active to *passive or attenuation-based* remediation, such as MNA or EA, other resources are available to support the decision-making process (Looney et al., 2006).

2.0 Overview of Decision Tool for Evaluating and Comparing Remedial Alternatives for cVOC Sites

The cVOC Tool is designed to be useful to those interested in exploring alternative approaches for addressing groundwater or soil cVOC contamination problems and reaching site closure. Such interest may be prompted by a variety of events, such as:

- discovery of previously unknown contamination;
- findings from periodic review of ongoing remediation activity outside of the anticipated performance of the system, e.g.,
    - active pump and treat systems yielding diminishing marginal returns;
    - monitoring results for an MNA solution not demonstrating the anticipated decrease in concentrations over time;
    - technical information suggesting that other remedies may be more effective and less costly than the ongoing remedy.

The cVOC Tool is based upon a structured analytic approach for comparing alternatives, involves a well-defined process for applying that approach, and is implemented through an easy-to-use Excel spreadsheet. The analytic approach is a proven, rigorous, and technically defensible method known as multi-attribute utility analysis (MAU), which is part of the practice of Decision Analysis (DA). DA is specifically designed to promote consistent and rational decision making in the face of technical complexity, significant uncertainties, and multiple, competing objectives. MAU helps the decision-maker balance competing objectives through application of value judgments reflecting the tradeoffs the decision-maker is willing to make between those objectives. Section 3.0 discusses the analytic basis for and the key elements of the cVOC Tool.

The MAU process is straightforward, although there is considerable flexibility in the scope and role of different stakeholder groups. To apply the process, a user (who could be the site remediation manager, regulatory-agency staff, a public stakeholder group, or some combination) will follow these steps:

- describe site characteristics and conditions;
- identify and specify a set of alternatives to be considered for the site;
- evaluate how well each alternative is expected to perform, using the objectives and performance metrics specified within the cVOC Tool;
- compare the evaluated alternatives using different techniques with a variety of visual outputs that are generated automatically:
    - comparison and consequences tables;
    - relative value of the alternatives using any of the value judgments built into the tool;
    - relative value of the alternatives using value judgments the user specifies.

Section 5.3 illustrates the types of outputs that were produced during the Pilot Test. Appendix A contains a detailed User’s Guide for the cVOC Tool spreadsheet.

3.0 Analytic Basis for and Structure of the cVOC Tool

An ideal decision support process and tool is defined by Merkhofer (1987) as:

- accurate, in that it produces results that are not biased towards or against any particular type of solution and that are not overly sensitive to untested assumptions;
- logically sound, so that results can be reproduced, and the basis for those results can be rationally explained;
- complete, in that it captures all key elements of the relevant decision problem;
- practical, in that users must be able to understand and apply the tool using resources available to them and in a reasonable time frame;
- effective, in that it serves its design purpose and is sensitive to the organizational issues regarding how and when decisions are made within an organization; and,
- acceptable to stakeholders, who have the power to influence decisions and outcomes.

The cVOC Tool recognizes that both technical and management value judgments are a necessary part of decision making and that different people may have different roles in the decision-making process. The sidebar describes the process of developing the MAU model, and each subsection below describes the results of that process as implemented in the cVOC Tool.

Technical judgments include definition of viable alternatives and evaluation of how well those alternatives are expected to perform. A variety of technical experts (e.g., risk assessors, groundwater modelers, remediation engineers, hydrogeologists, and cost estimators) are likely to be required to perform the evaluation. The technical judgments required are site-specific.

Management judgments include determination of the basic objectives for the site (which become the criteria by which the alternatives are evaluated), and the relative importance of each of the criteria. Formal procedures exist for developing scaling functions and weights that appropriately capture decision-maker and stakeholder values, and these judgments are commonly developed specific to an application with direct participation of the decision-makers. For the purposes of creating a tool that can be used by different sites and different users, several sets of management value judgments have been coded into the cVOC Tool, but an option is also provided for the user to specify his or her own set of value judgments.

MAU MODEL DEVELOPMENT PROCESS

There are three basic steps in developing a multi-attribute utility (MAU) model for a specific decision problem.

Identify the fundamental objectives of the decision makers and/or the stakeholders. These objectives represent the basic reasons why people care about the problem being considered, and the ultimate goals that an "ideal" decision or alternative would accomplish.

Develop performance metrics for each objective. Objectives are defined at a relatively high level: performance metrics specify how those objectives can be used to evaluate specific alternatives. Performance metrics are much more detailed than objectives, and are sometimes referred to as "scoring scales," because they are used to "score" the alternatives on the objectives.

Specify necessary value functions to allow quantification of the value of each alternative. Management value judgments include judgments about the relative value of improving on a single objective (e.g., is it more important to reduce the time to closure from 100 years to 50 years, or from 50 years to 1 year?), and about the relative value of improvements on one objective relative to another (e.g., is it more important to reduce the time to closure from 100 years to 50 years, or to reduce the total costs of the remediation from $50 million to $30 million?)

When no single alternative dominates the others (i.e., when no alternative is better than all others on all criteria), the management value judgments can be used to translate the evaluation on diverse criteria into a common, dimensionless scale of value. Decision makers can then compare disparate alternatives consistently and transparently. This type of decision process provides a defensible logic for the selection of a preferred alternative and enables communication of the results to a broader stakeholder group.

3.1 Objectives

Logical and defensible decisions about what remedial alternatives to implement at a site require that alternatives be evaluated against a set of fundamental objectives. To be most useful, objectives should be:

- clearly defined to facilitate generation and communication of insights for guiding the decision-making process;
- measurable to allow comparison between alternatives;
- non-redundant so that each objective captures a unique concern; and,
- relevant, so that all objectives represent consequences that could be used to differentiate among alternatives.

The cVOC Tool includes six objectives that are broadly applicable for managing and remediating cVOC plumes at any site, but which are also detailed enough to allow for consistent and logical evaluation of alternatives. An ideal alternative would accomplish all of the following objectives:

- minimize public health and safety risks
- minimize risk to worker safety
- minimize adverse environmental impacts
- maximize regulatory responsiveness
- minimize total cost, and
- minimize time to completion.

The CERCLA RI/FS process includes nine criteria to be used for evaluating alternatives. However, those criteria are often interpreted differently by various users and thus were not directly incorporated as specific objectives in the cVOC Tool. However, the six objectives in the cVOC Tool can be cross-referenced to the nine CERCLA criteria (see next page).

EXAMPLE: USING THE CVOC TOOL TO SUPPORT A CERCLA FS

If the cVOC Tool is used to compare alternative remediation approaches for a site as part of or in support of a CERCLA FS, it may be useful to present the results of that evaluation in terms of the nine "CERCLA decision criteria."

CERCLA includes two *"threshold criteria."* representing criteria that any alternative must meet to be considered acceptable. Each is included in the cVOC Tool:

- "Overall protection of human health and the environment" is evaluated by the estimated impact of each alternative on three objectives:
  - minimize risks to public health and safety
  - minimize risks to worker safety, and
  - minimize adverse environmental risks.
- "Compliance with ARARs" is evaluated by the objective "maximize regulatory responsiveness." Any alternative that is not compliant with ARARS will be assigned an evaluation of "not acceptable" on this performance metric.

The concept of a "threshold criteria" implies that there is some level of impact that the decision-maker had determined to be "unacceptable" (the threshold level). In any CERLCA evaluation, professional and managerial judgment is required to determine that threshold level of impact.

CERCLA also includes *"Balancing criteria,"* identified as important factors, but criteria that may be traded off or balanced in selecting the preferred alternative. Each is included in the cVOC Tool through at least one of the tools objectives:

- "Short-term effectiveness (STE)" and "Long-term effectiveness (LTE)" are both evaluated through a combination of the estimated time to completion and the impacts of each alternative on public health risks, worker safety, and adverse environmental impacts.
- "Reduction of toxicity, mobility, and volume (TMV) through treatment" is valued in the context of the cVOC Tool only as a means to reach other, more fundamental objectives, such as reducing health and environmental impacts, reducing time to completion, and maximizing regulatory responsiveness. To the degree that reduction of toxicity, mobility, and volume through treatment helps achieve these goals, the benefit is captured in the evaluation on those objectives.
- "Implementability" is evaluated through explicit consideration of the uncertainty in the costs of an alternative. Specifically, alternatives that are judged to be more difficult to implement will have more uncertainty about their final costs – and typically will have much greater high-side uncertainty – than those that are judged to be easy to implement.

CERCLA *"Modifying criteria"* represent additional considerations that can be taken into account in selecting the preferred alternative.

- Both "State acceptance" and "Community acceptance" are evaluated within the cVOC Tool through the objective of maximizing regulatory responsiveness.

The table below provides a "crosswalk" of the nine CERCLA criteria and how the objectives within the tool provide information relevant to each of those criteria.

Objective	**CERCLA Criteria**								
	Human Health and Environment	**ARARs**	**STE**	**LTE**	**Reduction of TMV**	**Implemen-tability**	**Costs**	**State Accep-tance**	**Comm. Accep-tance**
Public H&S	x		x	x	X				
Worker Safety	x		x	x	X				
Environ. impact	x		x	x	X				
Time to completion			x	x					
Regulatory responsiveness		x						x	x
Costs and cost uncertainty						x	x		

3.2 Performance Metrics

To better define the objectives and ensure they are useful in evaluating and comparing alternatives, we developed specific performance metrics for each. Performance metrics are a consistent set of measurement scales used to evaluate how well a specific alternative will meet a given objective. Performance metrics must accurately reflect the meaning of the fundamental objective and be defined in such a way that they are feasible to use. They should be clear and unambiguous, so that different individuals can interpret them consistently.

For the cVOC Tool, an important feature of the performance metrics is that they should be usable with whatever information is available at a site. Some sites may have detailed risk assessments and numerical modeling results, and in those cases the evaluation of alternatives can and should be based on the results of those detailed analyses. Other sites may have significantly less detailed or quantitative information available, and in those cases, the evaluation of the alternatives may have to be based primarily on expert judgments. The cVOC Tool performance metrics are designed to allow use of whatever type of information is available, from expert judgment to numerical modeling results.

Natural metrics exist for some of the objectives, and where such metrics exist, they are used. For example, cost is measured in dollars, and time to completion is measured in years. For other objectives, no natural metrics exist and special scales have been constructed. The metrics were developed specifically considering sites containing groundwater contaminated with cVOCs.

The metrics used in the cVOC Tool are described briefly below. Detailed scales for each of the performance metrics, and instructions to the user on how to interpret the scales in their evaluation are provided in Appendix A, the User Guide.

3.2.1 Impacts on Public Health and Safety

For cVOC groundwater plumes, the main human health risk concern is that people may be exposed to elevated levels of VOCs in groundwater through ingestion, inhalation, or dermal contact.

As shown in Figure 1, the impact on public health and safety is a function of several factors:

- ***Likelihood of Exposure*** (likelihood that anyone will be exposed to contaminants via the exposure pathway being evaluated);
- ***Number of People Potentially Exposed*** via that pathway;
- ***Timing of Exposure***;
- Risks to those individuals, if they are exposed. This in turn is a function of:
    - ***Likelihood of Health Impact, Assuming Exposure Occurs***, and
    - ***Severity of the Effect, Assuming It Occurs***.

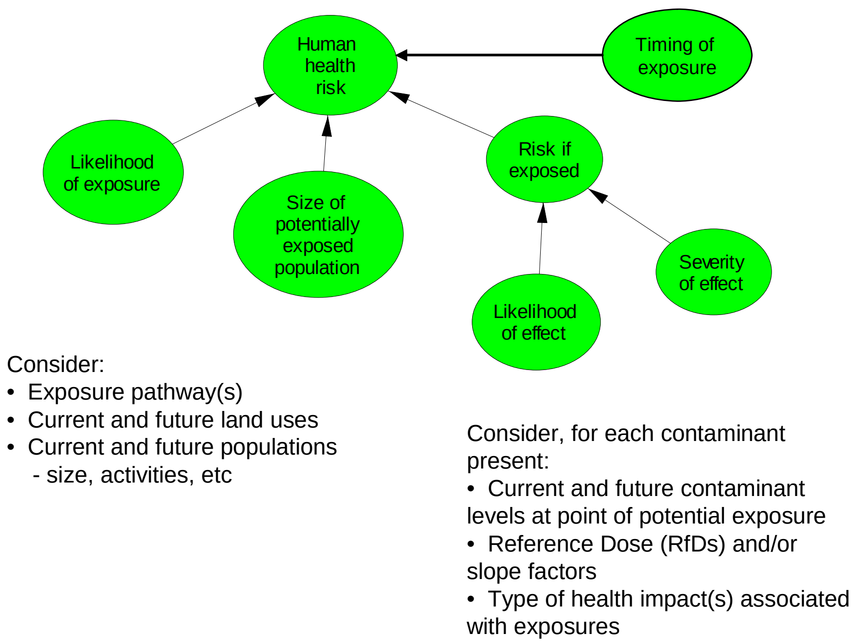

Figure 1. Performance Metrics for "Reduce Risk to Public Health and Safety"

Performance metrics with associated scales have been defined for each of these five factors that impact public health and safety; for example, the scale for ***Likelihood of Exposure*** ranges from *extremely unlikely* (e.g., 1 chance in 1,000,000) to *assured or almost certain.* Complete details are provided in the Users Guide, Appendix A.

3.2.2 Impacts on Worker Safety

In the course of implementing a specific remedial approach, site remediation workers may be exposed to a variety of safety and health risks, including risks related to the remediation activities themselves and potential exposures to contaminants. In evaluating risks to site remediation workers, users are asked to consider all potential pathways and mechanisms by which workers could be exposed to risks, and identify the most likely worker risk pathway. Examples of potentially relevant worker risks include:

- occupational injuries associated with construction activities,
- transportation-related risks associated with driving (e.g., transporting equipment and/or materials to and from a job site; driving to and from sampling locations required for long-term monitoring),
- inadvertent exposures to contaminants while conducting maintenance or monitoring activities.

Risk to worker safety is then a function of three factors:

- ***Likelihood of Worker Injury or Illness;***
- ***Number of Workers Potentially Affected***; and,
- ***Severity of Effect*** or seriousness of the most likely injury, assuming such injury occurs.

Performance metrics with associated scales of assessment have been defined for each of these three factors, and are described in detail in the Users Guide, Appendix A.

3.2.3 Impacts on the Environment

The overall impact on the natural environment from contamination problems at the site is a function of:

- ***Type of Environmental Resources*** potentially affected;
- ***Likelihood of an Adverse Impact*** on those resources;
- ***Severity and Duration of the Impact.***

To evaluate the impact on the environment from the specific site and/or problem, the user must first indicate what types of environmental resources might be affected by the contaminant plume, using a list of potential sensitive resources provided, and then use the performance metrics contained in the Users Guide (Appendix A) to estimate the likelihood and severity of the impact on each of the identified environmental resources.

3.2.4 Regulatory Responsiveness

To be considered viable, an alternative must comply with all applicable regulatory requirements. Although all viable alternatives are compliant, there may be a difference in how each alternative is perceived by the regulators, and how responsive to regulatory concerns they believe the alternative to be.

The scale for the Regulatory Responsiveness performance metric is used to estimate the degree to which an alternative will be seen as responsive to regulatory concerns. The metric ranges from "highly responsive" to "marginally responsive." "Not responsive" is also included on the scale, but alternatives judged "not responsive" are not considered viable options. Detailed description of the scale values are contained in the Users Guide in Appendix A.

3.2.5 Time to Completion

Time to completion is defined as the time at which further action aimed specifically at the site or problem being addressed will no longer be required. This includes any ongoing monitoring. The time to completion is often identified as the time at which contaminant concentrations in the groundwater are consistently below regulatory maximum contaminant limits.

Time to completion is estimated in years, although a performance metric, which accommodates uncertainty in the time required to reach closure, is provided in the Users Guide (Appendix A).

3.2.6 Total Estimated Costs

The final objective is to minimize the total costs to reach completion for the site problem being evaluated. Users are asked to provide an estimate of the total costs for the alternative being considered, assuming the alternative is implemented and continues through the end of the "time to completion" as estimated above. Total costs include any capital costs, operations and maintenance costs, and the costs associated with any ongoing monitoring associated with the alternative and the site.

