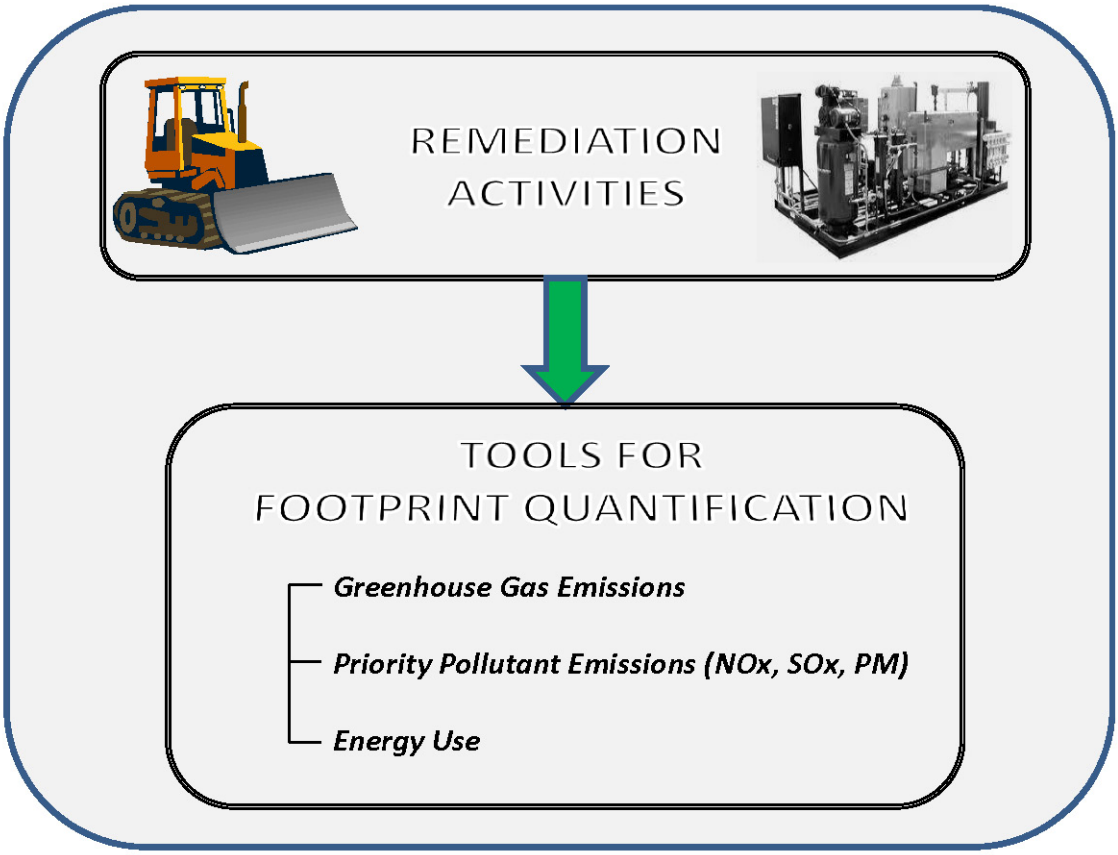
# ESTCP
# Cost and Performance Report

(ER-201127)




## Quantifying Life-Cycle Environmental Footprints of Soil and Groundwater Remedies

**August 2013**

ESTCP

ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

U.S. Department of Defense

# COST & PERFORMANCE REPORT
Project: ER-201127

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## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AFCEC | Air Force Civil Engineer Center |
| Alt | alternative |
| Alameda | Former Naval Air Station Alameda OU2B |
| ASTM | American Society for Testing and Materials |
| Beale | Beale Air Force Base |
| $CO_2$ | carbon dioxide |
| $CO_2e$ | carbon dioxide equivalent |
| CRREL | Cold Regions Research and Engineering Lab |
| cy | cubic yards |
| dem/val | demonstrate/validate |
| DERP | Defense Environmental Restoration Program |
| DoD | U.S. Department of Defense |
| ELCD | European Reference Life-Cycle Database |
| EM CX | Environmental Munitions Center of Expertise |
| EO | Executive Order |
| ERT2 | Environmental Restoration and Technology Transfer |
| ESTCP | Environmental Security Technology Certification Program |
| EVO | emulsified vegetable oil |
| FBR | fluidized bed reactor |
| FS | Feasibility Study |
| GAC | granular activated carbon |
| GBR | gravel bed reactor |
| GHG | greenhouse gas |
| gpm | gallons per minute |
| GSI | GSI Environmental |
| GSR | green and sustainable remediation |
| IC | institutional control |
| ISCO | in-situ chemical oxidation |
| ISO | International Organization for Standardization |
| ISTT | in-situ thermal treatment |
| ITRC | Interstate Technology & Regulatory Council |
| IX | ion exchange |
| LCA | life-cycle assessment |
| LCI | life-cycle inventory |
| LCIA | life-cycle impact assessment |
| Little Rock | Little Rock Air Force Base (LRAFB), Former Skeet Range |
| LRAFB | Little Rock Air Force Base |

| | |
|---|---|
| MNA | monitored natural attenuation |
| MJ | Megajoule |
| MMBTU | Million British Thermal Units |
| NAVFAC | Naval Facilities Engineering Command |
| NAVFAC EXWC | Naval Facilities Engineering and Expeditionary Warfare Center |
| NOx | nitrogen oxide |
| NREL | National Renewable Energy Laboratory |
| NWIRP | Naval Weapons Industrial Reserve Plant McGregor Area M |
| O&M | operations and maintenance |
| OSRTI | Office of Superfund Remediation and Technology Innovation |
| OUSD | Office of the Under Secretary of Defense |
| P&T | pump and treat |
| PM | particulate matter (in this report has same meaning as PM10) |
| PM10 | particulate matter less than 10 microns |
| POTW | publicly owned treatment works |
| PRB | permeable reactive barrier |
| PVC | polyvinyl chloride |
| QA | quality assurance |
| QC | quality control |
| SOx | sulfur oxide |
| SRT™ | Sustainable Remediation Toolkit |
| Travis | Travis Air Force Base, Site DP039 |
| USACE | U.S. Army Corps of Engineers |
| USEPA | U.S. Environmental Protection Agency |
| VFD | variable frequency drive |

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The project team consisted of the following organizations:

- Naval Facilities Engineering and Expeditionary Warfare Center (NAVFAC EXWC) (Tanwir Chaudhry, Sarah Rollston, Karla Harre)
- Tetra Tech (Doug Sutton, Rob Greenwald, Mike Pavarini, Sandra Goodrow, Erin Walsh)
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- Avenue C Advisors (H. Scott Matthews)
- CH2M Hill (Doug Downey, Paul Favara, Melissa Mora)

NAVFAC EXWC led the project, and had overall responsibility for ensuring that the goals of the project were met. NAVFAC EXWC also served as liaison to Navy sites and contributed to overall technology transfer and project execution. Tetra Tech (including subcontractor H. Scott Matthews) conducted the life-cycle assessment (LCA) analysis for demonstration sites, was primary author of reports, provided LCA expertise, performed comparison of results to the benchmark tool, and performed sensitivity evaluations. Battelle was responsible for applying SiteWise™ to three Army/Navy military facilities, while concurrently GSI and their team (including CH2M Hill) were responsible for supplying studies for three Air Force sites that had completed Sustainable Remediation Toolkit (SRT™) applications. Subsequent to initial results from the comparison to the LCA software, Battelle and GSI implemented improvements to their corresponding Department of Defense (DoD) tools (SiteWise™ and SRT™). AFCEC served as liaison to Air Force sites and provided technical review and technology transfer. The USACE served as liaison to the Army site and provided technical review and technology transfer. Detailed point of contact information is provided in Appendix A.

We would also like to thank all of the site personnel and contractors associated with the six demonstration sites that were part of this Environmental Security Technology Certification Program (ESTCP) project. The demonstration sites were as follows:

- U.S. Army Cold Regions Research and Engineering Lab (CRREL)
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- Little Rock Air Force Base (LRAFB), Former Skeet Range (Little Rock)
- Travis Air Force Base, Site DP039 (Travis)

Their time and efforts are greatly appreciated.



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# EXECUTIVE SUMMARY

## OBJECTIVES OF THE DEMONSTRATION

The objective of ESTCP project ER-201127 (the "project") was to demonstrate/validate (dem/val) two currently used publicly available Department of Defense (DoD) green and sustainable remediation (GSR) spreadsheet tools (SiteWise™ and Sustainable Remediation Toolkit [SRT™]) and benchmark these tools against an industry accepted life-cycle assessment (LCA) software package (SimaPro®).

## TECHNOLOGY DESCRIPTION

SimaPro® is for-purchase software that is widely used for many types of LCA evaluations, but it is not specifically designed for assessment of soil and groundwater remedies. SiteWise™ and SRT™ are publicly available (freeware) spreadsheet-based tools that are specifically designed for soil and groundwater remedies. Comparison of footprints calculated by SimaPro® and the DoD tools were made for the following five sustainability metrics:

- Greenhouse gas (GHG) emissions
- Total energy use
- Nitrogen oxide (NOx) emissions
- Particulate matter emissions less than 10 microns ("PM10" also referred to as "PM")
- Sulfur oxide (SOx) emissions

During this project SimaPro® was applied to six demonstration sites that consisted of a total of 20 remedy alternatives. For three of the demonstration sites (Army/Navy installations), consisting of 15 remedial alternatives, the SiteWise™ tool was applied for comparison to the SimaPro® results. For the other three demonstration sites (Air Force installations), consisting of 5 remedial alternatives, the SRT™ tool was applied for comparison to the SimaPro® results. Each tool uses footprint factors (e.g., how much NOx is emitted per gallon of diesel fuel combusted) to convert an input or process into a footprint.

## DEMONSTRATION RESULTS

Key findings and conclusions of the demonstration included the following:

- Significant improvements were made to SiteWise™ and SRT™ as part of this project, with respect to both the calculation of footprints and the usability of the tools.
- In general, all of the tools appear to provide reasonable footprints for sustainability metrics representing GHGs, energy use, NOx, PM, and SOx. It is expected that use of any of the tools to rank footprints for competing remedy alternatives will produce generally similar rankings (though perhaps not the same exact rankings) and provide adequate results for the decisions they are intended to support.
- The results from the DoD tools were not demonstrated to always be within a factor of 1.2 of the SimaPro® results (a performance objective for this project). However, SimaPro® requires the user to select from many potential choices to represent specific

remedy items such as materials, transportation, and disposal. This complicates use of SimaPro® as a benchmark because SimaPro® provides varied results (based on user selections) that also differ from each other by more than a factor of 1.2.

- The DoD tools have distinct advantages over SimaPro® with respect to cost, ease of use, and ability to share files for collaboration, peer review, and documentation.
- During the study, a chart was developed to help guide users of the DoD tools in specifying footprint factors for materials that might not be otherwise represented in the tools. This is a significant improvement compared to simply not accounting for those materials.
- The greatest contributor to the footprints depends on the remedy item. Electricity use, fuel use, materials, transportation, and disposal were all indicated as the highest contributor for one of the sustainability metrics for at least one remedy alternative.
- Some bias (high and low) is evident when the DoD tool footprints are compared to the SimaPro® footprints. In specific cases where SimaPro® accounts for items that are not accounted for in one of the DoD tools, there is bias towards higher results in SimaPro®. For other items, however, it is not possible to make a general statement regarding systematic bias because SimaPro® results being higher or lower than one of the DoD tools could simply be due to user selections in SimaPro® (as discussed above).
- Although the two DoD tools were not directly compared against each other in this project, based on the dem/val activities performed, there are differences in the footprint factors from user inputs between the two DoD tools used to calculate footprints.

The demonstration project suggests that use of the SiteWise™ and SRT™ tools should be generally preferred for use over the SimaPro® tool for DoD projects. SimaPro® would be recommended for cases where outputs for footprints are needed other than those offered by the DoD tools.

## IMPLEMENATION ISSUES

It is recommended that future efforts focus on improving standardization between tools used for DoD projects. Based on this dem/val project, efforts to standardize footprint factors are difficult to base on results from SimaPro®, and would be better achieved by consensus of experts in the field. Improved consistency between DoD tools would also result from standardizing the sustainability metric for global warming to carbon dioxide ($CO_2$) equivalent ($CO_2e$). The DoD tools should continue to be improved over time to add any items/processes that are not well represented in the tools.

# 1.0 INTRODUCTION

Green and Sustainable Remediation (GSR) has become an essential element of soil and groundwater remediation activities.

- GSR tools quantify the secondary effects (i.e., unintended environmental impacts) that the remediation has on the environment (e.g., resource consumption and emissions of pollutants).
- These impacts can be quantified with respect to "sustainability metrics" such as emissions of greenhouse gases (GHG), energy use, and emissions of priority pollutants (e.g., nitrogen oxides [$NO_x$], sulfur oxides [$SO_x$], and particulate matter [PM]).
- A footprint is quantitative result for one of the sustainability metrics.
- Tools are available that allow remedy managers to estimate and report the footprints for existing remediation activities and/or potential remedy alternatives, and to evaluate options for reducing the footprints while meeting the regulatory requirements governing a remedy.
- These tools utilize footprint factors to convert an input or process into a footprint. For instance, a footprint factor will indicate how much (NOx) emissions result per gallon of diesel fuel combusted.

The purpose of this project is to demonstrate/validate (dem/val) two currently used; publicly available Department of Defense (DoD) GSR spreadsheet tools (SiteWise™ and Sustainable Remediation Toolkit [SRT™]) and benchmark these tools against an industry accepted life-cycle assessment (LCA) software package (SimaPro®). The DoD tools have been and continue to be applied at DoD facilities, but to date, the accuracy and completeness of the calculated footprints have not been compared to an appropriate benchmark. For this project, GSR tools were applied to six demonstration sites that included a total of 20 remedial alternatives. Three demonstration sites included SiteWise™ and SimaPro®, and three demonstration sites included SRT™ and SimaPro®. The two DoD tools were not compared directly to each other. Based on the analysis of initial results for these demonstration sites, improvements to the two DoD tools were recommended, and many of those improvements were then implemented as part of this project.

## 1.1 BACKGROUND

SiteWise™ and SRT™ are spreadsheet-based GSR quantification tools developed for DoD. SimaPro® is a general-use LCA software package with process models that are generally more robust than the two DoD tools (and other similar non-DoD tools) with respect to processes included and options for output, but as a result SimaPro® is more complicated and expensive for an environmental professional to apply than the DoD tools because it is not structured specifically for environmental remedies and selecting the best processes to represent remedy items can be challenging.

## 1.2 OBJECTIVES OF THE DEMONSTRATION

The project has the following specific objectives:

- For a variety of environmental remedies at DoD sites, dem/val the ability of the SiteWise™ and SRT™ tools to quantify footprints using SimaPro® as a benchmark, and document the significant differences in functionality and results between the DoD tools and SimaPro®. The two DoD tools are benchmarked separately against SimaPro® and are not compared to each other.
- Document and compare the differences in footprints calculated by the DoD tools relative to footprints calculated by SimaPro®.
- Identify commonly used materials and/or activities that are not well represented in the tools, and suggest how such items can best be represented using generic inputs or other work-arounds.
- Identify improvements to the SiteWise™ and SRT™ tools (such as revised footprint factors, addition of materials or activities, etc.) that are needed. Implement improvements that can be made to SiteWise™ and SRT™ within the project budget (performed by the respective tool developers, both of which are part of the project team).
- Document the practices, procedures, and nuances of applying LCA software to remediation.
- Conduct sensitivity analyses that evaluate the sensitivity of footprints to key inputs of LCA tools, as well as how far back in the supply chain the analysis accounts for (i.e., "system boundary").