The estimated costs for any alternative are expected to be uncertain, and the level of uncertainty about the total cost may be a relevant factor in decision-making. For example, if a technology is mature and has been applied elsewhere at the same site, there is likely to be less uncertainty about the total cost than if the technology is relatively new and has not yet been proven. Scales for estimating the potential for both cost overruns and under-runs are provided in the Users Guide in Appendix A.

3.3 Value Judgments

In addition to evaluating how an alternative performs for each performance metric, two types of management value judgments are required to calculate a MAU value for an alternative: single-attribute scaling functions and multi-objective value weights. Both types of value judgments reflect the relative value to a decision-maker of improvements in the alternatives. Single-attribute scaling functions quantify the benefit of improvements within a single objective, while multi-objective value weights quantify the tradeoffs a decision-maker is willing to make amongst the objectives.

3.3.1 Single-attribute Scaling Functions

Single-attribute scaling functions are used to quantify the importance or value of changes within a single objective. For example, an alternative that reduces the time to reach closure from 100 years to 5 years is a better alternative than one that reduces the time to reach closure from 100 years to 50 years. Single-attribute scaling functions allow one to say *how much* better the first alternative is than the second. The specific scaling functions implemented in the cVOC Tool are described below. All scaling functions are defined so that higher risks are indicated by higher values, and thus, alternatives with lower “risk scores” are preferred.

3.3.1.1 Impacts on Public Health and Safety

As described above, the impact of an alternative (A) on public health and safety is evaluated using five metrics:

1) likelihood of exposure (p_e),
2) number of people exposed (n),
3) likelihood of an adverse health effect occurring given exposure ($p_{effect|exposure}$),
4) time at which those effects would occur (t), and
5) a constructed scale describing the severity of the health impact, if one occurs (S_{PHS}).

The risk to public health and safety if alternative A is implemented and if the health impacts are assumed to occur within the next 5 years ($R_{PHS,\, t<5}$), is calculated as:

$$R_{PHS,\, t<5}\,(A) = p_e * p_{effect|exposure} * n * V(S_{PHS})$$

where $V(S_{PHS})$ is a scaling function defined on the metric for the severity of health impacts, as shown in Figure 2. By convention, the “worst” outcome is assigned a value of 100 (highest risk), and the "best" outcome is assigned a value of 0 (lowest risk). This scaling function indicates that the value of reducing the severity of an anticipated health effect from a "serious" effect to a "moderate" effect is much greater than the value of reducing the severity of a health effect from "moderate" to "temporary and minor." Alternatively, it can be interpreted as saying a "serious" effect is 10 times as bad as a moderate effect. Appendix A includes a detailed description of each of the severity levels shown on the x-axis.

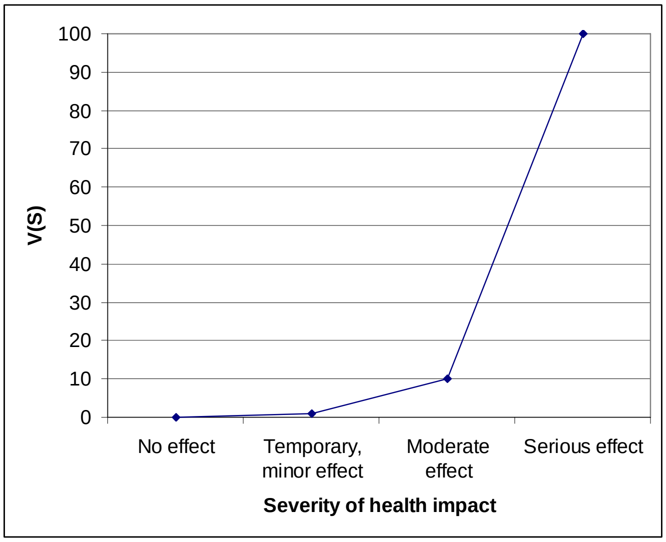

Figure 2. Scaling Function Indicating Relative Value of Reducing Severity of Public Health and Safety Impacts

Finally, the risk value associated with potential health impacts that may occur due to exposures in the near term is higher than if those exposures are expected to occur in the distant future. In the cVOC Tool, future health impacts are discounted at 3% per year, representing the social discount rate recommended by the Office of Management and Budget in their guidance on regulatory analysis (OMB, 2003)[1]. An option is available for the user to change that discount rate.

[1] OMB Circular A-4, September 2003, includes a detailed discussion of the rationale for discounting in cost-benefit and cost-effectiveness analyses, including the rationale for discounting health-related benefits and costs. The Circular specifies a "social rate of time preference" of about 3%. It also describes some of the reasons that "there is a professional consensus that future health effects, including both benefits and costs, should be discounted…" Those reasons include economic rationales (resources can be invested rather than spent today and result in higher future payoff in terms of lives saved) and rationales based upon observed preferences of individuals (health gains that occur immediately are preferred to health gains that occur in the future).

3.3.1.2 Impacts on Worker Safety

The impact of an alternative on worker safety is evaluated using three metrics:

1) likelihood of worker injury/injuries (p_{wi}),
2) number of workers at risk (n_w), and
3) a constructed scale describing the severity of the health impact, if one occurs (S_{WS}).

The risk to worker safety value [R_{WS} (A)] if alternative A is implemented is calculated as:

$$R_{WS}(A) = p_{wi} * n_w * V(S_{WS})$$

where $V(S_{WS})$ is a scaling function defined on the metric for the severity of worker safety impacts. This scaling function is identical to that for scaling the severity of public health impacts, as shown in Figure 2. The scaling functions are identical because the performance metric for estimating the severity of the health impact, should it occur, are identical, as seen in Appendix A, the User's Guide.

3.3.1.3 Impacts on the Environment

The seriousness of the impact of an alternative on the environment is a function of the:

- environmental resources affected [r]
- relative value associated with avoiding or eliminating impacts on each type of resource [Vr]
- likelihood of adverse impacts on those resources [$p_{ei,r}$]
- a value function for the severity of those impacts [$V(S_{E,r})$].

The risk to the natural environment [R_E (A)}if alternative A is implemented is calculated as the sum of the impacts on each affected environmental resource:

$$R_E(A) = \sum_r (Vr * p_{ei,r} * V(S_{E,r})).$$

Table 1, below, shows the relative value assigned to eliminating an adverse impact on various environmental resources (Vr). These values reflect the judgment that societal willingness to pay to protect some environmental resources (such as a threatened and endangered species) is greater than the willingness to pay to protect other environmental resources (such as recreational or open space public land uses). There is a wide range of opinions on the relative value of eliminating impacts on various environmental resources, and the tool includes the option for the user to modify these relative resource values to better match local values and conditions. Appendix A describes how to adjust the values.

Table 1. Relative Value of Eliminating an Adverse Impact on Various Environmental Resources

Environmental Resource	Relative value of eliminating an adverse impact on the resource
Coastal or marine environments	0.5
Sole-source ground water aquifer	1
Ground water potentially viable as drinking water	0.5
Ground water not viable as drinking water	0.1
Surface water	0.5
Wetlands	0.5
Population or habitat of Federal or state designated or candidate endangered or threatened species	1
Population or habitat of desginated sensitive species or species of concern	0.8
Population or habitat for other biological resources	0.3
Sites or areas of historic or cultural value, such as State or Tribal designated parks and recreation areas	0.5
Agricultural, recreational, open space or other public land uses	0.1

Figure 3 illustrates the value function for reducing the severity of impacts on an environmental resource [$V(S_{E,r})$]. Appendix A includes a detailed description of each of the severity levels shown on the x-axis.

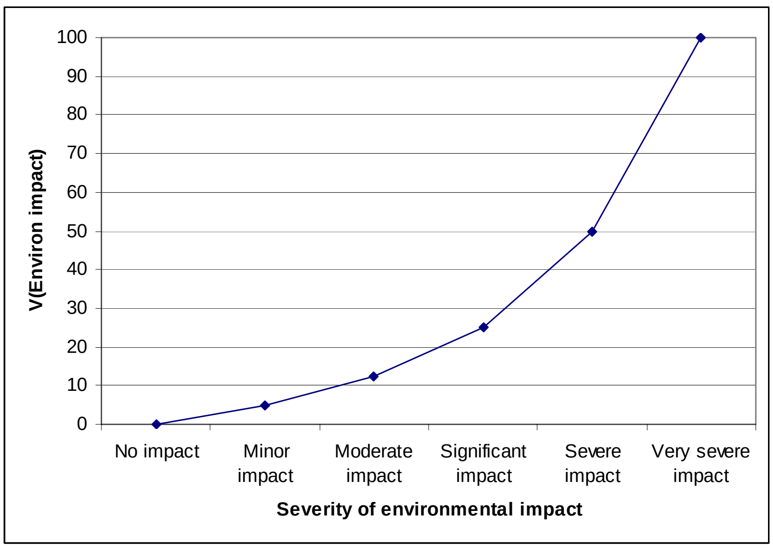

Figure 3. Scaling Function Indicating Relative Value of Reducing Severity of Adverse Environmental Impacts

3.3.1.4 Regulatory Responsiveness

The regulatory responsiveness of an alternative is evaluated using a single performance metric, and the value associated with improving from one level of impact to another is taken directly from the scaling function shown in Figure 4 (R_{rr}). As discussed above and shown in the User's Guide, the metric for regulatory responsiveness includes a level called "not responsive." Because alternatives that are not responsive are considered not viable, they are assigned an arbitrarily high[2] "regulatory responsiveness" value, not illustrated on this chart.

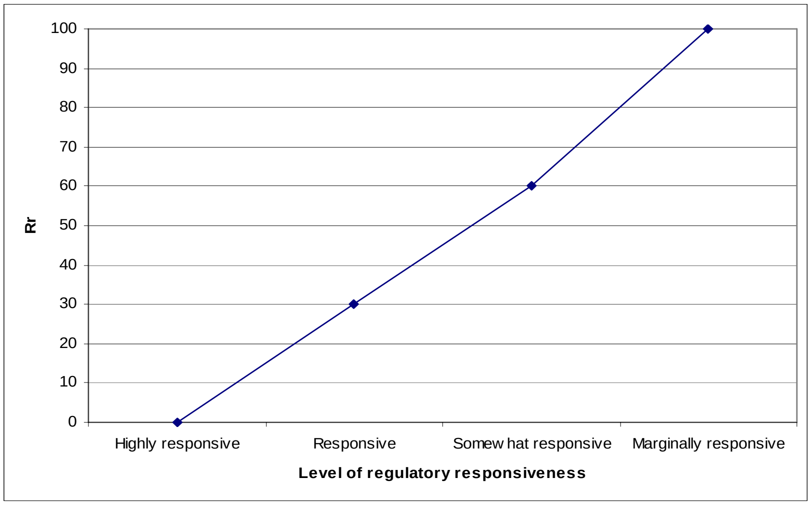

Figure 4. Scaling Function Indicating Relative Value of Achieving Different Levels of Regulatory Responsiveness

3.3.1.5 Time to Completion

Time to completion is evaluated using a single performance metric in terms of years to closure. The value associated with reducing the time required to reach closure is assumed to be in direct proportion to the reduction in years. For each scale descriptor, the mid-point of the range of years is used, and the value function for time to completion (R_t) is linear in years, reflecting a judgment that the value of reducing the time to completion from, say, 50 years to 40 years is the same as the value of reducing the time to completion from 20 years to 10 years. If the user has preferences for reducing time to completion that are significantly different from linear in years, an option is available for the user to modify this function. That option is described in Appendix A, the User's Guide.

3.3.1.6 Total Estimated Costs

In translating the total estimated costs into a value that can be combined with the values for the other objectives, both the total cost estimate and the uncertainty in the estimated total costs are used. Remediation costs are often thought to follow a lognormal distribution, where there is the potential, though small, for costs to far exceed the best estimate. The value associated with the cost estimate for Alternative A [$R_{c(}A)$] is calculated by assuming that the total estimated cost value represents what the user believes will be the most likely cost, and the low and high cost estimates represent the 10^{th} and 90^{th} percentiles of a probability distribution on total costs. The mean value of

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[2] The value was chosen to be sufficiently high that an alternative judged to be "not responsive" will always evaluate worse than any other option, unless zero weight is put on regulatory responsiveness (see Section 3.3.2).

the distribution is then calculated assuming the cost probability distribution is lognormal and used in the overall value calculation.

3.3.2 Multi-objective Value Weights

The second set of management value judgments are judgments about the importance of improvements on one objective relative to the others. The establishment of weights for each of the objectives results in a consistent evaluation of the alternatives. There are, however, no universally applicable weights that should necessarily be used for all sites under all conditions; the weights represent judgments by the responsible decision-makers about the tradeoffs they consider to be appropriate for their situation, and are typically the result of considerable discussion.

To facilitate evaluation and comparison of alternatives, the cVOC Tool includes three sets of weights specified to represent various stakeholder viewpoints. There is also an option for the user to specify his/her own set of weights. By performing the evaluation using the three sets of specified weights and also setting his own weights, the user can assess the results from multiple viewpoints, which will provide useful information about sensitivity of the results. This thorough assessment can then lead to interactive discussions between different stakeholders.

The three sets of weights were selected to represent three different viewpoints:

- *Weight Set 1*
    - places a high value on reducing risks to public health and on reducing worker risks;
    - balances those values against costs in a manner consistent with values derived from a wide range of studies of the tradeoffs implied in public spending and federal regulation[3].
- *Weight Set 2*
    - increases the value on reducing risks to public health and worker safety, and reducing adverse environmental impacts, by a factor of 10 over the values in Weight Set 1;
    - places a strong emphasis on risk reduction over any of the other objectives (costs, time to completion, regulatory responsiveness).
- *Weight Set 3*
    - places a high value on regulatory responsiveness and decreasing the time to closure;
    - tradeoffs between reducing public and worker risks and cost reduction are similar to that in Weight Set 1, but the values on improving regulatory responsiveness and reducing time are increased by a factor of 5.

In establishing and discussing the weights on each objective, it is critical to understand the context for and meaning of the weights. Weights in a MAU analysis do *not* represent

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[3] Based upon OMB Circular A-4, the willingness to pay for reductions in small risks of premature fatality, expressed as the "value of statistical life" from a broad range of studies, is between $1 million and $10 million. The weights used here represent a "value of statistical life" of $5 million.

some abstract notion of the relative importance of each objective; rather they represent the relative values o*f specific levels of improvement* on each objective. In establishing weights, the decision-maker is shown clearly defined changes in the level of performance on each scale and asked to consider which changes are most valuable, and how much more change on one objective is valued compared to change on the others.

Table 2 shows the three sets of weights specified in the cVOC Tool. Detailed instructions on how the user can define his or her own set of weights are included in the Users Guide in Appendix A.

Table 2. Three Alternative Sets of Weights

	What is the relative value of improving from this level of performance…	…to this level of performance	Weight set 1	Weight set 2	Weight set 3
Maximize public health and safety, minimize worker risks	Chances are likely (1 chance in 10) that about 1000 people will be exposed to elevated levels of contamination within the next 5 years. If such exposures occur, health effects are relatively likely (about 1 chance in 100), and such health effects will be serious	Chances of exposure to elevated levels of contamination are about 1 in a million. If exposures occur, only 1-2 people will be exposed and such exposures will be more than 500 years in the future. Health effects from the exposure are extremely unlikely (1 chance in a million), and such health effects will be minor and temporary	25	250	25
Minimize adverse environmental risks	There is about a 50% chance that a highly valued environmental resource, such as habitat for a threatened or endangered species will suffer a severe level of impact (i.e., widespread and potentially permanent) due to contamination from the site	There is less than a 10% chance that valued environmental resources suffer any adverse impacts due to contamination from the site. If such impacts occur they will be minor and self-correcting within a year.	12.5	125	12.5
Maximize regulatory responsiveness	The current solution is viewed as marginally responsive to regulatory concerns	The proposed solution will be viewed as highly responsive to regulatory concerns	10	10	50
Minimize time to completion	The time to reach completion for the site is estimated to be about 100 years	Closure is expected within 5 years	10	10	50
Minimize total estimated costs	The estimated discounted total costs to reach closure for the site are about $10 million	The estimated discounted total cost to reach closure for the site is about $5 million	25	25	25

3.4 Calculating an MAU Value for Each Alternative

The final step in the evaluation process is to calculate a single measure of value that represents all of the objectives for each of the alternatives, thus enabling an overall comparison among the alternatives. This step combines the technical judgments of knowledgeable site experts, encoded as the evaluation of the alternatives using the performance metrics with the management value judgments encoded in the cVOC Tool or provided by the responsible decision makers.

The objectives were selected to meet a special independence criterion known as preferential independence[4], which allows a simple additive form for calculating the value of an alternative, A:

$$V(A) = W_{PHS}*R_{PHS}(A) + W_{WR}*R_{WR}(A) + W_E *R_E(A) + W_R*R_R(A) + W_C *R_C(A) + W_T *R_T(A)$$

Where the W's represent the weights on each objective, and the R's represent the single attribute value functions for each objective.

[4] Objectives are preferentially independent if the value of improvements within an objective do not depend on the level of any other objective, as viewed by the decision maker. For example, if the value of reducing environmental impacts from a moderate to a low level is the same regardless of whether the alternative will lead to completion in 10 or 20 years, the two objectives are said to be preferentially independent.

4.0 Applying the cVOC Tool

The process for using the cVOC Tool calls for a collaborative discussion among the various stakeholders throughout the evaluation. It begins with review of the objectives currently specified in the cVOC Tool to ensure that all the critical objectives for a particular site are included in this assessment. We believe the cVOC Tool as currently constructed contains high-level objectives that meet the requirements for most, if not all, cVOC sites.

The sidebar outlines briefly the five steps required to apply the cVOC Tool. Discussion and additional detail on each of these application steps follows.

4.1 Identify Alternatives

Identification of viable alternatives for a site can be relatively straightforward, or may be quite complex, depending on the site and its current status. Identifying creative alternatives is one of the more challenging steps in any decision problem. This section outlines some of the types of alternatives that might be considered, based on work done elsewhere, and points to other resources that the evaluation team may consider using to get ideas on alternatives for their site.

The evaluation team must review current information that has been gathered about the site in terms of geology, hydrology, contaminant distribution, and performance of any ongoing remedial alternative. This information is typically input into a site conceptual model. The amount of information available to perform this part of the evaluation can vary significantly, but the team must work with the currently available data from which they then identify various alternatives to be considered for management of the site.

Considerable information on various alternatives is available on the Internet at sites such as EPA's www.clu-in.org, Ground Water Remediation Technologies Analysis Center's www.gwrtac.org and Interstate Technology Regulatory Council's www.itrc-web.org. The DOE MNA/EA Project produced a document on EA that provides significant discussion of remedial

APPLYING THE cVOC TOOL

There are five steps for implementing the cVOC Tool.

Identify alternatives to be evaluated. Alternatives describe what can be done to remedy the contamination at a site. They need to be identified by the decision-maker or other user, and defined with sufficient clarity that they can be evaluated.

Evaluate how well each alternative meets the objectives. The performance metrics are used to evaluate (or "score") expected performance of each alternative. Where significant uncertainties that may affect performance of several alternatives exist, separate evaluations for different future states of the world may be necessary.

Review consequence matrix. After careful evaluation of the alternatives, it may be possible to identify alternatives that are dominated (i.e., where another alternative exists that is better on all objectives), or, occasionally, a dominant alternative (i.e., one that is better than all other alternatives on all objectives).

If necessary, ***calculate a value for each alternative.*** If a dominated alternative does not exist, alternatives can be compared by using the evaluation and value judgments to calculate a value for each alternative. This provides a single metric that can be used to compare alternatives on a consistent basis.

Conduct sensitivity analyses. Model outputs depend, of course, on model assumptions and inputs. In cases where the user is uncertain about the evaluation of a given alternative, they may wish to conduct the evaluation with several different scores for that alternative. Other key model assumptions are the scaling functions and weights on the objectives. The cVOC Tool has alternative sets of weights built in, and results under different weight sets should be considered and compared.

alternatives, with a focus on EA and MNA approaches (Early, 2006).

For cVOC plumes, alternatives may include: pump and treat, MNA, in situ bioremediation, in situ chemical oxidation, in situ thermal treatment, permeable reactive barriers (PRB), containment options, hydraulic manipulation such as covers, etc. When considering alternatives, it is also critical to consider other factors, such as institutional controls and groundwater monitoring as part of the alternative.

Alternatives may be defined as a combination of approaches, where one type of action may be applied in one portion of a plume and a different action taken in another portion of the same plume. Alternatives may also be coupled as a treatment train, where one action is applied first, and then followed by another action. When evaluating whether an existing active treatment system should transition to an EA or MNA alternative, the continued operation of the existing system should be evaluated as one alternative. If the plume is large, as is often the case for cVOC plumes at DOE sites, it is often impractical to actively treat the full extent of the plume that is above MCLs. If this is the case, MNA should be considered as one alternative for the distal portion of the plume.

Alternatives selected must be unique and tailored for each site based upon the geology, hydrology, distribution and concentration of contaminants and co-contaminants, travel time to receptors, plume stability and mobility, etc. Figure 5 below shows the transition from active to passive technology classes as well as examples of technologies along this continuum.

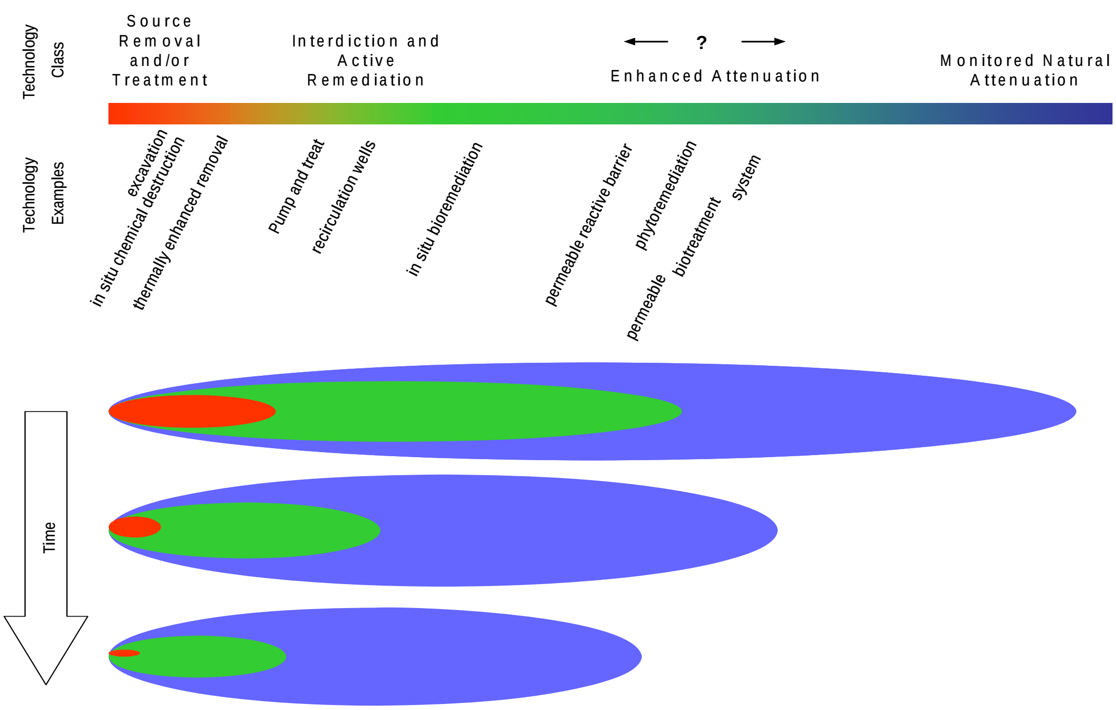

Figure 5. A Range of Technologies is Required to Meet Plume Remediation Needs (from Looney et al., 2006)

4.2 Evaluate Alternatives

After identifying and specifying the alternative remediation and monitoring approaches to be considered for the site, the evaluation team uses the performance metrics and the cVOC Tool to "score" each alternative against the objectives. Detailed directions for this step are included in the Users Guide in Appendix A.

4.3 Review Consequence Table

The inputs can be summarized in a "consequence table," which compares the alternatives on each of the objectives, based on the scores provided by the evaluation team. Although such a table is simply a re-iteration of the evaluation inputs, it often makes a powerful communication tool and facilitates discussion of the alternatives among stakeholders.

As an example, Table 3 in Section 5 shows the consequence table from the Pilot Test: nine alternatives were evaluated; this table shows how each scored on the objectives.

There are two typical uses of the consequence matrix. The first is to look for dominant or dominated alternatives; if an alternative exists that is better than another on all objectives, the latter alternative need not be considered further.

The second use is to stimulate creative thinking about new alternatives, particularly in discussion of the matrix with stakeholder groups. Seeing how an alternative compares with others often causes individuals or groups to identify ways that an alternative can be modified to make it more attractive, leading to an iterative analysis.

4.4 Calculate a Value for Each Alternative and Compare

With the cVOC Tool, this step is automatically carried out. Once the evaluation step is completed, a value for each alternative is calculated and the alternatives can be compared in terms of their calculated values. The next step, however, is critical for understanding and interpreting the results.

4.5 Conduct Sensitivity Analyses

With the cVOC Tool, there are a wide range of sensitivity analyses that can be conducted. The ability to carry out such analyses is included in the cVOC Tool, and many sensitivity analyses are automated. Recommended sensitivity analyses include:

- Compare the alternatives one objective at a time: this allows the user to see the relative "value" of each alternative from a single perspective, and is equivalent to giving all other objectives zero weight. Figures 6-11 in Section 5 illustrate these outputs for the Pilot Test.
- Compare the relative value of the alternatives using the three built-in weight sets. In some cases, the best alternative might not vary with the different weights. If the three sets span or encompass the value judgments of the decision-makers for the site, then selection of a single set of weights might not be necessary. Figures 12-14 in Section 5.0 illustrate these outputs for the Pilot Study.
- Consider whether the evaluation team wants to define alternative value functions or an alternative set of weights to calculate the value of each alternative. If the

team or the relevant decision-maker has a set of values that is significantly different from the three built-in options, specifying a new set of weights may be useful and informative. Detailed instructions on how to define new weights within the cVOC Tool are included in the Users Guide in Appendix A.

5.0 The Pilot Test

5.1 Site/Problem Description

The site selected for the Pilot Test of the cVOC Tool is the A-Area Burning Rubble Pit/Metals Burning Pit and Miscellaneous Chemical Basin (ABRP/MBP/MCB) Operable Unit (OU) at the DOE Savannah River Site (SRS) in South Carolina. The focus of the cVOC Tool Pilot Test at this OU is on groundwater contamination, which primarily consists of cVOCs.

5.1.1 Site Geology, Hydrology, and Contaminant Distribution

The site is underlain by Atlantic Coastal Plain sediments in a southeast-dipping wedge (WSRC, 2004). The sediments, from Cretaceous to Miocene in age, are composed of sands, silts, and clays. Groundwater flows easily through the sand layers, but is retarded by less permeable clay beds, creating a complex system of aquifers.

Groundwater contamination under the ABRP/MCB/MBP OU is found in the M-Area aquifer zone (MAAZ) and in the deeper Lost Lake aquifer zone (LLAZ). Depth to the water table is approximately 150 feet. Flow is principally vertically downward from the MAAZ to the LLAZ. The cVOC groundwater plume is approximately one mile in length in the LLAZ. Measured concentrations in 2005 are significantly lower than in previous years, with a maximum concentration of less than 500 μg/l.

5.1.2 Site Status

The ABRP/MBP/MCB OU underwent a Remedial Investigation (RI) and Feasibility Study (FS) under CERCLA for the sources, vadose zone, and groundwater portions of the unit. Because the site is located down-gradient of the larger M-Area groundwater plume, which is managed under RCRA, the groundwater portion of this OU has recently been moved to RCRA jurisdiction, so that it can be managed in a similar fashion to the up-gradient groundwater plume by the South Carolina Department of Health and Environmental Control (SCDHEC). Final source control actions, including soil vapor extraction, excavation, and capping have been completed or will be expanded as part of the CERCLA final ROD. An interim action for groundwater (three lines of recirculation wells) has been operating in the LLAZ since 2002.

In addition to the CERCLA FS, a Proposed Plan (WSRC, 2005) was prepared using the FS as a basis. The Proposed Plan established the following Remedial Action Objectives and Remedial Goal Options for groundwater:

- prevent human exposure to contaminated groundwater above MCLs;
- reduce contaminant concentrations in groundwater to below MCL levels;
- prevent the discharge of contaminated groundwater to surface water above MCLs and migration to lower aquifers to the extent practicable.

RGO's for TCE and PCE are 5 μg/l and for DCE are 70 μg/l.

For the FS and the Proposed Plan, sixteen alternatives were evaluated for groundwater subunits. All alternatives, except for the no action alternative, had institutional controls and periodic groundwater monitoring as a component. The alternatives included various combinations of groundwater recirculation wells, chemical oxidation, PRB, and MNA to various cleanup goals, either 100 µg/l or 500 µg/l in either or both of the two aquifers, MAAZ and LLAZ. The alternative recommended in the Proposed Plan (WSRC, 2005) was MNA in both the MAAZ and LLAZ, but consensus among stakeholders was not reached.

5.2 The Evaluation Process

One of the key components of the evaluation process was involvement of the SCDHEC regulators. Prior to conducting the evaluation, the project team met with SCDHEC to get their feedback. SCDHEC provided valuable input on the objectives included in the tool and useful, informal, discussion of the alternatives. The pilot test is recognized as only a test of the cVOC Tool, and does not imply any regulatory acceptance of the results in term of final remediation actions for the site.

After the meeting with SCDHEC, the project team met for about five hours to conduct a preliminary evaluation, which included: 1) selection of alternatives to be considered, 2) use of the metrics to evaluate the alternatives, 3) review of preliminary results, and 4) conduct of sensitivity studies. Because an FS had been conducted for the site, a strong data base, including groundwater modeling predictions of time to cleanup and detailed cost estimates, was available to support the evaluation.

During the Pilot Test, the project team recommended addition of the objective called "Minimize Risks to Worker Safety." Because this objective was added to the cVOC Tool after the preliminary evaluation was completed, the project manager completed the evaluation of alternatives in terms of their risks to worker safety at a later time.

5.2.1 Alternatives Considered for the Pilot Test

For the Pilot Test, the alternatives considered were a modified sub-set of those used in the CERCLA FS plus one additional alternative, that of continuing with current operations. The sub-set of alternatives from the CERCLA FS was modified to reflect the improvement in water quality that has occurred since the FS evaluation. As such, the treatment target was lowered from100 µg/l to 50 µg/l and alternatives with 500 µg/l treatment targets were not included. All alternatives, except for "No Action," include institutional controls and groundwater monitoring. Nine alternatives were considered for the Pilot Test evaluation:

- No action (stop interim treatment, no institutional controls, no monitoring)
- Continue with operation of current recirculation wells to 50 µg/l
- MNA in LLAZ and MAAZ
- Active treatment to 50 µg/l in the LLAZ, MNA in the MAAZ and residual LLAZ
    - Groundwater recirculation (new wells to be installed)
    - Chemical oxidation
    - Permeable reactive barrier
- Active treatment to 50 µg/l in the LLAZ and MAAZ and MNA in residual

- Groundwater recirculation in the LLAZ and MAAZ
- Chemical oxidation in the LLAZ and groundwater recirculation in the MAAZ
- Permeable reactive barrier in the LLAZ and groundwater recirculation in the MAAZ.

The permeable reactive barrier was the only EA alternative evaluated. Biological enhancements were considered, but based on the aerobic aquifer conditions and large extent of the contaminant plume, multiple injections over time would be needed, which would make it an active treatment, not likely to be feasible.

The no action alternative was included in the pilot for comparative purposes only. As shown below, the no action alternative is judged to be "not responsive" to regulatory requirements, and thus is not considered a viable alternative. In general, alternatives that are not responsive to regulatory requirements need not be evaluated, unless there is some other reason to do so. In the case of the Pilot Test, the team found it useful to consider the public health risks and environmental risks associated with "no action" as a starting point for estimating the risk reductions provided by the other alternatives. CERCLA FS's generally require that a no action alternative be evaluated, even if that alternative is not considered feasible.

5.3 Results of the Evaluation

5.3.1 Consequence Table

Table 3 illustrates the results of the evaluation of alternatives in a consequence table. Based on this table, it might be possible to eliminate some alternatives from further consideration. In particular, note that the two alternatives involving a PRB perform the same as the other active treatment options in terms of time to completion, risks to public health and the environment and regulatory responsiveness, but at about four times the cost. Unless there are other reasons not captured by the analysis for including these options, they could be eliminated for further consideration.