## 1.3 REGULATORY DRIVERS

Current DoD policy regarding GSR is driven by Executive Order (EO) 13514 and EO 13423. In August of 2009, the Office of the Under Secretary of Defense (OUSD) released a memorandum regarding GSR stating its commitment to conducting DoD's environmental program in a sustainable manner, in accordance with EO 13423. The Defense Environmental Restoration Program (DERP) Management Manual (DoD, 2012) supersedes the OUSD Memorandum from 2009 and instructs DoD Components to consider and implement GSR opportunities in all phases of remediation and for all DoD environmental remediation projects, when feasible, and ensure the use of GSR remediation practices, where practicable based on economic and social benefits, as well as costs. In addition, the March 2012 DERP Manual gives phase-specific instruction for GSR consideration in the Feasibility Study (FS) and Remedial Action Work Plan (Design) phases, and within optimization evaluations performed in the Remedial Operation phase. There are also specific programs to consider and implement GSR in specific DoD and regulatory agencies including the Navy, Army, Air Force, U.S. Environmental Protection Agency (USEPA), and the Interstate Technology & Regulatory Council (ITRC).

## 1.4 FOOTPRINTS EVALUATED

For this project, comparison of the footprints calculated by SimaPro® and the DoD tools were made for the following five sustainability metrics (the units for the metrics often differ between the tools and require conversion for comparison):

- GHG emissions, which are calculated for multiple GHGs and reported as carbon dioxide equivalent ($CO_2e$) in SimaPro® and SiteWise™, and calculated for carbon dioxide ($CO_2$) and reported as $CO_2$ in SRT™
- Total energy use
- NOx
- Particulate matter (less than 10 microns) emissions ("PM10," which in this report is sometimes also abbreviated as "PM")
- SOx emissions

These five metrics were the focus of the project per the Demonstration Plan, and were chosen because they are the metrics provided as output by each of the tools. Water use for remediation (e.g., for mixing with chemicals) can have footprints, such as GHG emissions and energy use to extract/transport/treat potable water, and these footprints were included in this project to the extent each tool included such calculations for water use (discussed below). Actual use of water as a resource, and re-use or reclamation of water, were not addressed as separate metrics in this project because they are not included as output by all three tools. Additionally, addressing water reclaimed by successful remediation is subject to complicating factors, such as differentiating between "limited use" and "full use" of the resource resulting from the remediation (and the definition of "limited use" and "full use"). Reclamation of water due to successful remediation is perhaps best addressed qualitatively as part of a site-specific GSR evaluation.

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# 2.0 TECHNOLOGY

SimaPro® is for-purchase software that is widely used for many types of LCA evaluations, but it is not specifically designed for assessment of soil and groundwater remedies. SiteWise™ and SRT™ are publicly available (freeware) spreadsheet-based tools specifically designed for soil and groundwater remedies. The SiteWise™ and SRT™ tools were advanced tools that were already being employed for DoD projects (and other projects) at the time this ESTCP project began, and improvements to SiteWise™ and SRT™ were implemented as part of this project.

## 2.1 TECHNOLOGY DESCRIPTION

### 2.1.1 SimaPro® (LCA Software) Description

SimaPro®, developed by Pré Consultants in the Netherlands, allows the modeling of products and systems from a life-cycle perspective. SimaPro® can cost between $3000 and $12,000 dollars to purchase depending on the number of user licenses and features, with additional annual costs in service and support, if required. SimaPro® LCA software provides a user interface and tools to facilitate the use of life-cycle inventory (LCI) databases in LCA studies that are consistent with governing International Organization for Standardization (ISO) Standards 14040:2006 and 14044:2006. SimaPro® comes fully integrated with life-cycle databases that are purchased (for instance, Ecoinvent is an optional database that can be purchased). A few key terms important to this project with respect to SimaPro® are as follows:

- *System Boundary*: The system boundary establishes the resources and processes included in the study. In this project, the sensitivity of results to one type of system boundary (including or excluding infrastructure) was evaluated. "Without Infrastructure" considers only the direct resource usage of a process. For example, truck transport footprints calculated "without infrastructure" only account for footprints associated with fuel used during the transport process. However, footprints calculated "with infrastructure" account for other contributions to footprints associated with the transport process such as the construction of the truck and maintenance of the road network.
- *Impact Assessment:* An impact assessment converts the quantified footprints into actual environmental impacts such as climate change, acidification/eutrophication, release of carcinogens, ecotoxicity, etc.

The DoD tools do not include choices to choose "with infrastructure" or "without infrastructure," and do not include the impact assessment functionality.

### 2.1.2 SiteWise™ Description

SiteWise™ is a Microsoft Excel-based tool that quantifies sustainability metrics of multiple remedial alternatives/technologies based on site-specific information. The tool's initial development was by Battelle as part of its internal research and development program. The Navy and U. S. Army Corps of Engineers (USACE) collaborated for the further development of the tool for public use. Since that time, two versions of the tool have been released in the public domain at the Technology Transfer Web Tools - Environmental Restoration website:

http://t2.serdp-estcp.org/t2template.html#tool=GSR&page=Intro

SiteWise™ Version 2 was used for the initial evaluations for the demonstration sites in this study. This version was upgraded to SiteWise™ Version 3 as a part of this ESTCP project based on findings from the initial evaluations, and SiteWise™ Version 3 was used for the final evaluations for the demonstration sites in this study. The following sustainability metrics are calculated by SiteWise™ using footprint factors that are provided in a lookup table:

- Total energy use (Million British Thermal Units [MMBTU])
- GHG emissions (metric tons of $CO_2$e)
- On-site and total (i.e., on-site plus off-site) NOx emissions (metric tons of NOx)
- On-site and total (i.e., on-site plus off-site) SOx emissions (metric tons of SOx)
- On-site and total (i.e., on-site plus off-site) PM (less than 10 microns) emissions (metric tons of PM10)
- Accident/safety risk (number of work related injuries, number of work related fatalities, and lost hours due to work related injury)
- Resource Consumption (tons of top soil used, gallons of groundwater lost, cubic yard of landfill space)
- Water use (gallons)
- Electricity usage (in megawatt-hours) and percent electricity from renewable sources

For each remedy alternative evaluated, the calculations are made on various tabs organized by component (this could be by remedy phase or any other user-defined component type) and summarized in tables and charts on a summary folder for that alternative. Another final summary file presents the data for all alternatives evaluated for a comparative analysis between different remedial alternatives. SiteWise™ includes an evaluation of footprint reduction methods, mostly related to reduction in energy consumption. SiteWise™ includes calculation modules for landfill gas microturbines, solar energy, wind energy, and use of renewable energy certificates as part of its renewable energy application.

In SiteWise™, footprint factors for GHG emissions and energy used for materials, fuel, and electricity are life-cycle based. The boundary condition that is drawn for calculating the life-cycle-based footprint factors is around the entire life-cycle or 'cradle-to-grave' of the material used or fuel/electricity consumed. This means that complete life-cycle emissions for material production is taken into account. The analysis includes energy used and emissions due to production and transportation of raw materials, manufacturing of consumable materials, fabrication of installed equipment (e.g., pumps, polyvinyl chloride [PVC] piping), production of the electricity, and on-site operation, maintenance, and monitoring of remediation systems.

The SiteWise™ spreadsheets allow for full transparency of all calculations and provide referenced footprint factors for activities and materials. Fuel usage rates are provided for various

forms of transportation and various types of equipment. Electricity usage can be entered using one of three methods, including actual lump-sum usage, usage based on fluid head and flow rate, and usage based on motor size. State-specific footprint factors are provided for calculating emissions from electricity generation to account for different types of electrical generation in different parts of the country, and a module exists that allows the user to input custom blends of electricity sources (e.g., percent from coal plants, hydroelectric, wind turbines, etc.).

### 2.1.3 SRT™ Description

The SRT™ is built on the Microsoft Excel platform and is structured using analytical "tiers." This tiered structure allows the user to choose the level of effort and detail appropriate for the project at hand.