Table 3. Consequence Table for the Pilot Test

ALTERNATIVE	No action	MNA in MAAZ & LLAZ	Operate exsisting gw recirc wells to 50 ppb; MNA in residual	GW recirc in LLAZ to 50 ppb; MNA in remaining	ChemOx in LLAZ to 50 ppb; MNA remaining	PRB in LLAZ to 50 ppb; MNA remaining	GW recirc in LLAZ & MAAZ to 50 ppb	ChemOx in LLAZ to 50 ppb; GW recirc in MAAZ to 50 ppb	PRB in LLAZ to 50 ppb; GW recirc in MAAZ to 50 ppb	
Time to Completion (in years)	43	43	40	30	25	25	27	24	24	
Costs										
Estimated total costs	$0	$4,800,000	$7,500,000	$11,200,000	$11,400,000	$45,100,000	$11,400,000	$11,600,000	$48,300,000	
Costs could be as low as:	$0	$3,600,000	$5,625,000	$8,400,000	$8,550,000	$40,590,000	$8,550,000	$8,700,000	$43,470,000	
Costs could be as high as:	$0	$7,200,000	$11,250,000	$16,800,000	$22,800,000	$56,375,000	$17,100,000	$23,200,000	$60,375,000	
Regulatory Responsiveness										
The proposed solution is likely to be viewed by the regulator as:	Not responsive	Somewhat responsive	Responsive	Highly responsive	Highly responsive	Highly responsive	Highly responsive	Highly responsive	Highly responsive	
Impact on Public Health and Safety										
Exposure to elevated levels of contaminants is:	Relatively likely (e.g., 1 in 100)	Extremely unlikely (e.g., 1 in 1,000,000)	Extremely unlikely (e.g., 1 in 1,000,000)	Extremely unlikely (e.g., 1 in 1,000,000)	Extremely unlikely (e.g., 1 in 1,000,000)	Extremely unlikely (e.g., 1 in 1,000,000)	Extremely unlikely (e.g., 1 in 1,000,000)	Extremely unlikely (e.g., 1 in 1,000,000)	Extremely unlikely (e.g., 1 in 1,000,000)	
If such exposure occurs, the number of people exposed will be:	Moderate: roughly 100 people	Very small: 1-2 people	Very small: 1-2 people	Very small: 1-2 people	Very small: 1-2 people	Very small: 1-2 people	Very small: 1-2 people	Very small: 1-2 people	Very small: 1-2 people	
And the exposure will occur in about:	10 to 20 years	10 to 20 years	10 to 20 years	10 to 20 years	10 to 20 years	10 to 20 years	10 to 20 years	10 to 20 years	10 to 20 years	
If exposure occurs, adverse impacts on health are:	Very unlikely (e.g., 1 in 100,000)	Very unlikely (e.g., 1 in 100,000)	Very unlikely (e.g., 1 in 100,000)	Extremely unlikely (e.g., 1 in 1,000,000)	Extremely unlikely (e.g., 1 in 1,000,000)	Extremely unlikely (e.g., 1 in 1,000,000)	Extremely unlikely (e.g., 1 in 1,000,000)	Extremely unlikely (e.g., 1 in 1,000,000)	Extremely unlikely (e.g., 1 in 1,000,000)	
And the severity of the effect will be:	Serious effect	Serious effect	Serious effect	Serious effect	Serious effect	Serious effect	Serious effect	Serious effect	Serious effect	
Impact on Worker Safety										
The number of worker potentially exposed to safety risks is about:	N/A	Very small: 1-2 people	Very small: 1-2 people	Very small: 1-2 people	Very small: 1-2 people	Small: less than 10 people	Very small: 1-2 people	Very small: 1-2 people	Small: less than 10 people	
The likelihood any worker will suffer an adverse safety or health effect is:	N/A	Somewhat unlikely (e.g., 1 in 1,000)	Relatively likely (e.g., 1 in 100)	Relatively likely (e.g., 1 in 100)	Likely (e.g., 1 in 10)	Relatively likely (e.g., 1 in 100)	Relatively likely (e.g., 1 in 100)	Likely (e.g., 1 in 10)	Relatively likely (e.g., 1 in 100)	
And the severity of that effect will be:	NA	Moderate effect	Moderate effect	Moderate effect	Moderate effect	Moderate effect	Moderate effect	Moderate effect	Moderate effect	
Impact on Environmental Resources										
Ground water										
The likelihood this resource will suffer an adverse impact is:	N/A	Greater than 90%	Greater than 90%	Greater than 90%	Greater than 90%	Greater than 90%	Greater than 90%	Greater than 90%	Greater than 90%	
The impact, if it occurs, will be:		Significant impact	Significant impact	Moderate impact	Moderate impact	Moderate impact	Moderate impact	Moderate impact	Moderate impact	

Note: all alternatives except the "No Action" alternative include institutional controls and monitoring.

5.3.2 Comparison of Alternatives on Each Objective

Figures 6 through 11 display the results of the alternatives evaluation on each of the objectives:

- Risks to Public Health and Safety (Figure 6)
- Risks to Worker Safety (Figure 7)
- Risks to Environmental Resources (Figure 8)
- Regulatory Responsiveness (Figure 9)
- Time to Completion (Figure 10), and
- Estimated Total Costs (Figure 11).

In each of these figures, lower numerical values indicate better alternatives. For example, a lower calculated value for public health and safety risk indicates the alternative poses lower risks to the health and safety of the public.

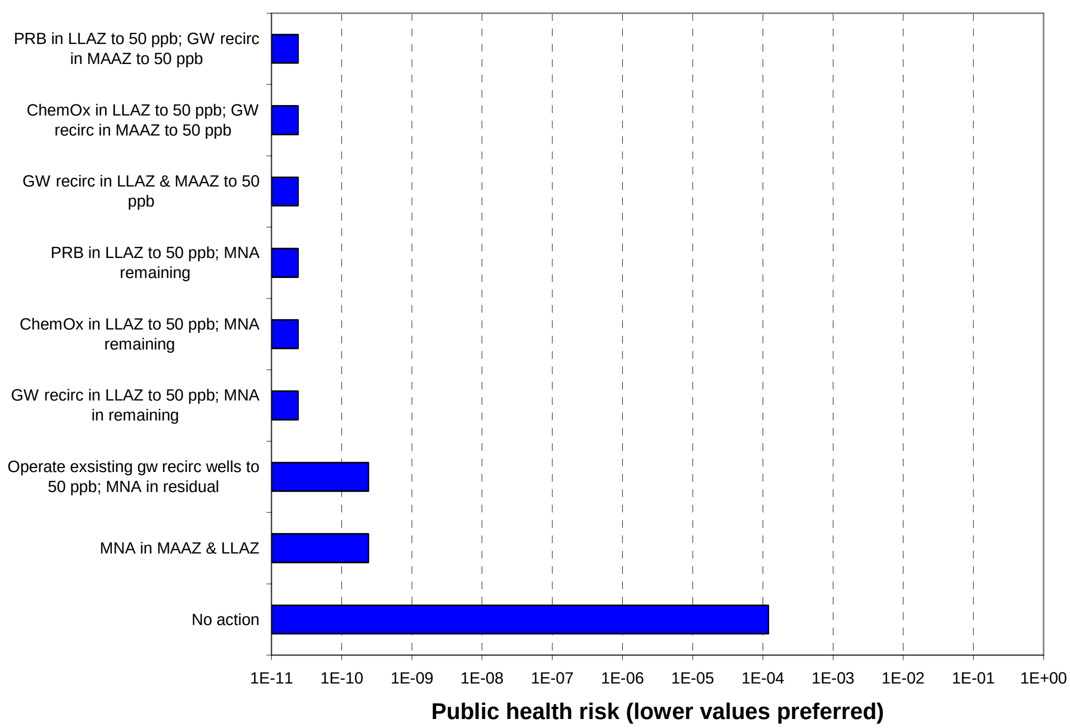

Figure 6. Comparison of Pilot Test Alternatives in Terms of Their Impact on Public Health and Safety

Figure 6 illustrates that the no action alternative is the worst from the perspective of minimizing risks to public health and safety; the MNA alternative and the status quo alternative (continuing to operate the existing recirculation wells) are equivalent in terms of protecting public health (and are an improvement over no action); and all six active-treatment alternatives further reduce risks to public health.

In terms of public health risks, the no action alternative differs from the MNA and status quo alternatives in that it does not assume the presence of institutional controls. As shown in Table 3, the institutional controls that are part of the MNA and status quo alternatives reduce the probability that anyone will be exposed to elevated levels of contaminants, and reduce the number of people who could potentially be exposed, thereby reducing the overall risks to public health associated with the site. The additional reduction in risk associated with the six more aggressive treatment alternatives is a result of further reduction in concentrations in the groundwater, which leads to the illustrated reduction in the probability of adverse impacts, if exposure should occur.

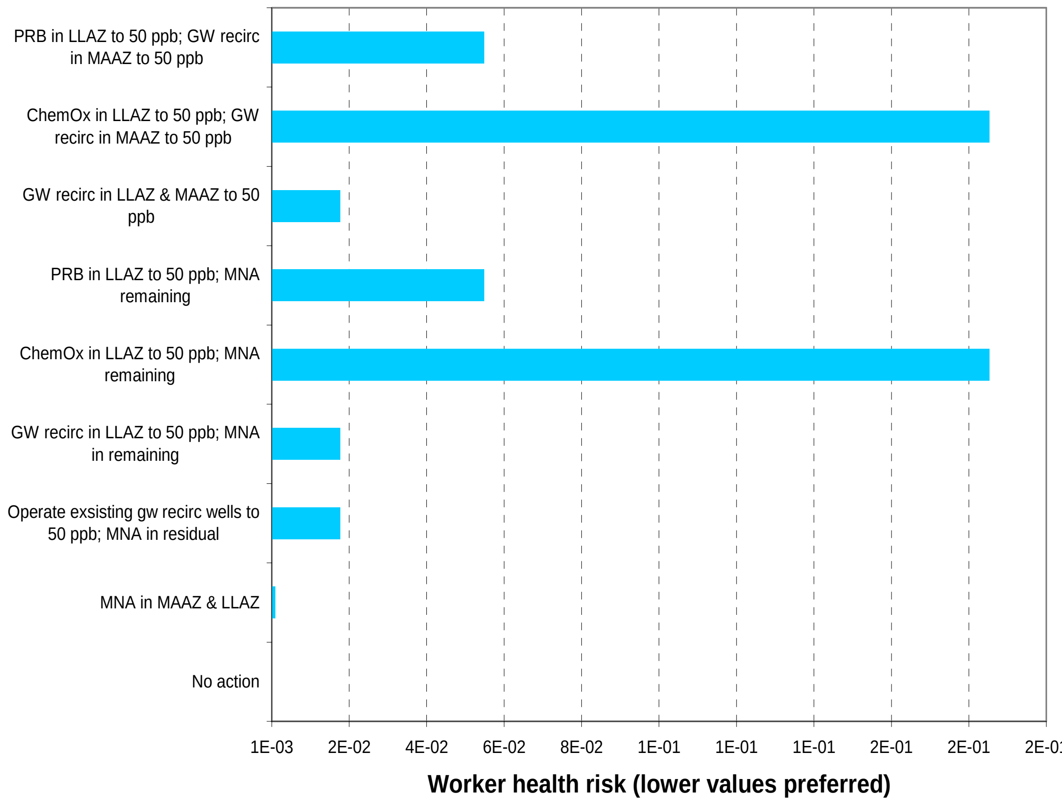

Figure 7. Comparison of Pilot Test Alternatives in Terms of Their Impact on Worker Safety

Figure 7 illustrates the relative risk to worker safety posed by each of the alternatives. The no action alternative poses the lowest risk to worker safety, because no one will be taking actions on the problem. The MNA alternative poses very low risks, although some risks to workers are incurred by the required monitoring activities. Of the more active alternatives: 1) chemical oxidation involves the highest risk to workers because of the risks from working with the chemicals involved, 2) the permeable reactive barrier alternatives have the second highest risk, because more people will be exposed to construction-related risks, and 3) the groundwater recirculation wells have the lowest risk to workers.

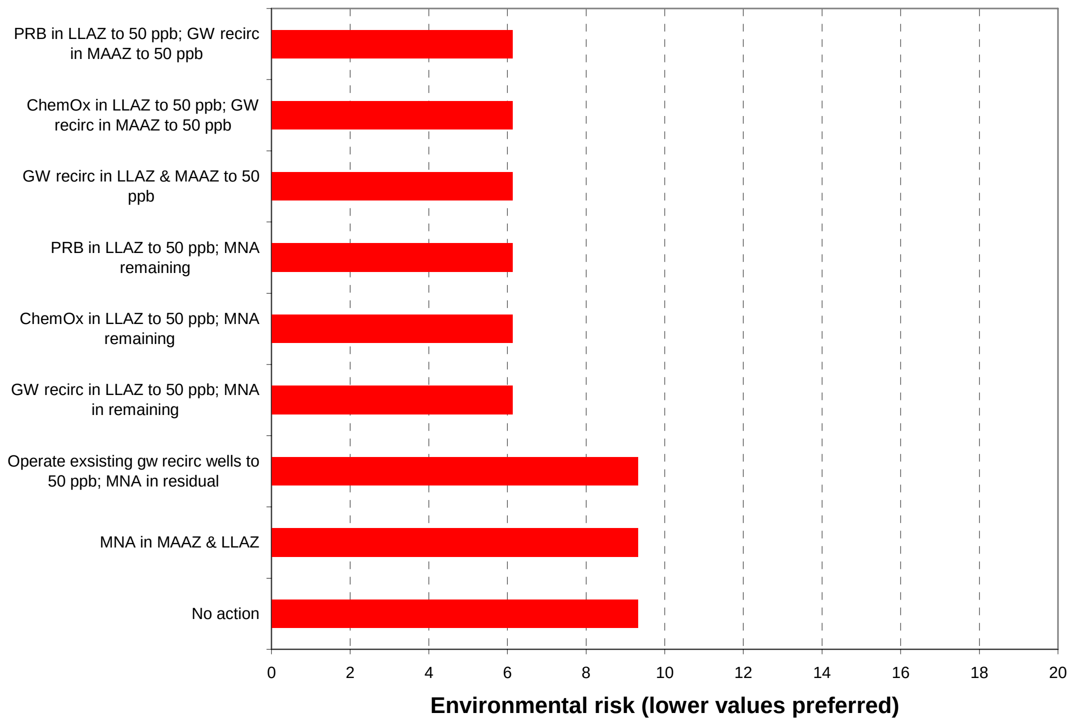

Figure 8. Comparison of Pilot Test Alternatives in Terms of Their Impact on Environmental Resources

Figure 8 illustrates the relative environmental impact associated with each alternative. For this case, the only resource impacted is groundwater, as numerical modeling of the contaminant plume predicts that contaminant concentrations will attenuate to below MCLs prior to surface water discharge. The no action alternative, continuation of the current recirculation well system, and MNA result in greater environmental risk than the other six alternatives.

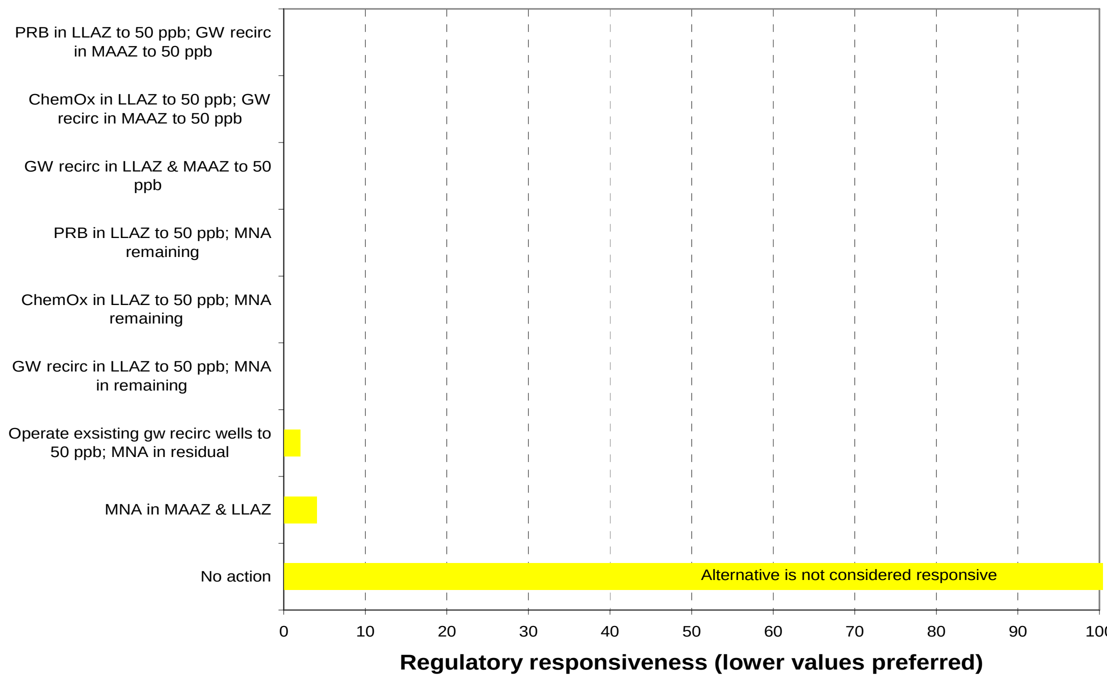

Figure 9. Comparison of Pilot Test Alternatives in Terms of Their Responsiveness to Regulatory Concerns

Figure 9 compares the alternatives in terms of their perceived responsiveness to regulatory concerns. All six of the more active approaches were judged to be highly responsive to regulatory concerns, while the other alternatives were considered less responsive. As discussed previously, it should be noted that the no action alternative is not considered to be compliant with ARARs, and thus is not considered to be a viable alternative. It was included in the analysis for comparative purposes only.

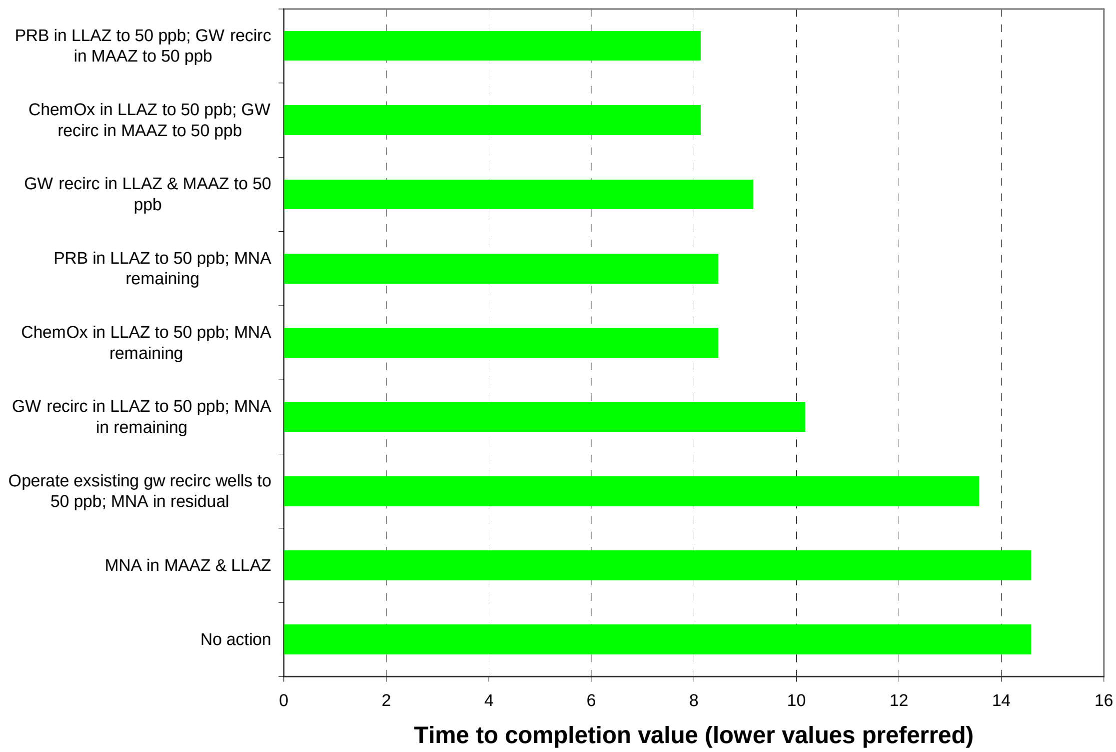

Figure 10. Comparison of Pilot Test Alternatives in Terms of Their Expected Time to Reach Completion

Figure 10 shows the value of the estimated time to completion under each alternative. Because detailed numerical modeling of the various alternatives had been conducted, the project team was able to provide a specific-value estimate of the number of years to completion for each alternative. For all alternatives, additional contaminant loading to the aquifers was assumed to have been stopped by the source and vadose-zone actions (excavation and capping), and dispersion was the only operative attenuation process. Due to the large dilute nature of the plume, active alternatives reduced the time to completion by less than half.

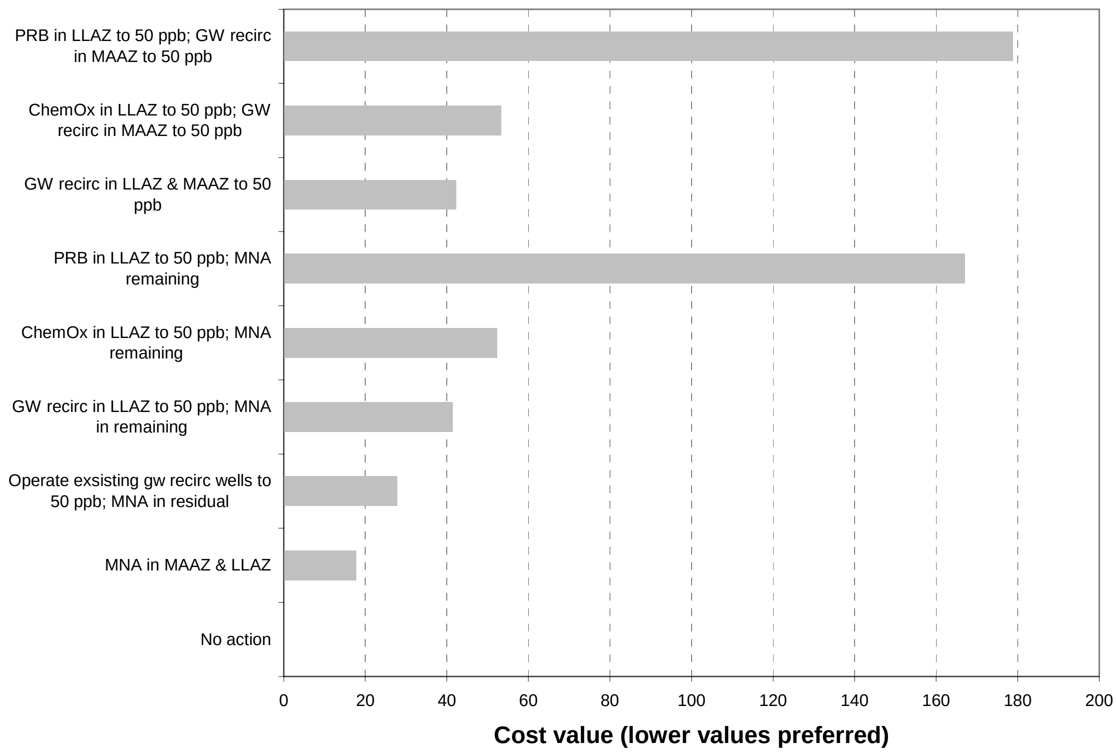

Figure 11. Comparison of the Costs and Cost Uncertainty of Pilot Test Alternatives

Figure 11 illustrates the value associated with the cost and cost uncertainty of each option. As also shown in the consequences table, the costs of the alternatives with a PRB are about four times the costs of the next most expensive alternative.

5.3.3 Comparison of Alternatives on All Objectives Combined

As described in Section 3.3.2, the evaluation of alternatives is combined with relative weights for each objective to calculate a single value that can be used to compare the alternatives. Three alternative sets of weights were built into the tool (Table 2), and were used to compare the alternatives.

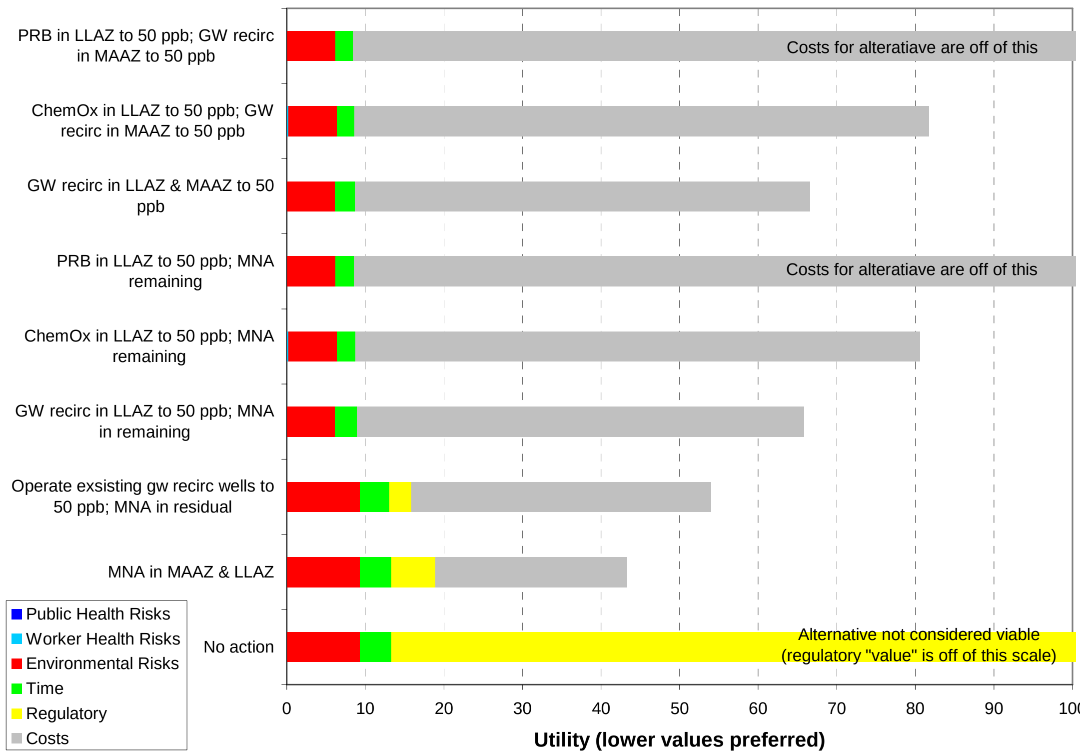

Figure 12. Comparison of Pilot Test Alternatives Incorporating All Objectives, using Weight Set 1

(Graph has been scaled to show differences between alternatives: values for No Action and the two PRB alternatives are off scale.)

Figure 12 illustrates the overall value calculated for each alternative, with the contributions from each objective color coded, so that it is easy to see what the largest contributors to the calculated value are. Again, lower values indicate lower overall "risk," and thus are preferred. Because the costs for the alternatives that include a PRB are so much higher than for the other alternatives, Figure 12 has been scaled so that the full costs of those options do not show, but the other differences between alternatives are easier to see. Figure 12 uses Weight Set 1. The preferred alternative under Weight Set 1 is MNA in the MAAZ and LLAZ.

Figures 13 and 14 show the comparison of alternatives under Weights Sets 2 and 3, respectively. Weight Set 2 increases the relative weight on public health and safety and on environmental impacts by a factor of 10 over the values in the Weight Set 1; Weight

Set 3 increases the weights on time to closure and regulatory responsiveness by a factor of five over the values in Weight Set 1.

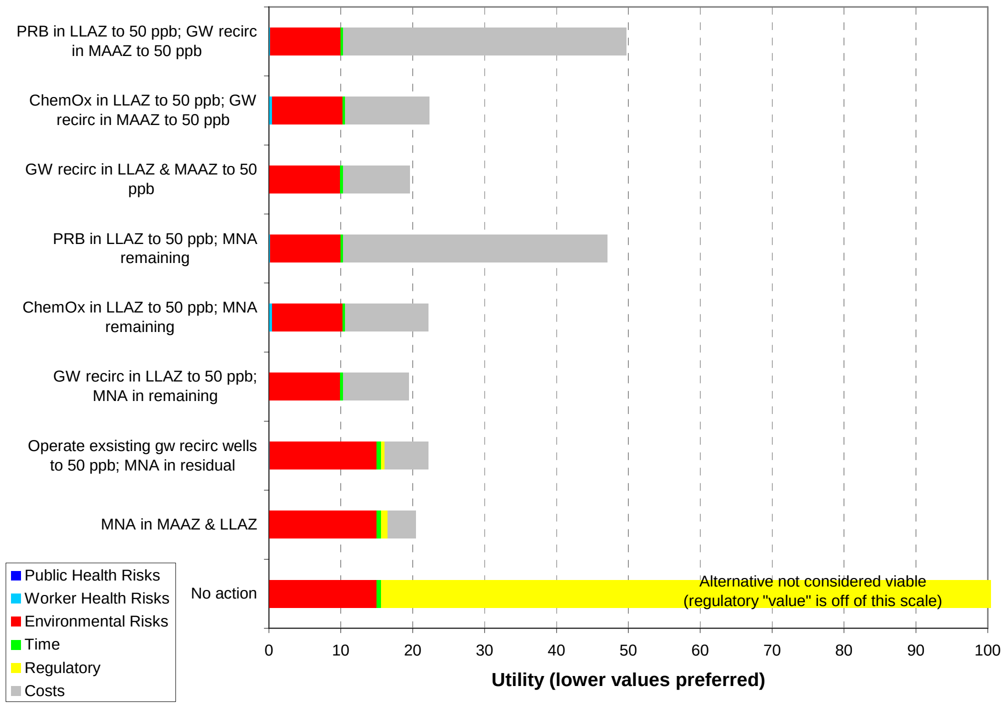

Figure 13. Comparison of Pilot Test Alternatives Incorporating All Objectives Using Weight Set 2
(increased emphasis on health, safety, and environmental risks)

With greatly increased weight on minimizing health, safety, and environmental risks (Figure 13), groundwater recirculation in the LLAZ to 50 ppb and MNA in the residual plume becomes marginally preferred over 1) MNA in the MAAZ and the LLAZ and 2) groundwater recirculation in the LLAZ and MAAZ. It is preferred over MNA because it reduces the environmental impact sooner, and it is preferred over groundwater recirculation in both aquifers because it is less costly and delivers the same benefits.

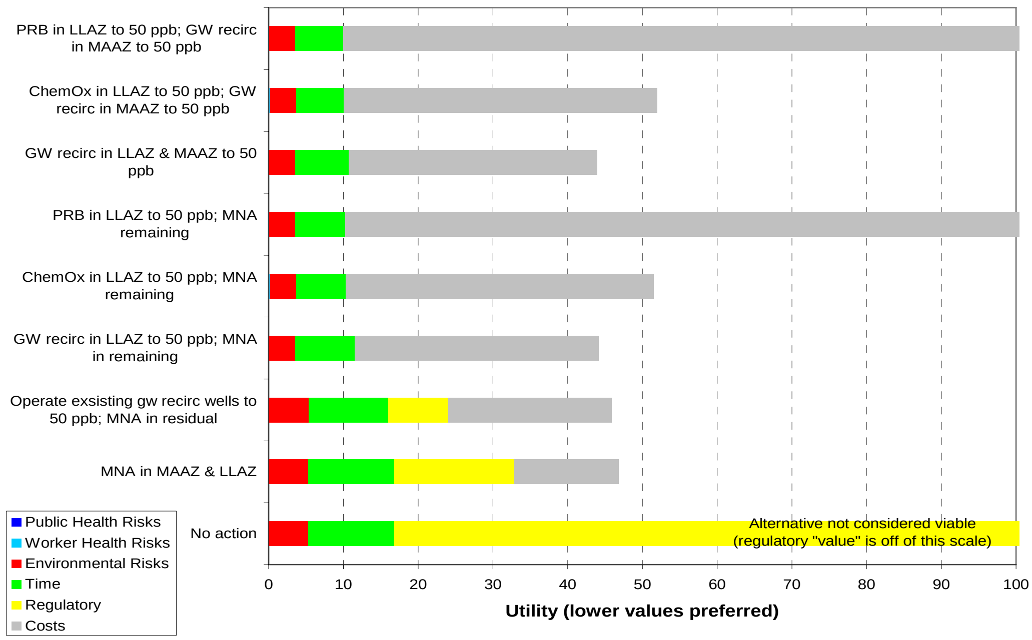

Figure 14. Comparison of Pilot Test Alternatives Incorporating All Objectives Using Weight Set 3

(increased emphasis on regulatory responsiveness and time to closure)

With increased weight on minimizing time to completion and maximizing regulatory responsiveness (Figure 14), groundwater recirculation in the LLAZ to 50 ppb and MNA in the MAAZ and residual plume becomes preferred by a small amount over groundwater recirculation in the LLAZ and MAAZ. The relative advantage of this alternative under this weight set is that it is perceived to be more responsive to regulatory concerns.