- Tier 1 (simpler tier) calculations are based on rules-of-thumb that are widely used in the environmental remediation industry. A user might choose Tier 1 if the analysis needs to be completed quickly, if detailed or extensive site-specific data are not readily available, if a highly site-specific evaluation is not required, or if the objective is to make general comparisons between remediation technologies.

- Tier 2 calculations are more detailed and allow user to incorporate more site-specific factors. Tier 2 is recommended for evaluations that are not time sensitive, detailed site-specific data are readily available, or more stand-alone results are required such as for evaluating existing systems or projects that have advanced to the FS stage. At the FS stage, conceptual designs should be available, allowing the user to enter more site-specific inputs, resulting in more accurate outputs tailored to the project.

SRT™ Version 2.1 was used for the initial evaluations for the demonstration sites in this study. This version was upgraded to SRT™ Version 2.3 as a part of this ESTCP project, based on findings from the initial evaluations, and SRT™ Version 2.3 was used for the final evaluations for the demonstration sites in this study. A website link for the recently revised version of SRT™ is not currently available but the updated tool will be posted on Air Force Civil Engineer Center (AFCEC) public website in the near future.

SRT™ allows the user to evaluate multiple technologies simultaneously, which is a benefit during planning/evaluation of either a singular treatment technology (e.g., long-term monitoring) for one type of media, or for combined treatment technologies to address impacts to both soil and groundwater (e.g., excavation and pump and treat [P&T]). SRT™ allows users to estimate footprints for sustainability metrics for the following eight common remedial action technologies, grouped by affected media (soil and groundwater):

- Soil: excavation, soil vapor extraction, and thermal treatment
- Groundwater: P&T, enhanced bioremediation, permeable reactive barrier (PRB), in situ chemical oxidation (ISCO), and long-term monitoring/monitored natural attenuation (MNA)

Throughout the tool, there are direct site-specific user inputs as well as defaults and calculated values based on rules of thumb or algorithms. Many of the calculated values can be overridden by the user if more site-specific data or newer literature reference values are available. SRT™ calculates footprints for $CO_2$ emissions, criteria pollutant emissions, economic cost, energy consumption, safety/accident risk, and change in resource service from land and/or groundwater. These metrics are organized by environmental media so that soil or groundwater technologies can be compared side-by-side.

The tool allows for conversion of all sustainability metrics to a consistent set of units (e.g., converting carbon emissions to life-cycle costs using existing carbon offset costs set by carbon trading markets), as well as "Scenario Planning" where different futures for carbon offset costs and energy costs are presented (for example, the user can view the results of the sustainability calculations for either a "Business as Usual" or a "Carbon Constrained World" scenario). There is also a "consensus-building virtual meeting room" where different decision-makers can weigh the importance of different sustainability metrics (i.e., one stakeholder might weigh economic cost as the most important metric, while another stakeholder might weigh carbon emissions as the most important metric).

## 2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY IDENTIFIED PRIOR TO THE STUDY

This section identifies key advantages and limitations of the various tools identified prior to the study (i.e., in the Demonstration Plan). Other advantages and disadvantages of the various tools identified during the execution of the project are discussed later in this report (Sections 5 to 8).

### 2.2.1 SimaPro® Advantages (Limitations of DoD Tools)

Advantages of the SimaPro® LCA Software relative to the DoD tools identified prior to execution of this project included the following:

- SimaPro® software is a mature technology (first released in 1990) that is able to readily support the production of models and reports that conform to the relevant LCA ISO standards, and it has been applied in numerous studies (though generally for manufacturing rather than for environmental remediation projects). SiteWise™ and SRT™ are also mature technologies (first released in 2011 and 2010, respectively) that have been applied at multiple DoD facilities, but these tools do not conform to ISO standards.
- SimaPro® can be purchased with the Ecoinvent database, which is a leading global proprietary LCI database that is generally more robust than publicly available databases (e.g., National Renewable Energy Laboratory [NREL] U.S. LCI). By purchasing support service contracts for the software, the user can incorporate updates to the databases over time. The DoD tools each include their own database with footprint factors developed from publicly available sources, but currently, there is no standard process for the default footprint factors in SiteWise™ and SRT™ to be updated over time.

- SimaPro® can create assemblies or processes of more complex products or activities that might be used in remediation but are not already included in a LCI database. An example might be a custom assembly for an innovative remediation substrate for bioremediation or oxidation that consists of specific blend of materials. SiteWise™ and SRT™ have the ability to add in other "known" quantities, emissions, or environmental effects for materials, but do not have the inherent ability to utilize LCIs to create new assemblies or processes for future use.
- The SimaPro® software incorporates impact assessment, which is a component of LCA analysis that is not incorporated within SiteWise™ or SRT™. Impact assessment converts the sustainability metrics into environmental impacts such as acidification, climate change, and ecotoxicity.

### 2.2.2 DoD Tool Advantages (Limitations of SimaPro®)

Advantages of SiteWise™ and SRT™ relative to SimaPro® identified prior to execution of this project include the following:

- SiteWise™ and SRT™ are freeware, whereas SimaPro® requires an up-front purchase of between $3000 to $12,000 for a single user (includes support for one year), plus additional costs of approximately $1500 per year for a single user for support beyond the first year.
- SiteWise™ and SRT™ are designed specifically for application to environmental remedies. Therefore, the input sheets request information in a form that is generally familiar to environmental professionals. SimaPro® is a general LCA support tool and is not designed specifically for environmental remediation. As a result, the SimaPro® input has a significant learning curve, and is relatively more complicated and/or difficult to navigate for soil and groundwater remedies. Also, specific footprint factors for materials or activities specific to typical environmental remedies (e.g., granular activated carbon [GAC]) are not always defined within SimaPro®.
- SiteWise™ and SRT™ are Microsoft Excel based. Microsoft Excel is easily available and universally used. Both DoD tools let the user change most of the inputs and information in the tool and enter user-specific information. In SiteWise™, the specific calculations performed by the tool are also transparent to the user within the spreadsheet. In SRT™, the calculations are not transparent to the user within the tool but are provided to the user in the User's Guide. The user has less control over the calculations in SimaPro®.
- SiteWise™ and SRT™ were developed by DoD contractors, and therefore these tools can be modified and improved in the future based on needs or specifications of the DoD. However, DoD and other government agencies cannot influence specifications or future improvements for SimaPro®.

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# 3.0 PERFORMANCE OBJECTIVES

The quantitative and qualitative performance objectives are listed in Table 1. The demonstration results are summarized in Section 5. Evaluation of those results with respect to the performance objectives is presented in Section 6.

**Table 1. Performance objectives.**

| Performance Criteria | Data Requirements | Success Criteria |
|---|---|---|
| ***Quantitative Performance Objectives*** | | |
| Footprint contributor ranking | Rank the top 10 contributors to each sustainability metric and verify that the order is the same for the DoD tool and the benchmark (SimaPro®). | Success is defined according to whether or not the ranking of contributions between the tools is the same. This assessment is quantitatively performed in a "binary" manner (i.e., the rankings <u>are</u> the same, or the rankings <u>are not</u> the same). To the extent that they differ, those differences are qualitatively assessed to identify if the differences are significant. |
| Result ratios | This is evaluated quantitatively for each sustainability metric (e.g., NOx) by determining the ratio between the tool results (larger result divided by smaller result, positive in one direction and negative in the other direction). | Success is defined according to the degree to which the quantified output values differ. Ratios greater than 1.2 are considered significant, and the primary causes for such differences are explored. |
| Boundary Effects* | Boundary conditions are extended in SimaPro® and the effects are evaluated quantitatively for each sustainability metric (e.g., NOx) by determining the ratio between the tool results (larger result divided by smaller result, positive in one direction and negative in the other direction). | The previous two performance objectives are re-calculated for the case with SimaPro® run with more extensive boundaries (i.e., "with infrastructure" rather than "without infrastructure"). |
| Sensitivity analysis*** | For several items, assess the range of footprint obtained from the benchmark tool based on viable competing selections by the user, and compare those to footprints obtained with the DoD tools. | A successful outcome results if footprints from the DoD tools are within the range of reasonable values from the benchmark tool. |
| Correlation or bias? | For each DoD tool, the results for particular sustainability metrics (e.g., NOx) from all the associated demonstration remedies are compared to SimaPro® results to illustrate potential correlation or bias in the results. For example, are the DoD tool results consistently higher, lower, or unbiased relative to the SimaPro® results? | Success is indicated if the quantitative results suggest there is no consistent bias introduced by using one of the tools. |