5.3.4 Additional Sensitivity Analyses

The primary sensitivity analyses of interest to the evaluation team were those described above – the comparison of alternatives using different sets of weights. Several other questions arose, however, suggesting additional sensitivity analyses might be useful.

5.3.4.1 Impact of Risks to Public Health and Safety

As discussed above, risks to public health and safety are not a significant factor in the comparison of alternatives under any weighting scheme for the Pilot Test site, nor are they a significant factor in the comparison of the no action alternative with the other alternatives. This was initially surprising to the evaluation team, and was discussed and explored in depth.

Through review of the consequences table, with focus on the evaluation of risks to public health and safety from cVOC contamination at the site, it became clear that the estimated public health risks are extremely low, resulting in the low impact of this objective in the multi-attribute comparison. The factors behind this risk score include sufficiently low contaminant concentrations that the likelihood of any adverse health effects are quite low (about 1 chance in 100,000) and institutional controls in all alternatives, except for the "no action" alternative. However, even in the "no action" alternative, which assumes no institutional controls, the highest possible exposures of the public to elevated levels of cVOCs does not result in high impact of this objective in the multi-attribute analysis.

To assure ourselves that the tool was functioning appropriately, the team hypothesized a situation where a plume with higher concentrations had the potential to directly impact a municipal water supply system. The team generated a set of evaluation scores for this hypothetical situation, as shown in Table 4. The comparison of these four hypothetical alternatives using Weight Set 1, as shown in Figure 15, illustrates that with larger potential public health impacts, that objective becomes a significant driver of the overall evaluation of alternatives.

Table 4. Consequence Table Comparing Alternatives for a Hypothetical Site With High Potential Public Health Risks

(Hypothetical impacts on Public Health and Safety are highlighted)

ALTERNATIVE	H - NA	H1	H2	H3
Time to Completion (in years)	43	43	30	30
Costs				
Estimated total costs	$0	$3,408,000	$5,413,000	$7,229,000
Costs could be as low as:	$0	$2,556,000	$4,059,750	$5,421,750
Costs could be as high as:	$0	$5,112,000	$8,119,500	$10,843,500
Regulatory Responsiveness				
The proposed solution is likely to be viewed by the regulator as:	Not responsive	Somewhat responsive	Responsive	Highly responsive
Impact on Public Health and Safety				
Exposure to elevated levels of contaminants is:	Assured or almost certain	Assured or almost certain	Likely (e.g., 1 in 10)	Extremely unlikely (e.g., 1 in 1,000,000)
If such exposure occurs, the number of people exposed will be:	Very large: roughly 10,000 people	Large: roughly 1,000 people	Large: roughly 1,000 people	Very large: roughly 10,000 people
And the exposure will occur in about:	Less than 5 years	Less than 5 years	Less than 5 years	Less than 5 years
If exposure occurs, adverse impacts on health are:	Somewhat unlikely (e.g., 1 in 1,000)	Somewhat unlikely (e.g., 1 in 1,000)	Somewhat unlikely (e.g., 1 in 1,000)	Extremely unlikely (e.g., 1 in 1,000,000)
And the severity of the effect will be:	Serious effect	Serious effect	Serious effect	Serious effect
Impact on Worker Safety				
The number of workers potentially exposed to safety risks is about:	NA	Very small: 1-2 people	Very small: 1-2 people	Very small: 1-2 people
The likelihood any worker will suffer an adverse safety or health effect is:	NA	Somewhat unlikely (e.g., 1 in 1,000)	Somewhat unlikely (e.g., 1 in 1,000)	Relatively likely (e.g., 1 in 100)
And the severity of that effect will be:	NA	Moderate effect	Moderate effect	Moderate effect
Impact on Environmental Resources				
Groundwater				
The likelihood this resource will suffer an adverse impact is:	Greater than 90%	Greater than 90%	Greater than 90%	Greater than 90%
The impact, if it occurs, will be:	Significant impact	Significant impact	Moderate impact	Moderate impact

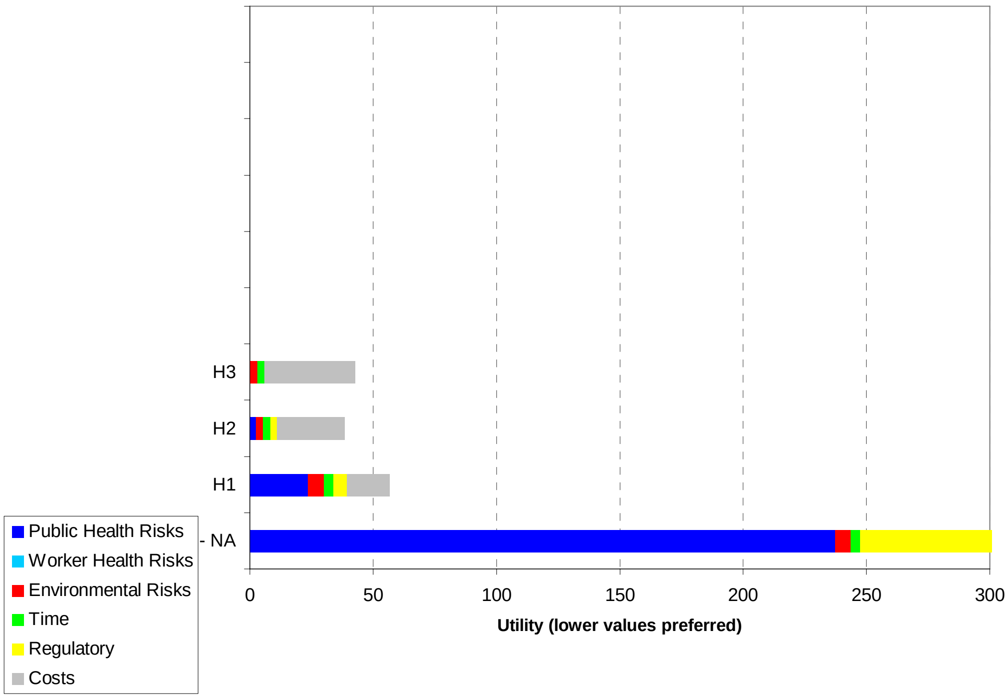

Figure 15. Sensitivity Analysis: Comparison of Alternatives for Hypothetical Site with Higher Public Health Risks, using Weight Set 1

5.3.4.2 Removing Potential Overlap Between Objectives

In the Pilot Test application, there is a potential redundancy between the evaluation of environmental risk and the estimated time to completion. Because the only environmental resource impacted by this contamination is the groundwater, the scale for the severity of impact is tied to the duration of the impact, and the groundwater is assumed to be impacted adversely for exactly as long as the contamination in the groundwater is above MCLs, there is a perfect correspondence of the severity of the environmental impact and the time to completion. This is not necessarily a problem: if the decision-makers value reduced time to completion for reasons completely independent of the environmental impact, the correlation of impacts does not invalidate the methodology.

Nevertheless, the evaluation team felt that it was worth considering a sensitivity analysis where the weight on time to completion was set to zero – representing a judgment that the value of reducing time to completion is solely to reduce the duration of the impact on groundwater, and thus that value is captured by the scores and weights for environmental impact. Figure 16 illustrates the results of this sensitivity analysis: the weights used correspond to Weight Set 1, but with zero weight assigned to time to completion. Similar analyses were conducted using Weight Sets 2 and 3, but with zero weight on time to completion. In all cases, the relative evaluation of the alternatives is unchanged by eliminating consideration of time to completion.

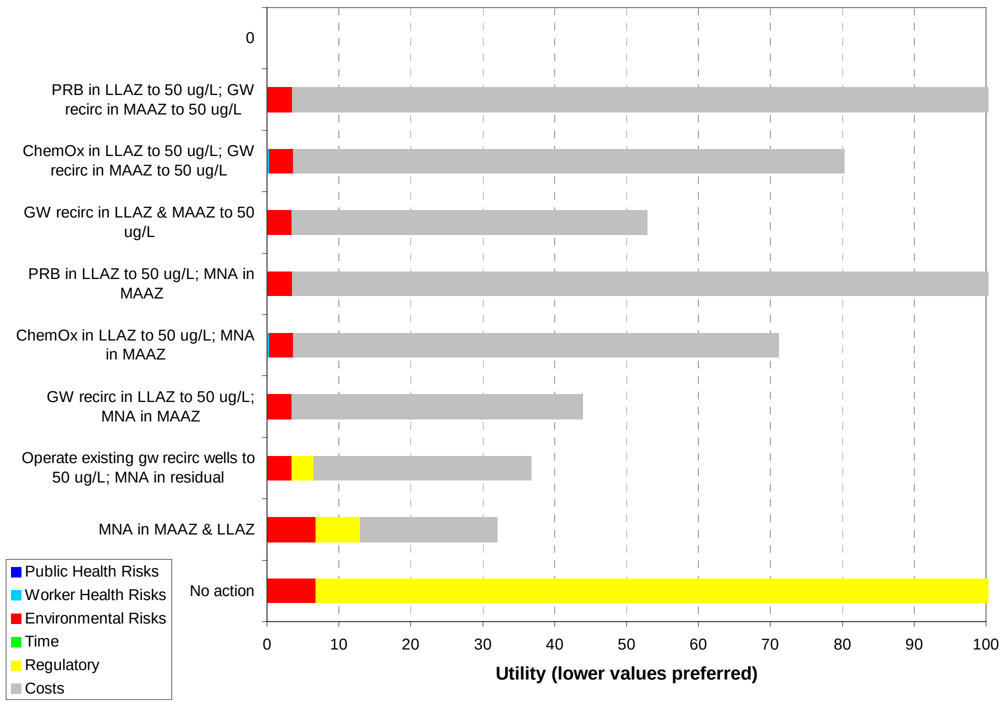

Figure 16. Sensitivity Analysis: Comparison of Pilot Test Alternatives with Zero Weight on Time to Completion

5.3.4.3 Changing Preferences for Time to Completion

During informal discussions of the preliminary results with State regulatory authorities, discussions focused on the predicted time to completion for the different alternatives. It was suggested that regulatory agencies might have preferences for time to completion that are not linear in time – for example, that reducing the time to completion from 300 years to 100 years is not as valuable as reducing the time from 40 years to 20 years. To test the implications of these types of preferences, the evaluation team used the cVOC Tool to specify a user-defined value function for time to completion as shown in Figure 17. That function codifies value judgments that say there is much more value to reducing time to closure from 50 years to 10 to 20 years than there is for any other reduction in time. Note that it also implies that there is relatively little value to reducing the time to closure from 500 years to 100 years.

Given that the estimated time to completion for all of the Pilot Test alternatives are between 24 and 42 years, this value function both maximizes the distinction between alternatives on this objective, and increases the relative importance of the actual time to completion relative to the other objectives. Figure 18 illustrates the results of using this value function and Weight Set 1. Comparing Figure 18 with Figure 12 shows that, under this sensitivity analysis, the relative contribution of time to completion to the overall evaluation is greater, and there is more differentiation between the alternatives based on the difference in time to completion, but the overall ranking of alternatives is not changed.

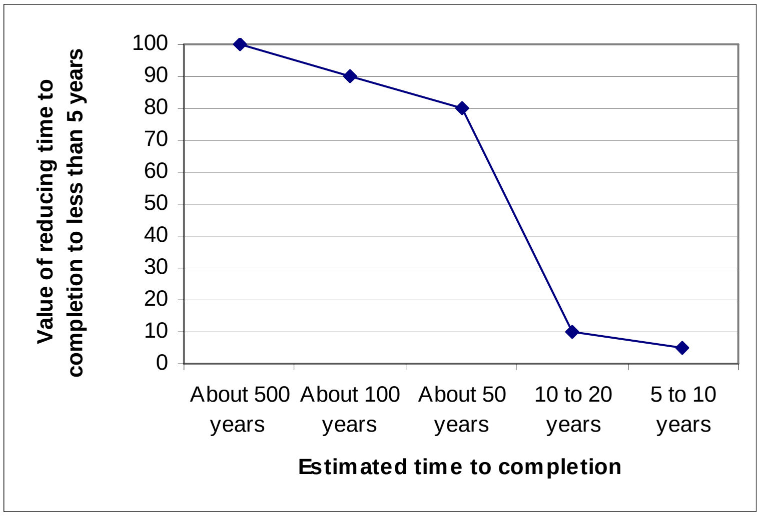

Figure 17. Sensitivity Analysis: User-specified Value Function for Time to Completion

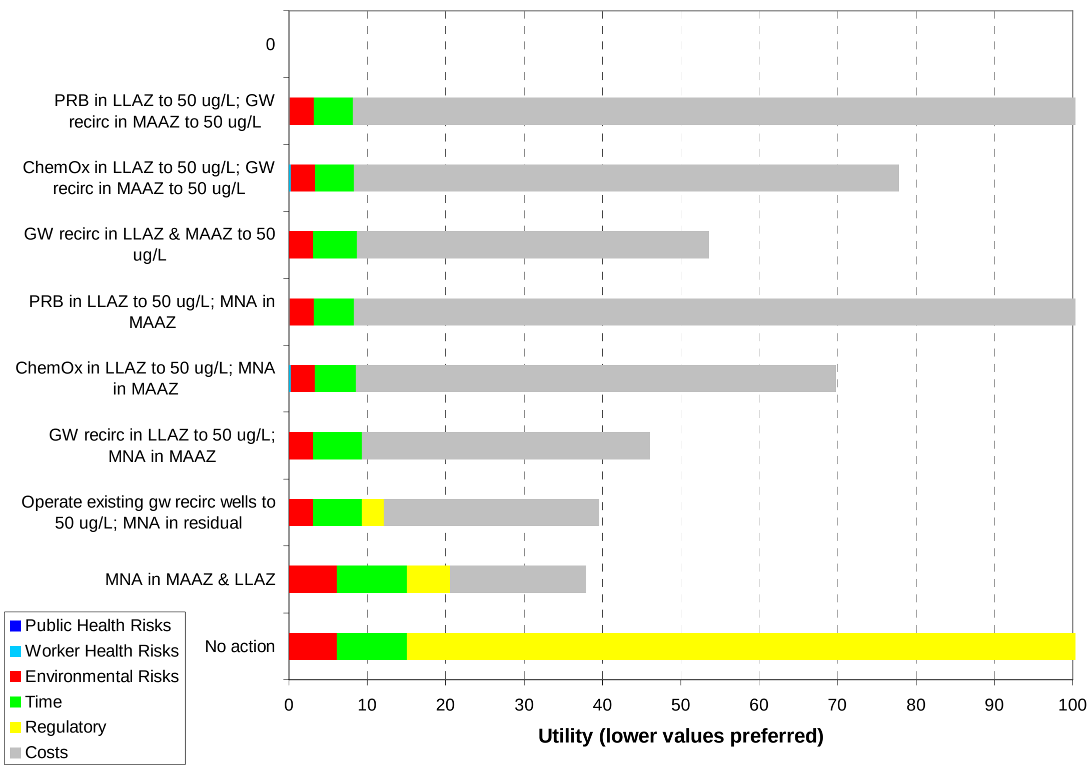

Figure 18. Sensitivity Analysis: Comparison of Pilot Test Alternatives with User-Specified Value Function for Time to Completion and Weight Set 1

6.0 References

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Appendix A: Spreadsheet Users' Guide

1.0 INTRODUCTION

The cVOC Remediation Decision Tool (cVOC Tool) is designed to be useful to those interested in exploring alternative approaches for addressing cVOC contamination problems and reaching site completion.

The cVOC Tool is based upon an analytic approach for comparing alternatives, which is described in detail in the main body of this report. The tool has been implemented in a Microsoft Excel spreadsheet, and this Appendix is provided as a Users' Guide for the implementing the spreadsheet.

2.0 cVOC Tool Inputs

The cVOC Tool spreadsheet includes three input worksheets, where the user specifies the site or problem characteristics, the alternatives to be evaluated, and uses the spreadsheet to enter the estimates of how well each alternative will perform, using the performance metrics built into the tool. Each worksheet and the necessary inputs are described in the following sections.

2.1 Site and Problem Information

Site characteristics and information on the contamination problems at the site are entered on the Site Info worksheet. If you are starting from a version of the spreadsheet that has data or information from a previous application and you wish to start over, you can click the Clear problem button on this sheet. Be sure to save the spreadsheet with a new file name.

- Under the heading Site or Problem Information, type in general information that describes the problem. This information includes the site name, site location, and current site status.

- ☑ Under the heading **Health & Safety,** check the boxes that indicate the potential exposure pathways for the exposure of human populations to elevated levels of contaminants from the site or problem.

For cVOC groundwater plumes, the main human health risk concern is that people may be exposed to elevated levels of VOCs in groundwater through the following potential exposure pathways:

- ☑ **Ingestion** of contaminated groundwater or, potentially, surface water impacted by the groundwater plume;
- ☑ **Dermal contact** with contaminated water through use of the groundwater resource via private wells; and
- ☑ **Inhalation** of vapor from groundwater or soil contamination permeating into enclosed airspaces (e.g., buildings), or from volatilization of contaminants from water in use in the building (e.g., during showering).

The user is encouraged to consider all potential exposure pathways in estimating the impacts on public health and safety for the site. If the exposure pathway is not relevant, you should provide a brief explanation as to why you believe human exposures via that pathway are not credible.

- ☑ Under the heading **Environment,** check the boxes to indicate which environmental resources are potentially impacted by elevated levels of contaminants from the site or problem.

If groundwater is a resource that is potentially impacted, use the drop-down menu to indicate whether the groundwater affected is a sole-source aquifer, is potentially viable for drinking water, or is not viable for drinking water. If multiple aquifers are affected, select the value for the more sensitive aquifer (e.g., if any sole-source aquifer is affected, select "sole source aquifer").

2.2 Alternatives

Alternatives describe what can be done to remedy the identified contamination at a site. They are input by the user into the cVOC Tool for the specific site undergoing evaluation. Alternatives, such as no action, status quo (i.e. continue doing what you are already doing), active treatment options both in situ and ex situ, passive treatment options (EA), and MNA, are recommended for consideration. The main text of the report provides some discussion of how to identify potential alternatives.

Specify the alternatives that will be considered for the site on the Alternatives worksheet.

- ⌨ Type in a name and brief description for each alternative that you want to consider for the site or problem. Up to 20 alternatives can be evaluated.

2.3 Evaluation of Alternatives

Each of the alternatives must be evaluated in terms of their impacts on the objectives and performance metrics described in the main body of the report.

This evaluation is carried out on the INPUTS worksheet.

- ↳ Use the drop-down menu in the upper left corner of the INPUTS worksheet to select the first alternative in the list.

For that alternative, the user will provide estimates of how well that alternative is expected to perform.

2.3.1 Public Health and Safety

↳ For each pathway selected on the Site Info worksheet as being a potential route for public exposures to elevated levels of contaminants, use the drop-down menus to enter a value for each of the five performance metrics under the **Public Health and Safety** objective.

Each pathway indicated as a potential exposure route is shown in a separate column on the INPUTS worksheet: if a pathway was not selected, the pathway name is not shown on the worksheet (it is shown as "NA") and no values need to be provided. You may need to scroll to the right to see all of the relevant columns.

For the exposure pathway being evaluated, the user must estimate the likelihood that any individuals will be exposed to elevated levels of contaminants (i.e., above background) from the site or the contamination problem being evaluated. The scale below provides detailed explanation of the levels in the pull-down menus.

Likelihood of exposure to elevated levels* of contaminants from the site
Extremely unlikely. The chances that anyone will be exposed to elevated levels of contaminants from the site via this exposure pathway are no more than 1 chance in 1,000,000.
Very unlikely. The chances that one or more people will be exposed to elevated levels of contaminants from the site via this exposure pathway are on the order of 1 chance in 100,000.
Unlikely. The chances that one or more people will be exposed to elevated levels of contaminants from the site via this exposure pathway are on the order of 1 chance in 10,000.
Somewhat unlikely. The chances that one or more people will be exposed to elevated levels of contaminants from the site via this exposure pathway are on the order of 1 chance in 1,000.
Relatively likely. The chances that one or more people will be exposed to elevated levels of contaminants from the site via this exposure pathway are on the order of 1 chance in 100.
Likely. The chances that one or more people will be exposed to elevated levels of contaminants from the site via this exposure pathway are on the order of 1 chance in 10.
Assured or almost certain. Exposure of one or more individuals to elevated levels of contaminants from the site is virtually certain
* "Elevated levels" for this metric are defined as levels above background concentrations and exposures.

To estimate the number of people that will potentially be exposed to contamination via the pathway being evaluated, consider the history and current status (location, concentrations) of the plume and the projected evolution of the plume, if the specific alternative being considered is implemented. Also consider characteristics and habits of the local populations now and in the future. The scale below provides detailed explanation of the levels in the pull-down menu.

Size of Population Exposed
Very small. On the order of 1 or 2 people. Exposed population might be very small, if for example, a few people who are working on the site in a n unrelated job are incidentally exposed to the contamination
Small. About 10 people. Exposed population might be small, if for example, one or two families near the site use water from domestic wells, which become contaminated by the groundwater plume.
Moderate. Roughly 100 people.
Large. Roughly 1,000 people.
Very large. Roughly 10,000 or more people. Exposed population might be very large, if for example, groundwater contamination from the site reaches a municipal water supply well.

For groundwater contamination on access-controlled property, the first potential exposures to any adverse health effects may occur far in the future. Use the scale below to estimate the time at which any individual could be exposed to elevated levels of risk from the contamination problem being addressed: consider the history and current status of the plume, and the proximity of the plume to populations. The scale below provides detailed explanation of the levels in the pull-down menu.

Time of exposure
Exposures, should they occur, are expected in less than 5 years.
Exposures, should they occur, are expected in 5 to 10 years.
Exposures, should they occur, are expected in 10 to 20 years.
Exposures, should they occur, are expected in about 50 years.
Exposures, should they occur, are expected in about 100 years.
Exposures, should they occur, are expected in about 500 years.

There is often uncertainty about whether any adverse health impact will occur, even if individuals are exposed to cVOCs. The likelihood of an impact may depend on many factors, including some related to the characteristics of the contaminant plume and the exposure pathways and duration, and some related to the individuals who are exposed.

In estimating the likelihood of an effect, assume that the exposure occurs, and then consider what is known about the cVOC concentrations and the exposure pathways, and where possible, what is known about the people who might be exposed. The scale below provides detailed explanation of the levels in the pull-down menu.

Likelihood of Health and Safety Effects
Extremely unlikely. The chances of the health or safety effect are no more than 1 chance in 1,000,000.
Very unlikely. The chances of the health or safety effect are on the order of 1 chance in 100,000.
Unlikely. The chances of the health or safety effect are on the order of 1 chance in 10,000.
Somewhat unlikely. The chances of the health or safety effect are on the order of 1 chance in 1,000.
Relatively likely. The chances for the health or safety effect are on the order of 1 chance in 100.
Likely. The chances of the health or safety effect resulting from the order of 1 chance in 10.
Assured or almost certain. Health or safety effect is virtually certain

The final measure of the degree of health and safety risk is an assessment of the type and severity of the effect, assuming it occurs. The types of health effects potentially associated with environmental exposures to cVOCs range from temporary minor irritations (skin and lung irritations, headaches), to longer-term damage to the central nervous system, liver or kidneys. Some chlorinated solvents are classified by the EPA as possible or probable carcinogens.

In estimating the severity of the effect, assume that the exposure occurs and that the exposure leads to adverse health impacts. Consider the concentrations, exposure pathways and duration, and where possible, what is known about the people who might be exposed. The scale below provides detailed explanation of the levels in the pull-down menu.

Severity of Effect
No effect.
Temporary, minor effect. Exposures are unlikely to produce more than temporary irritation and discomfort (e.g., skin irritations, headaches).
Moderate effect. Exposures may produce moderate injury or illness, damage to the central nervous system, the liver, or the kidneys, with moderate-to-long-term effects possible.
Serious effect. Exposures may produce serious long-term illnesses (effects last 5 years or more) that result in significant loss of quality of life.

2.3.2 Impacts on Worker Health and Safety

In the course of implementing a specific remedial approach, site remediation workers may be exposed to a variety of health and safety risks, including risks related to the remediation activities themselves and potential exposures to contaminants. In evaluating potential risks to site remediation workers, consider all potential pathways and mechanisms by which workers could be exposed to risks. Examples of potentially relevant worker risks include:

- occupational injuries associated with construction activities,

- transportation-related risks associated with driving (e.g., transporting equipment and/or materials to and from a job site; driving to and from sampling locations required for long-term monitoring),
- inadvertent exposures to contaminants while conducting maintenance or monitoring activities.

Briefly describe the worker risks of concern for the alternative being evaluated. Identify what you consider to be the most likely pathway for worker injury or illness. For that specific pathway, you are asked to quantify the risk by using the following scales and the pull-down menus.

Consider industry-specific occupational safety statistics, if relevant, in making these estimates. For example, DOE facilities track safety statistics such as "Total Recordable Cases" and "Days Away, Restricted, or Transferred" in terms of the number of cases (injuries) per 200,000 hours worked. For the Pilot Test application, the project manager estimated the likelihood of worker injuries by estimating the number of hours required to implement the alternative and using the site-specific average injury rate.

For the most likely pathway by which worker safety or health could be affected, estimate the likelihood that any individual will suffer an injury or adverse health effect as a direct result of the planned remedial actions. Use the detailed descriptions below to select an appropriate level from the pull-down menu

Likelihood of worker injury or illness
Extremely unlikely. The chances that workers will be injured or suffer occupational illness as a direct result of the planned activities are no more than 1 chance in 1,000,000.
Very unlikely. The chances that workers will be injured or suffer occupational illness as a direct result of the planned activities are on the order of 1 chance in 100,000.
Unlikely. The chances that workers will be injured or suffer occupational illness as a direct result of the planned activities are on the order of 1 chance in 10,000.
Somewhat unlikely. The chances that workers will be injured or suffer occupational illness as a direct result of the planned activities are on the order of 1 chance in 1,000.
Relatively likely. The chances that workers will be injured or suffer occupational illness as a direct result of the planned activities are on the order of 1 chance in 100.
Likely. The chances that workers will be injured or suffer occupational illness as a direct result of the planned activities are on the order of 1 chance in 10.
Assured or almost certain. Worker injury or illness as a direct result of the planned activities is virtually certain.

Use the detailed descriptions below to record your estimate of the number of workers who might be exposed to increased safety risks as a direct result of the alternative being evaluated.

Number of workers potentially affected
Very small: One or two workers. The most likely pathway for worker injury or illness is such that only one or two individuals are exposed to the risk of injury.
Small: Three to 10 workers. The most likely pathway for worker injury or illness is one wherein several workers could be affected simultaneously by the same events.
Moderate: About 100 workers. The most likely pathway for worker injury is one in which a moderate size workforce is exposed to a chance of injury or illness.

Finally, assuming that the identified worker risk does occur, use the detailed scale below to select an appropriate value from the pull-down menu, reflecting your estimate of the severity of the most likely effect on the exposed worker(s).

Severity of Effect
No effect.
Temporary, minor effect. If a worker experiences an injury or illness, the most likely effect is expected to be temporary and minor (e.g., cuts, bruises, etc). First aid may be required.
Moderate effect. If a worker experiences an injury or illness, the most likely effect is expected to be moderate. Medical attention (e.g., emergency room or doctor's office visit) is likely to be required, but the effect is not but not likely to be long-term (effects last less than a year) or life-threatening (e.g., broken bones, moderate burns, etc.)
Serious effect. If a worker experiences an injury or illness, the effect is likely to be a permanent debilitating injury or serious long-term illness, producing permanent loss of quality of life.

2.3.3 Impacts on the Environment

↳ For each of the environmental resources selected on the Site Info worksheet in Step 1, use the drop-down menu to enter values for the two performance metrics under the **Environment** objective.

Each environmental resource is represented by a separate column in the INPUTS worksheet. Titles for resources that were not selected as relevant are replaces with "NA," and no values need to be provided. You may need to scroll to the right to see and evaluate the affected resources.

For the resource(s) potentially impacted, estimate the likelihood the resource will be affected by the contaminant plume. Consider both the likelihood the resource will be exposed to contaminants, and the likelihood the exposure will result in adverse impacts on those resources. Use the scale below and the pull-down menu.

Likelihood of adverse environmental impacts
Less than 10% chance
About 10%
About 25%
About 50%
About 75%
About 90%
Greater than 90%

Use the scale below and the pull-down menu to estimate the magnitude of the adverse impact on the environmental resources identified above. This metric includes both the level of damage and the duration of the effect. Consider the type and concentration of the contaminants from the site, and the pathways by which environmental resources will be exposed.

Severity of environmental impacts
No impact.
Low or minor impact. The characteristics of the hazard (e.g., the contaminants and the exposure pathways) and/or the sensitivity of the resources exposed to the hazard are such that no significant damage or injury to those resources is expected to occur. At worst, exposures would produce a minor, temporary impact that would be likely to self-correct within about a year of its onset.
Moderate impact. The characteristics of the hazard and the sensitivity of the resources exposed are such that those resources are likely to suffer damage or injury. Such injury is expected to affect a small portion of the resources affected (e.g., it may affect the local abundance or health of sensitive species). The impact is expected to be temporary and would likely self-correct within about 10 years of its onset.
Significant impact. The characteristics of the hazard and the sensitivity of the resources exposed are such that those resources are likely to suffer significant and long-lasting damage or injury. Such injury is expected to affect a moderate to large portion of the resource, and the damage is expected to last beyond 10 years from its onset.
Severe impact. The characteristics of the hazard and the sensitivity of the resources are such that the adverse impact is likely to be widespread and severe; permanent damage is expected to result.
Very severe impact. The level of impact on the identified environmental resources is likely to be extreme. Impact will be irreversible and result in the permanent loss of one or more environmental resources. This level of impact is commensurate with what qualifies as a “natural resource emergency” under the Natural Resource Damage Assessment Act (43CFR11).

2.3.4 Regulatory Responsiveness

It is assumed that any alternative considered viable has been judged by site managers to comply with all applicable regulatory requirements. Although all viable alternatives are compliant, there may be a difference in how each alternative is perceived by the regulators, and how responsive to regulatory concerns they believe the alternative to be.

The scale below is designed to allow the user to estimate the degree to which an alternative will be seen as responsive to regulatory concerns. To evaluate regulatory responsiveness, assume that the alternative being considered is selected as the remedy for the site. Make your best estimate of the response of the regulators.

As described in the main text of this report, a "not responsive" option is included to allow users to evaluate any other benefits that may result from a non-compliant option, and to facilitate comparison, if desired, of alternatives with a "no action" alternative. The tool is constructed so that any alternative scoring "not responsive" will have an arbitrarily high risk value, and thus will score worse than any other alternative.

Regulatory responsiveness
Highly responsive. The alternative being considered is viewed as highly responsive to all regulatory concerns. If selected, the alternative will almost certainly be positively reviewed and readily accepted by the regulators. Examples of alternatives that might be judged to be highly responsive include: alternatives with a long and proven track record for similar problems; alternatives identical or nearly identical to those approved for other areas by the same regulatory agency.
Responsive. The alternative being considered is responsive to all regulatory concerns. If selected, the alternative will likely be accepted by the regulators with little or no discussion or modification.
Somewhat responsive. The alternative being considered is somewhat controversial. Although compliant with applicable regulations, the regulators may view the alternative as potentially less than satisfactory. If the alternative is selected, site managers expect a fairly lengthy and detailed negotiation process before the approach is approved. Examples of alternatives that might be judged to be only somewhat responsive include: alternatives that are unproven in the current context.
Marginally responsive. Although compliant with applicable regulations, the alternative being considered is viewed unfavorably by the regulators. If the alternative is selected, site managers expect regulatory challenge and a difficult and potentially contentious negotiation with the regulatory agency. Ultimate approval is likely but not certain. An alternative might be considered marginally responsive if: it represents or is substantially similar to an option previously rejected by the agency for a similar problem.
Not responsive. This value is included to allow a user to include, for the sake of comparison, alternatives that they do not believe are responsive to regulatory requirements, such as a "no action" alternative.