**Table 1. Performance objectives (continued).**

| Performance Criteria | Data Requirements | Success Criteria |
|---|---|---|
| ***Qualitative Performance Objectives*** | | |
| Technical confidence? | This is evaluated when results differ by a ratio of more than 1.2 for a sustainability metric between the DoD tool result and the benchmark result, and the relative degree of confidence in one result versus the other is qualitatively evaluated based on discussion among the project team. | For cases where there are differences greater than a ratio of 1.2 for a sustainability metric between the DoD tool result and the benchmark result, success is achieved if a technical justification can be established for having more confidence in one of the results. |
| Functionality comparison | A list of key functionality in SimaPro® not included in the DoD tools (and vice versa). | Adding functionality to SiteWise™ and/or SRT™ within this ESTCP project to address functionality limitations relative to SimaPro®. |
| "Work around" versus accurate representation | An inventory of "work-arounds" for SimaPro® and the DoD tools that are employed during the evaluations to overcome limitations. | Identifying practical "work-arounds" for the GSR tools to effectively model the demonstration remedies. |
| Learning Curve | The process of learning about each tool and successfully completing a well-documented evaluation will be analyzed. | Success is defined by understanding the background required to implement these tools for the benefit of the remediation sites, identifying if SimaPro® has a significantly greater learning curve than the DoD tools, and highlighting techniques for efficiently applying SimaPro® to soil and groundwater remedies. |

**This was determined to not be practical as stated, and instead the comparison was made between the total footprint for each remedy plus additional sensitivity runs specifically addressing this boundary condition.*

# 4.0 SITE DESCRIPTION

The six demonstration sites that were ultimately chosen for this dem/val project were:

*Evaluated with SiteWise™ and SimaPro®*

- U.S. Army Cold Regions Research and Engineering Lab (CRREL), Hanover, NH
- Former Naval Air Station Alameda, OU2B (Alameda), Alameda, CA
- Naval Weapons Industrial Reserve Plant (NWIRP) McGregor, Area M, McGregor, TX

*Evaluated with SRT™ and SimaPro®*

- Beale Air Force Base, Site 35 (Beale), Beale Air Force Base, CA
- Little Rock Air Force Base (LRAFB), Former Skeet Range (Little Rock), Jacksonville, AR
- Travis Air Force Base, Site DP039 (Travis), Travis Air Force Base, CA

Figure 1 shows the locations of the six selected demonstration sites.

**Figure 1. Locations of selected demonstration sites.**

A brief summary of the remedial alternatives evaluated with SiteWise™ and SimaPro® is presented in Table 2a, and a brief summary of the remedial alternatives evaluated with SRT™ and SimaPro® is presented in Table 2b. Specifics regarding the remedy at each demonstration site, and how the input was derived for the remedy alternatives are detailed in the "Coordination of Site Input Data" sheets included in Appendix B of the Final Report.

**Table 2a. Remedy alternatives evaluated with SiteWise™ and SimaPro®.**

| Alternative | Description of Remedy Elements |
|---|---|
| CRREL Alt 1 | Existing P&T system that involves extraction of 500 gpm and the following treatment:<br>• Greensand filters and permanganate injection for metals removal<br>• Air stripping via two packed tower air strippers in series<br>• Treatment of air stripper off-gas via vapor phase carbon<br>• Re-use of the treated water for cooling at the facility<br>• Water conditioning by $CO_2$ addition and filtration |
| CRREL Alt 2 | Modification of CRREL Alt 1 in which the two packed tower air strippers are replaced with one new tray stripper |
| CRREL Alt 3 | Modification of CRREL Alt 1 in which the greensand filters and air strippers (and associated off-gas treatment) are replaced with liquid phase activated carbon vessels and addition of a biocide and sequestering agent |
| CRREL Alt 4 | Replacement P&T system that extracts and treats 40 gpm with liquid phase activated carbon and addition of a biocide and sequestering agent |
| Alameda Alt G-2 | Groundwater remedial alternative involving the following:<br>• ISTT applied to an area of over 29,000 square feet<br>• 500-foot long PRB to control plume migration<br>• MNA and IC |
| Alameda Alt G-3a | Groundwater remedial alternative involving the following:<br>• ISTT applied to an area of over 29,000 square feet<br>• Shallow groundwater treatment with ISCO<br>• MNA and ICs |
| Alameda Alt G-3b | Groundwater remedial alternative involving the following:<br>• ISTT applied to an area of over 29,000 square feet<br>• Shallow groundwater treatment with in-situ bioremediation involving injection of emulsified vegetable oil<br>• MNA and ICs |
| Alameda Alt G-4 | Groundwater remedial alternative involving the following:<br>• Installation and operation of a P&T system with ultraviolet oxidation treatment and reinjection of treated water<br>• Over 1100 feet of PRBs installed through direct-push injections<br>• Plume and performance groundwater monitoring and ICs |
| Alameda Alt S-2 | Soil excavation remedial alternative in which over 7000 cy of soil is moved and over 4000 cy of soil is disposed of off-site (some as hazardous waste and some as non-hazardous waste) |
| McGregor Alt 1 | Existing groundwater remedy with the following:<br>• Extraction and treatment of approximately 130 gpm on average with a fluidized bed bioreactor or FBR<br>• O&M of seven biobarriers<br>• Performance monitoring |
| McGregor Alt 2 | Modification of McGregor Alt 1 in which the average extraction rate is approximately 65 gpm |
| McGregor Alt 3 | Modification of McGregor Alt 1 in which the FBR is replaced with IX |
| McGregor Alt 4 | Modification of McGregor Alt 1 in which the FBR is replaced with construction and operation of a GBR |
| McGregor Alt 5 | Modification of McGregor Alt 1 in which the FBR is replaced with construction and operation of constructed wetlands |
| McGregor Alt 6 | Construction and modification of biowalls consisting of vegetable oil, mushroom compost, wood chips, and limestone |

Alt - alternative
cy - cubic yards
FBR - fluidized bed reactor
GBR - gravel bed reactor
gpm - gallons per minute
IC - institutional controls
ISTT - In-situ thermal treatment
IX - ion exchange
O&M - Operations and maintenance

**Table 2b. Remedy alternatives evaluated with SRT™ and SimaPro®.**

| Alternative | Description of Remedy Elements |
|---|---|
| Beale Alt 2 | • Excavation and off-site disposal of over 2000 cy of soil<br>• Construction and operation of a mulch bioreactor, well installation, and monitoring. |
| Beale Alt 3 | • Excavation and off-site disposal of over 2000 cy of soil<br>• ISCO with 21 injection wells and 21,000 pounds of oxidant<br>• Well installation and monitoring |
| Little Rock | Excavation of over 13,000 cy of soil, stabilization of some soil with cement, and off-site disposal |
| Travis Alt 1 | • Extraction and treatment of approximately 2 gpm of groundwater with a system assumed to consist of an air stripper<br>• Groundwater monitoring |
| Travis Alt 2 | • Construction and operation of a bioreactor<br>• Installation of a biobarrier involving injection of 54,000 pounds of emulsified vegetable oil<br>• Groundwater monitoring |

Each of the final demonstration sites presents characteristics that contribute to the overall quality and diversity of remedial actions evaluated for the study.

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# 5.0 TESTING DESIGN

## 5.1 CONCEPTUAL EXPERIMENTAL DESIGN

SimaPro® was applied to all the demonstration sites. SiteWise™ was applied to three of the demonstration sites (consisting of 15 remedy alternatives), and SRT™ was applied to the other three demonstration sites (consisting of 5 remedy alternatives). The ESTCP project team consisted of the following four teams (key points of contact are listed in Appendix A).

- SiteWise™ Team – Applied/updated SiteWise™ (Battelle).
- SRT™ Team – Applied/updated SRT™ (GSI Environmental [GSI] with support from CH2M Hill).
- Benchmark Team – Operated SimaPro® and evaluated the results of the tool comparisons, and led the project briefings and preparation of project reports (Tetra Tech with support from Dr. H. Scott Matthews of Avenue C Advisors, LLC).
- DoD Team – Representatives from the AFCEC, Navy, and USACE who interfaced with installations, offered general guidance throughout the project, and provided input during tool evaluation and report preparation.

Further details of the experimental design are presented in the subsequent sections of this report.

## 5.2 BASELINE CHARACTERIZATION

A detailed "Coordination of Site Data Input" document was developed for each demonstration site (Appendix B of the Final Report) to document the values (and basis) for the information ultimately represented within the tools (e.g., on-site electricity use, fuel use, materials use, etc.) and ensure that both evaluation teams were provided standardized information in suitable form to be represented in the respective tools.

## 5.3 TREATABILITY OR LABORATORY STUDY RESULTS

Not applicable to this project.

## 5.4 FIELD TESTING

The field testing was performed in three phases.

- Phase 1 – An initial application of the tools was performed.
- Phase 2 – Improvements (including additions and revisions to footprint factors) were then implemented in the DoD tools.
- Phase 3 – Subsequent to implementation of improvements to each DoD tool, a second application of the DoD tools was performed, with another comparison made to the SimaPro® results.

The SimaPro® user was required to select processes to represent remedy items that were from a wide variety of possible choices not tailored for remediation scenarios. For several items, the Benchmark Team assessed the range of quantitative footprint results obtained from SimaPro® based on viable process choices by the user (i.e., performed a "sensitivity" analysis regarding variability in the benchmark tool). Also, for one of the demonstration remedies, the "impact assessment" component of the LCA analysis was demonstrated.

## 5.5 SAMPLING METHODS

Field sampling was not a part of this project so this is not applicable.

## 5.6 QUANTITATIVE RESULTS: SITEWISE™ VERSUS SIMAPRO®

SiteWise™ (Version 2 and 3) and SimaPro® were compared for 15 demonstration site remedy alternatives in a format that illustrates the result ratios between the SiteWise™ and SimaPro® results (a positive value indicates the SimaPro® footprint was higher, and a negative value indicates the SiteWise™ footprint was higher). Table 3 presents the comparison for SimaPro® results that include infrastructure, and Table 4 presents the comparison for SimaPro® results without infrastructure.

**Table 3. SiteWise™ versus SimaPro® results – result ratios for remedy alternatives. (SimaPro® results include infrastructure)**

| Result Ratio SiteWise™ V2 versus SimaPro® | | | | | | Result Ratio SiteWise™ V3 versus SimaPro® | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $CO_2e$ | Energy | NOx | PM | SOx | | $CO_2e$ | Energy | NOx | PM | SOx |
| CRREL Alt 1 | -1.0 | 1.2 | 1.8 | 1.5 | 2.5 | CRREL Alt 1 | -1.0 | 1.0 | 1.2 | -10.0 | 1.3 |
| CRREL Alt 2 | -1.1 | 1.2 | 1.8 | 1.5 | 2.5 | CRREL Alt 2 | 1.0 | 1.1 | 1.3 | -9.1 | 1.4 |
| CRREL Alt 3 | 1.2 | 1.4 | 3.6 | 83.2 | 4.4 | CRREL Alt 3 | 1.2 | 1.4 | 1.5 | -6.6 | 1.7 |
| CRREL Alt 4 | -15.2 | 1.4 | -16.0 | -1.3 | -4.0 | CRREL Alt 4 | -1.0 | 1.4 | -1.1 | -2.2 | 1.1 |
| Alameda G2 | -1.2 | -1.3 | 3.3 | 26.2 | 16.8 | Alameda G2 | -1.1 | -1.1 | 1.5 | -1.2 | 2.8 |
| Alameda G3a | 1.3 | 1.2 | 4.2 | 8.8 | 19.3 | Alameda G3a | 1.4 | 1.2 | 1.4 | -3.4 | 3.3 |
| Alameda G3b | 1.1 | -1.0 | 3.3 | 5.0 | 17.2 | Alameda G3b | 1.1 | 1.0 | 1.9 | -5.3 | 3.8 |
| Alameda G4 | 1.2 | -1.2 | 2.8 | 29.1 | 16.6 | Alameda G4 | 1.2 | 1.0 | 2.4 | -2.5 | 5.2 |
| Alameda S2 | 1.0 | 1.2 | 3.2 | -6.6 | 1.9 | Alameda S2 | -1.1 | 1.0 | 1.7 | -8.0 | -2.0 |
| NWIRP Alt 1 | -1.1 | 1.3 | 9.0 | 4.2 | 5.7 | NWIRP Alt 1 | 1.0 | 1.4 | 6.8 | -5.3 | 4.7 |
| NWIRP Alt 2 | -1.2 | 1.3 | 12.0 | 3.5 | 6.2 | NWIRP Alt 2 | 1.0 | 1.4 | 9.5 | -4.4 | 5.0 |
| NWIRP Alt 3 | -1.5 | -1.3 | 8.6 | 2.2 | 7.5 | NWIRP Alt 3 | -1.5 | -1.3 | 1.8 | -4.8 | 1.6 |
| NWIRP Alt 4 | 1.0 | 1.3 | 7.2 | -2.9 | 5.5 | NWIRP Alt 4 | -1.0 | 1.3 | 4.3 | -6.6 | 3.0 |
| NWIRP Alt 5 | -1.2 | 1.3 | 9.1 | 7.3 | 5.9 | NWIRP Alt 5 | -1.3 | 1.2 | 1.9 | -4.0 | -1.0 |
| NWIRP Alt 6 | 1.0 | 1.5 | 3.2 | -4.2 | 3.7 | NWIRP Alt 6 | -1.2 | 1.2 | 1.6 | -5.5 | -2.9 |

Orange shading – SiteWise™ higher
Blue shading – SimaPro® higher
Alt = Alternative

**Table 4. SiteWise™ versus SimaPro® results – result ratios for remedy alternatives (SimaPro® results do not include infrastructure)**

| Result Ratio SiteWise™ V2 versus SimaPro® | | | | | |
|---|---|---|---|---|---|
| | $CO_2e$ | Energy | NOx | PM | SOx |
| CRREL Alt 1 | -1.1 | 1.2 | 1.8 | 1.3 | 2.5 |
| CRREL Alt 2 | -1.1 | 1.2 | 1.8 | 1.3 | 2.5 |
| CRREL Alt 3 | 1.2 | 1.4 | 3.5 | 72.7 | 4.4 |
| CRREL Alt 4 | -17.6 | 1.3 | -19.4 | -3.9 | -4.3 |
| Alameda G2 | -1.2 | -1.3 | 3.3 | 25.6 | 16.7 |
| Alameda G3a | 1.3 | 1.2 | 4.0 | 6.7 | 18.9 |
| Alameda G3b | 1.0 | -1.1 | 3.2 | 4.1 | 17.1 |
| Alameda G4 | 1.2 | -1.2 | 2.8 | 27.9 | 16.6 |
| Alameda S2 | -1.3 | -1.4 | 2.3 | -13.3 | 1.1 |
| NWIRP Alt 1 | -1.1 | 1.3 | 8.9 | 3.5 | 5.7 |
| NWIRP Alt 2 | -1.2 | 1.3 | 11.8 | 2.9 | 6.1 |
| NWIRP Alt 3 | -1.5 | -1.4 | 8.3 | 1.6 | 7.3 |
| NWIRP Alt 4 | -1.0 | 1.2 | 7.0 | -3.8 | 5.3 |
| NWIRP Alt 5 | -1.3 | 1.2 | 8.8 | 5.1 | 5.7 |
| NWIRP Alt 6 | -1.1 | 1.3 | 3.0 | -5.8 | 3.0 |