2.3.5 Time to Completion

Time to completion is defined as the time at which further action aimed specifically at the site or problem being addressed will no longer be required. This includes any ongoing monitoring. The time to completion is often identified as the time at which contaminant concentrations in the groundwater are below regulatory maximum contaminant limits.

↳ / ⌨ For the **Time to Completion** objective, use the drop-down menu and the scale below to enter a value for the performance metric OR enter a user-specified value in the input box to the right of the drop-down menu.

Time to completion
Less than 5 years.
Five to 10 years.
10 to 20 years.
About 50 years.
About 100 years.
About 500 years.

2.3.6 Total Estimated Costs

Please provide an estimate of the total costs for the alternative being considered. Assume the alternative is implemented and continues through the end of the "time to completion" as estimated above.

Total costs should include any capital costs, operations and maintenance costs, and the costs associated with any ongoing monitoring associated with the alternative and the site. Please document the discount rate used in the cost estimates.

⌨ Under the **Cost** objective, enter directly your estimate of the discounted total costs to completion. Also enter the discount rate used in the cost estimate.

Costs to completion are almost always very uncertain. You are asked to provide estimates of the uncertainty about the total costs by providing an estimate of how much lower and how much higher the costs might be.

↳ Under the **Cost** objective, use the pull-down menus and the detailed scale descriptions below to indicate how much lower and how much higher the costs might be.

In estimating the cost uncertainty, consider the maturity of the technology, its history, if any, of application to similar sites and problems, and any other "unknowns" that could cause the cost to be significantly higher or lower than your best estimate. Alternatives are likely to differ in terms of their cost uncertainty: for example, if a technology is mature and has been applied elsewhere at the same site, there is likely to be less uncertainty about the total cost than if the technology is relatively new and has not yet been proven.

In estimating cost uncertainty, try to estimate a sufficiently low cost estimate that you believe there is only a 10% chance costs will be lower than that value, and estimate a high cost estimate that you believe has only a 10% chance of being exceeded.

Costs may be lower than the best estimate, but there is only about a 10 % chance costs will be lower than:
95% of the estimated total cost
90% of the estimated total cost
75% of the estimated total cost
Half the estimated total cost

Costs may be higher than the best estimate, but there is only about a 10 % chance costs will be higher than:
5% higher than (or 1.05 times) the estimated total cost
10% higher than (or 1.1 times) the estimated total cost
25% higher than (or 1.25 times) the estimated total cost
50% higher than (or 1.5 times) the estimated total cost
Twice the estimated total cost
Three times the estimated total cost

Click the Save this Run button in the upper left corner of the INPUTS worksheet to save the inputs for the first alternative.

↳ **Return to the drop-down menu in the upper left corner of the INPUTS worksheet to select the next alternative in the list and repeat each step described above. Do this for each alternative.**

3.0 cVOC Tool Automated Outputs and Analysis Tools

Three different types of outputs are automatically generated when the alternatives are evaluated:

1. A consequence table
2. Single-objective comparisons of all alternatives
3. Multi-objective comparisons of all alternatives (under different weighting assumptions).

3.1 Consequence Table

The consequence table is simply a matrix that compares the alternatives on each of the objectives, based on the scores provided by the user. Although this table is simply a re-iteration of the evaluation results, it often makes a powerful communication tool and facilitates discussion of the alternatives among stakeholders.

Click the Consequence table worksheet to view the consequences table. Normal Excel formatting changes can be made to this table if the user wishes to print or view the table differently.

3.2 Single-objective Comparisons

To view a comparison of the alternatives based on their estimated performance on a single objective at a time, click on the appropriate worksheet tab. Two graphs are automatically provided for each metric, the first showing the first 10 alternatives ("Alt. 1-10" as shown below), and the second showing alternatives 11 through 20 ("Alt 11-20"). If you have evaluated 10 or fewer alternatives, the second graph will be blank.

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The value of the alternative on an objective is represented as a bar, *with lower values being preferred* (e.g., lower value on Public Health and Safety means lower risk)

> Note that the graph comparing alternatives on public health and safety is by default on a log-scale. Alternatives scoring "0" (such as any undefined alternatives) can not plot correctly on a log scale, and you will get a warning message from Excel. If you click "OK," the graph will display with the zero-valued alternatives shown as a value of 1. You can reformat the graph using normal Excel formatting controls.

You can, and it may be necessary, to adjust these graphs to correctly display your particular results. In particular, it may be useful to change the x-axis scale to appropriately display your results. If the evaluation includes an alternative that scored "not acceptable" on the regulatory scale, the value associated with that objective will be extremely large and you will want to truncate the graph – see examples in Section 5 of the main body of the report.

3.3 Comparison of Alternatives

3.3.1 Comparison Using Built-in Weight Sets

The final comparison of alternatives combines the results of the evaluation team's "scoring" of alternatives with the value functions and weights described in the main body of the report to calculate a single dimensionless value for each alternative. This value combines all the factors into one metric that can be used to compare the alternatives.

As with the single-objective values, the calculation is such that lower values are preferred – they represent alternatives with lower overall risk.

As described in the report, three alternative sets of weights are built into the tool, representing different viewpoints:

- *Weight Set 1*
    - places a high value on reducing risks to public health and on reducing worker risks;

    - balances those values against costs in a manner consistent with values derived from a wide range of studies of the tradeoffs implied in public spending and federal regulation[5].
- *Weight Set 2*
    - increases the value on reducing risks to public health and worker safety, and to reducing adverse environmental impact, by a factor of 10 over the values in Weight Set 1;
    - places a strong emphasis on risk reduction over any of the other objectives (costs, time to closure, regulatory responsiveness).
- *Weight Set 3*
    - places a high value on regulatory responsiveness and decreasing the time to closure;
    - tradeoffs between risk reduction and cost reduction are similar to that in Weight Set 1, but the values on improving regulatory responsiveness and reducing time are increased by a factor of 5.

To view the comparison of alternatives under different weight sets, click on the tab for the appropriate worksheet. Again, two sets of graphs are provided, the first displaying alternatives 1 through 10, the second displaying alternatives 11 through 20.

4.0 cVOC Tool User-specified Value Functions, Outputs and Analysis Tools

In order to make the cVOC Tool as flexible as possible and to allow users to tailor it to their site-specific values and needs, several options are included to allow users to modify the value functions and the weights applied to the alternatives evaluation. To take full advantage of the spreadsheet implementation of the tool and allow flexibility in how results are viewed, an option is provided for the user to generate a table of calculated values, which can then be viewed, formatting, graphed, and printed using any of Excels functions.

This section describes how an interested user can specify different value functions and weights within the tool, and how to generate an output table.

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[5] Based on OMB Circular A-4, the willingness to pay for reductions in small risks of premature fatality, expressed as the “value of statistical life” from a broad range of studies is between $1 million and $10 million. The weights used here represent a “value of statistical life” of $5 million.

4.1 User-specified Value Functions

There are three value functions that can be adjusted by the user: 1) the relative value of eliminating adverse impacts on different environmental resources, 2) the relative value of reducing the time to completion, and 3) the discount rate used in estimating the value of reducing public health risks.

4.1.1 Specifying the Value of Eliminating Adverse Impacts on Different Environmental Resources

As described in the main text of this report, the value of eliminating adverse environmental impacts depends in part on the specific resources impacted. The default values for the relative value of eliminating impacts on each of the resources are shown below and in Table 1 in the body of the report.

To modify these values, click on the User-specified env. res. values tab. You will see the table below, populated with the system-default resource values. Follow the directions on the worksheet to specify your own value functions indicating the relative importance of eliminating impacts on each type of resources. It is important that you provide a relative value for all resources, even if they are not present at or near your site. If at any time you wish to revert to the system-default values you can click the Import default resource values button.

Impacts on different environmental resources may have different values to the decision-maker.
To specify the relative value of avoiding or eliminating adverse impacts on each of the resources below,
1) assign a value of 1 to the resource you consider to be most important to protect
2) assign values of 1 or less to all other resources, indicating the relative importance of prote[cting] each of those resources
If it is equally important to avoid or eliminate adverse impacts to all resources, assign a value of 1 to each

Import default resource values

Environmental Resource	Relative value of eliminating an adverse impact on the resource
Coastal or marine environments	0.5
Sole-source ground water aquifer	1
Ground water potentially viable as drinking water	0.5
Ground water not viable as drinking water	0.1
Surface water / Sediment	0.5
Wetlands	0.5
Population or habitat of Federal or state designated or candidate endangered or threatened species	1
Population or habitat of desginated sensitive species or species of concern	0.8
Population or habitat for other biological resources	0.3
Sites or areas of historic or cultural value, such as State or Tribal designated parks and recreation areas	0.5
Agricultural, recreational, open space or other public land uses	0.1

4.1.2 Specifying the Value of Reducing the Time to Completion

As described in the main body of this report, the value of reducing time to completion is assumed to be linear in years: that is, the value of a reduction in time to completion of 5 years is the same whether that reduction is from 50 years to 45 years or from 10 years to

5 years. If there are special reasons *not associated with any of the other objectives* for considering this value to be non-linear, you can specify an alternative value function on the "User-specified time value" worksheet.

In considering the value of reducing the time to completion in this context, it is important to separate the value you associated with faster completion from the value of reducing public and worker health and safety risks and environmental risks, and from the value of reducing costs and maximizing regulatory compliance. Those impacts are captured in the individual objectives.

To modify these values, click on the User-specified Time value tab. You will see the table below, populated with the system-default resource values. Follow the directions on the worksheet to specify your own value functions indicating the relative importance of reducing the time to closure. By convention, the largest time reduction (from 500 years to less than 5 years) is assigned a value of 100, and that number can not be modified. All other changes must be assigned a value of 100 or less, reflecting the relative value to the user of reducing the time to completion by the specific amounts shown in the table. The tool default values (accessible by clicking the "Import default values" button) are linear in years. If you feel that the value of reducing the time to completion from 100 years to 5 years is exactly the same as reducing the time from 500 years to less than 5 years, you would assign a value of 100 to the second line. Note that this judgment is equivalent to a judgment that there is no value in reducing the time to completion from 500 years to 100 years.

What is the relative value of reducing the time to completion from…	To…	Weight the value of the improvement
About 500 years	Less than 5 years (a reduction of over 495 years)	100
About 100 years	Less than 5 years (a reduction of over 95 years)	20
About 50 years	Less than 5 years (a reduction of about 45 years)	10
10 to 20 years	Less than 5 years (a reduction of ~10 to 15 years)	5
5 to 10 years	Less than 5 years (a reduction of 5 to 10 years)	2.5

4.1.3 Specifying a Different Discount Rate to Be Used in Valuing the Benefit of Reducing Risks to Public Health and Safety

The value of reducing risks to public health and safety is in part a function of when those health risks would be realized. Specifically, health risks resulting from exposures that may occur far in the future (e.g., in 30 years) may be considered less urgent than identical risks resulting from exposures that may occur in the near future (e.g., next year). This difference results in a different "value" associated with eliminating risks associated with exposures at different times in the future, and is addressed by discounting the risk-reduction value based on the estimated time at which exposure would occur.

The default value is a 3% annual discount rate. As discussed in the main text, this value is consistent with OMB's discussion in Circular A-104 on appropriate discount values representing a "societal discount rate." If you believe a different discounting rate should be used, you may specify that at the bottom of the "User-specified weight" worksheet.

Other values typically considered are (a) 0, indicating that one's willingness-to-pay today to reduce public health risks is completely independent of when those risks may be realized, and (b) the same discount rate used for discounting the total cost estimate, indicating that the tradeoff between dollars and health risk reduction should be constant over time.

4.2 User-specified Weights

Because the weights represent a significant management value judgment about what is important to accomplish at a site, and what trade-offs the decision-maker is willing to make amongst objectives, the cVOC Tool provides an option for the user to define an alternative set of weights.

Those weights must be specified in a precisely defined manner, however, and it is important that the user understand how their weighting judgments are interpreted. Weights in this type of analysis do *not* represent some abstract notion of the relative importance of each objective; rather they represent the relative values o*f specific levels of improvement* on each objective.

Use the User-specified Weights worksheet to define an alternative set of weights.

To define weights, the user should consider the relative value of making improvements on each objective; specifically, consider the value of improving from the level of performance in the left column to the level of performance in the right column (See table below).

First, identify the improvement that has the least value to you, and assign it a "relative value" of 10.

For the next least valuable improvement, estimate how much more important it is to achieve that improvement than to achieve the improvement with a value of 10. Assign a value to the second-least-important objective that reflects its importance relative to the 10. If it is twice as important, for example, you would assign a value of 20.

Continue until you have assigned relative values to each of the improvements shown in the table.

Option buttons are provided at the top of the worksheet that will fill in the values with those that correspond to each weight set, if you wish to use any of the three built-in sets as a starting point.

Assume you have a site/contamination problem that has all the features in the left column, and you can improve it one objective at a time to the level in the right column.
Decide which improvement has the LEAST value to you, and assign it a relative weight of 10.
Assign each of the other improvements a value indicating how much more valuable that improvement is than the other.
(For example,if an improvement is twice as valuable to you as the least valuable, assign it a value of 20).

Import Weight Set 1

Import Weight Set 2

Import Weight Set 3

	What is the relative value of improving from this level of performance...	...to this level of performance	Weight the value of the improvement
Maximize public health and safety, minimize worker risks	Chances are likely (1 chance in 10) that about 1000 people will be exposed to elevated levels of contamination within the next 5 years. If such exposures occur, health effects are relatively likely (about 1 chance in 100), and such health effects will be serious.	Chances of exposure to elevated levels of contamination are about 1 in a million. If exposures occur, only 1-2 people will be exposed and such exposures will be more than 500 years in the future. Health effects from the exposure are extremely unlikely (1 chance in a million), and such health effects will be minor and temporary	25
Minimize adverse environmental risks	There is about a 50% chance that a highly valued environmental resource, such as habitat for a threatened or endangered species will suffer a severe level of impact (i.e., widespread and potentially permanent) due to contamination from the site.	There is less than a 10% chance that valued environmental resources suffer any adverse impacts due to contamination from the site. If such impacts occur they will be minor and self-correcting within a year.	12.5
Maximize regulatory responsiveness	The current solution is viewed as marginally responsive to regulatory concerns	The proposed solution will be viewed as highly responsive to regulatory concerns	50
Minimize time to completion	The time to reach completion for the site is estimated to be about 100 years	Closure is expected within 5 years	50
Minimize total estimated costs	The estimated discounted total costs to reach closure for the site are about $10 million	The estimated discounted total cost to reach closure for the site is about $5 million	25

4.3 Generating a Numerical Results Table

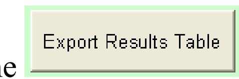
The tool provides built-in displays for some of the most common and useful ways of comparing alternatives, as described in Section 3. However, there are as many ways to look at the results of an MAU analysis as there are analysts, and the user may find it useful to consider results in a different form or format.

To make that process as easy as possible, the cVOC Tool provides a utility to generate a table of numerical results, which can then be formatted and graphed however the user thinks will be most informative. This table is generated from the the INPUTS worksheet. At the top of that worksheet there are two drop-down menus and the Export Results Table button.

To generate a table of numerical results, first use the two pull-down menus to select what results you want to generate. First, you can select which scaling functions you would like to apply. Scaling functions are those functions used to translate the evaluation on each objective into a numerical comparison on that objective. You have two options:

- the built-in functions associated with each objective are described in the report and are used to generate all of the automatically generated outputs, or
- the user-specified functions, which might be of interest if you specified alternative environmental resource values, an alternative scaling function for time to closure, or an alternative discount rate.

Second, you can generate results using any set of weights: Weight Sets 1 through 3, or the User-Specified Weights.

Once you have selected which results you want to produce, click the 

button.

This will create a new worksheet containing the following:

- A row for each alternative. If fewer than 20 alternatives have been evaluated, you can delete the rows below the last evaluated alternative in the new worksheet.
- A column for each objective. The value for each alternative on each objective is the scaled and weighted value using the scaling functions and weights that you selected. These correspond to the values that are plotted on the built-in single attribute value figures.
- A column for the calculated multi-attribute value based on the weights you selected.

You can format this table and generate graphs from it using all of the tools available within Excel.