| Result Ratio SiteWise™ V3 versus SimaPro® | | | | | |
|---|---|---|---|---|---|
| | $CO_2e$ | Energy | NOx | PM | SOx |
| CRREL Alt 1 | -1.0 | 1.0 | 1.2 | -11.6 | 1.3 |
| CRREL Alt 2 | 1.0 | 1.1 | 1.3 | -10.6 | 1.4 |
| CRREL Alt 3 | 1.2 | 1.3 | 1.5 | -7.6 | 1.7 |
| CRREL Alt 4 | -1.2 | 1.2 | -1.4 | -6.6 | 1.0 |
| Alameda G2 | -1.1 | -1.2 | 1.5 | -1.2 | 2.8 |
| Alameda G3a | 1.3 | 1.2 | 1.3 | -4.5 | 3.2 |
| Alameda G3b | 1.1 | 1.0 | 1.9 | -6.6 | 3.8 |
| Alameda G4 | 1.2 | 1.0 | 2.4 | -2.6 | 5.2 |
| Alameda S2 | -1.4 | -1.6 | 1.2 | -16.2 | -3.3 |
| NWIRP Alt 1 | 1.0 | 1.4 | 6.7 | -6.5 | 4.6 |
| NWIRP Alt 2 | 1.0 | 1.4 | 9.3 | -5.1 | 4.9 |
| NWIRP Alt 3 | -1.5 | -1.4 | 1.8 | -6.6 | 1.5 |
| NWIRP Alt 4 | -1.0 | 1.2 | 4.2 | -8.7 | 3.0 |
| NWIRP Alt 5 | -1.4 | 1.1 | 1.9 | -5.7 | -1.1 |
| NWIRP Alt 6 | -1.4 | 1.0 | 1.5 | -7.8 | -3.6 |

Orange shading – SiteWise™ higher
Blue shading – SimaPro® higher
Alt = Alternative

Observations from these results for overall remedy alternatives (including additional results detailed in the Final Report) include the following:

- One major improvement to SiteWise™ during the project was the addition of footprints for NOx, PM, and SOx calculated for materials production, therefore, footprint totals for these parameters are generally higher for SiteWise™ Version 3 compared to SiteWise™ Version 2 (which did not include NOx, PM, and SOx footprints for materials production). Also in SiteWise™ Version 2, PM was not calculated for electricity consumption but it is for Version 3, which results in greater PM emissions in Version 3. Other changes were made in Version 3 with respect to electricity footprint factors.
- For CRREL Alt 4, SiteWise™ Version 2 had particularly large footprints for $CO_2e$ and energy, due primarily to the representation of water disposal to the publicly owned treatment works (POTW). These footprint factors were modified in SiteWise™ Version 3, significantly improving the match between tools.
- The $CO_2e$ and energy footprints more closely match between SiteWise™ and SimaPro® than the footprints for NOx, PM, and SOx. There is likely more variability in footprint factors for the three criteria pollutants than $CO_2e$ and energy.
- There are no alternatives where the total footprints are within a factor of 1.2 between tools for all metrics, suggesting that variations in footprint results of greater than 20%

are typical (i.e., should be expected) when comparing SiteWise™ and SimaPro®. However, for $CO_2e$ and energy, the total footprints for each remedy alternative from SiteWise™ Version 3 are always within a factor of 1.6 of the results from SimaPro® (i.e., not extremely different) and are within a factor of 1.2 for 10 of the 15 alternatives (both with and without infrastructure).

- Even though the tool results do not generally agree within a factor of 1.2, SiteWise™ Version 3 provides results that are generally comparable to SimaPro®. The ranking of alternatives at a given site based on footprint results generally agrees between SiteWise™ Version 3 and SimaPro® (see full results in Final Report).
- When comparing SiteWise™ Version 3 to SimaPro® with respect to the total footprints for remedy alternatives, the $CO_2e$ results show little or no bias as to which tool is higher. However, the energy, NOx, and SOx show some bias in that they are generally higher for SimaPro®, and the PM is generally higher for SiteWise™.
- As expected, the footprints calculated by SimaPro® "without infrastructure" are lower than the footprints calculated "with infrastructure." The effect of changing the system boundary to include infrastructure varies by alternative and sustainability metric. In general, adding infrastructure had a small effect on remedy footprint totals relative to the overall difference in footprint totals between the tools.

All remedy items included in the SimaPro® calculations were also included in the SiteWise™ Version 3 calculations, so no differences are attributable to items being left out of one of the tools. However, there is potential variability in the benchmark tool footprints based on processes selected in SimaPro® to represent remedy items (discussed in Sections 6 and 8 of this report).

A more detailed comparison of SiteWise™ and SimaPro® results, broken down by remedy components, is provided in Appendix C and Appendix D of the Final Report. That analysis evaluated each of the five sustainability metrics with regard to result ratio between the two tools, as well the rank and percent contribution to overall footprint, for different components of the remedy alternative (e.g., electricity use, fuel use, materials use, transportation, water use, and disposal). Observations included the following:

- The rankings for the footprint contributors are generally similar, but do not match exactly. The remedy item that contributes most to the footprints (e.g., electricity use for some remedy alternatives) depends on the remedy.
- The result ratios indicate some patterns regarding bias. For instance, PM in SiteWise™ Version 3 is typically much higher than the SimaPro® results for electricity and disposal in a landfill, but is typically lower than the SimaPro® results for transportation.

## 5.7 QUANTITATIVE RESULTS: SRT™ VERSUS SIMAPRO®

SRT™ (Version 2.1 and 2.3) and SimaPro® were compared for five demonstration site remedy alternatives in a format that illustrates the result ratios between the SRT™ and SimaPro® (a positive value indicates the SimaPro® footprint was higher, and a negative value indicates the SRT™ footprint was higher). Table 5 presents the comparison for SimaPro® results that include infrastructure. Table 6 presents the comparison for SimaPro® results without infrastructure.

**Table 5. SRT™ versus SimaPro® results – result ratios for remedy alternatives. (SimaPro® results include infrastructure)**

| Result Ratio SRT™ V2.1 versus SimaPro® | | | | | | Result Ratio SRT™ V2.3 versus SimaPro® | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $CO_2$ | Energy | NOx | PM | SOx | | $CO_2$ | Energy | NOx | PM | SOx |
| Beale Alt 2 | 1.4 | 2.0 | 2.1 | 3.6 | 21.7 | Beale Alt 2 | 1.4 | 1.9 | 1.5 | 2.1 | 21.7 |
| Beale Alt 3 | 1.2 | 3.2 | 3.6 | 5.8 | 8.7 | Beale Alt 3 | 1.7 | 1.9 | 2.0 | 1.4 | 1.8 |
| Little Rock | 6.0 | 5.4 | 3.8 | 6.1 | 589.0 | Little Rock | 4.4 | 4.3 | 2.9 | 3.7 | 589.0 |
| Travis Alt 1 | -1.3 | 1.0 | -5.4 | -39.7 | -1.8 | Travis Alt 1 | 1.7 | 1.0 | 6.2 | -1.4 | 52.2 |
| Travis Alt 2 | -2.7 | 49.7 | 9.7 | 16.0 | 23.9 | Travis Alt 2 | 1.2 | 1.4 | 1.5 | -3.0 | 1.4 |

SRT™ calculates $CO_2$, but the SimaPro® values are $CO_2e$ (i.e., includes other GHGs)
Orange shading – SRT™ higher
Blue shading – SimaPro® higher
Alt = Alternative

**Table 6. SRT™ versus SimaPro® results – result ratios for remedy alternatives. (SimaPro® results do not include infrastructure)**

| Result Ratio SRT™ V2.1 versus SimaPro® | | | | | | Result Ratio SRT™ V2.3 versus SimaPro® | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $CO_2$ | Energy | NOx | PM | SOx | | $CO_2$ | Energy | NOx | PM | SOx |
| Beale Alt 2 | 1.3 | 1.8 | 2.0 | 3.1 | 17.3 | Beale Alt 2 | 1.2 | 1.7 | 1.5 | 1.8 | 17.3 |
| Beale Alt 3 | 1.0 | 2.7 | 3.4 | 4.5 | 7.1 | Beale Alt 3 | 1.5 | 1.6 | 1.9 | 1.1 | 1.5 |
| Little Rock | 4.8 | 2.8 | 2.9 | 3.9 | 384.0 | Little Rock | 3.6 | 2.2 | 2.2 | 2.4 | 384.0 |
| Travis Alt 1 | -1.3 | 1.0 | -5.5 | -50.0 | -1.8 | Travis Alt 1 | 1.7 | 1.0 | 6.1 | -1.8 | 52.0 |
| Travis Alt 2 | -2.9 | 48.0 | 9.0 | 11.5 | 21.2 | Travis Alt 2 | 1.1 | 1.4 | 1.4 | -4.2 | 1.2 |

SRT™ calculates $CO_2$, but the SimaPro® values are $CO_2e$ (i.e., includes other GHGs)
Orange shading – SRT™ higher
Blue shading – SimaPro® higher
Alt = Alternative

Observations from these results for overall remedy alternatives (including additional results detailed in the Final Report) are listed below:

- The results from SRT™ Version 2.3 are generally closer to the SimaPro® results than SRT™ Version 2.1. This is due to improvements made to the SRT™ tool during the course of the project.
- For Travis Alt 2, SRT™ Version 2.1 had particularly low footprints for each of the sustainability metrics other than $CO_2$. This has to do with footprint factors for vegetable oil (bioremediation substrate), which is the dominant footprint contributor for this remedy. SRT™ Version 2.1 only calculated a $CO_2$ footprint for vegetable oil, whereas SRT™ Version 2.3 calculates a footprint for each of the sustainability metrics for vegetable oil (and also uses a smaller footprint factor for the $CO_2$ footprint).

- For Travis Alt 1, SRT™ Version 2.1 had much higher values for the three criteria pollutant footprints (NOx, PM, and SOx) than SRT™ Version 2.3. This is because the SRT™ Version 2.3 incorporates a local, rather than national, electricity mix.
- For several alternatives (Beale Alt 2, Little Rock, and Travis Alt 1) the SOx value calculated by SRT™ Version 2.3 is much smaller than the SimaPro® result. The cause differs by alternative. For Beale Alt 2 and Little Rock, the reason is that the primary SOx contributor(s) in SimaPro® (e.g., landfill activities associated with soil disposal) were not represented within the SRT™ tool (transport of soil for disposal is accounted for in the excavation total, but the landfill operations footprint is not fully considered). For Travis Alt 1, the difference is primarily the result of a difference in the SOx footprint factor for electricity use.
- The SRT™ results are nearly always less than the SimaPro® results for each sustainability metric, indicating some bias. This is primarily due to the fact that there were many remedy items (e.g., cement production) represented in the SimaPro® tool that not were not represented in the SRT™ tool.
- There are no alternatives where the total footprints are within a factor of 1.2 between tools for all metrics, suggesting that variations in footprint results of greater than 20% are typical (i.e., should be expected) when comparing SRT™ and SimaPro®. With the exception of Little Rock, for $CO_2$ and energy, the total footprints for each remedy alternative from SRT™ Version 2.3 are always within a factor of 1.7 of the results from SimaPro® (i.e., not extremely different). As detailed in Appendix E of the Final Report, Little Rock very large contributors to the $CO_2$e and energy footprints in SimaPro® were not represented in SRT™ (cement production and landfill operations for soil disposal).
- Even though the tool results do not generally agree within a factor of 1.2, the SRT™ Version 2.3 provides results that are generally comparable to SimaPro® (although there are some exceptions for reasons noted above).
- The ranking of alternatives at a given site, based on footprint results generally agrees between SRT™ Version 2.3 and SimaPro® (this evaluation is somewhat limited since two of the sites had two alternatives and the other site had one alternative).
- As expected, the footprints calculated by SimaPro® "without infrastructure" are lower than the footprints calculated "with infrastructure." The effect of changing the system boundary to include or exclude infrastructure varies by alternative and sustainability metric. In general, adding infrastructure had a small effect on remedy footprint totals relative to the overall difference in footprint totals between the tools.

There is some variability in the benchmark tool footprints based on processes selected in SimaPro® to represent remedy items (discussed in Sections 6 and 8 of this report), which impacts comparisons between tools. Some variance between tools is due to the original program design specifications and objectives of SRT™, which do not include some remedy items and calculations included in the SimaPro® calculations. Additionally, per the design of the project, the SRT™ tool was applied to the demonstration sites prior to this study, which limited some input values relative to Coordination of Site Data Input sheets developed for the Air Force sites.

A more detailed comparison of SiteWise™ and SimaPro® results, broken down by remedy components, is provided in Appendix E and Appendix F of the Final Report. That analysis evaluated each of the five sustainability metrics with regard to result ratio between the two tools, as well the rank and percent contribution to overall footprint for different components of the remedy alternative (e.g., electricity use, fuel use, materials use, transportation, water use, and disposal).

SRT™ was designed as a screening tool for specific types of remediation common at AFCEC sites, and therefore does not include all of the remedy items represented by SimaPro®. In some cases, the highest contributors according to SimaPro® were not included in the SRT™ evaluations. For instance, for Little Rock, SimaPro® indicates the highest contributor to $CO_2$ is the use of cement, but this material is not represented in SRT™. Water use is also not represented in SRT™, but for these demonstration sites water use did not contribute significantly to the footprints based on the SimaPro® results. Additional observations include the following:

- Notwithstanding the issues described above, the rankings for the footprint contributors are often similar, but do not match exactly.
- The remedy item that contributes most to the footprints depends on the remedy. Electricity use, fuel use, materials production, transportation, and disposal were all indicated as the highest contributor for one of the sustainability metrics for at least one alternative.
- The result ratios for specific remedy components indicate less overall bias than the results for the remedy totals, which indicates that the bias observed for remedy totals (i.e., SimaPro® footprints are almost always higher than SRT™) is primarily due to items not included in the SRT™ evaluations.

## 5.8 SUMMARY OF IMPROVEMENTS MADE TO SITEWISE™ AND SRT™

SiteWise™ was updated from Version 2 to Version 3 and SRT™ was updated from Version 2.1 to Version 2.3 as part of this project, based on initial results from the demonstration sites and associated recommendations from the Benchmark Team. Many of the improvements pertained to methods or footprint factors for calculation of footprint values, and others pertained to ease of use or formatting. These are summarized in Appendix B (SiteWise™) and Appendix C (SRT™).

## 5.9 SENSITIVITY ANALYSES REGARDING SIMAPRO® OPTIONS

### 5.9.1 Extending SimaPro® Boundary to Include Infrastructure

To illustrate the sensitivity of SimaPro® results to this type of boundary condition, several items were represented in SimaPro® both “with infrastructure” and “without infrastructure.” Figure 2 (for the $CO_2$e sustainability metric) represents the percent contribution of infrastructure when infrastructure is included for the processes evaluated. On Figure 2 each bar represents 100 percent of the footprint total, and the red upper portion indicates the percentage of the total that is due to the “with infrastructure” option. Similar plots for energy, NOx, PM, and SOx are presented in Appendix G of the Final Report. These figures illustrate that some items are affected by the addition of infrastructure more than others. In general, the impact of infrastructure on

transport footprints is significantly larger than the impact of infrastructure on materials footprints. A primary reason is that the lifespan of a transport vehicle such as a tractor trailer is shorter than the lifespan of a chemical facility used to manufacture materials; and the depreciation occurs more rapidly for the tractor trailer, such that footprints (e.g., $CO_2e$) for infrastructure are greater for transport than for materials. For the materials evaluated, some have almost no impact from the infrastructure (e.g., lime or PVC resin), whereas others have a greater impact from infrastructure (e.g., sulfuric acid).

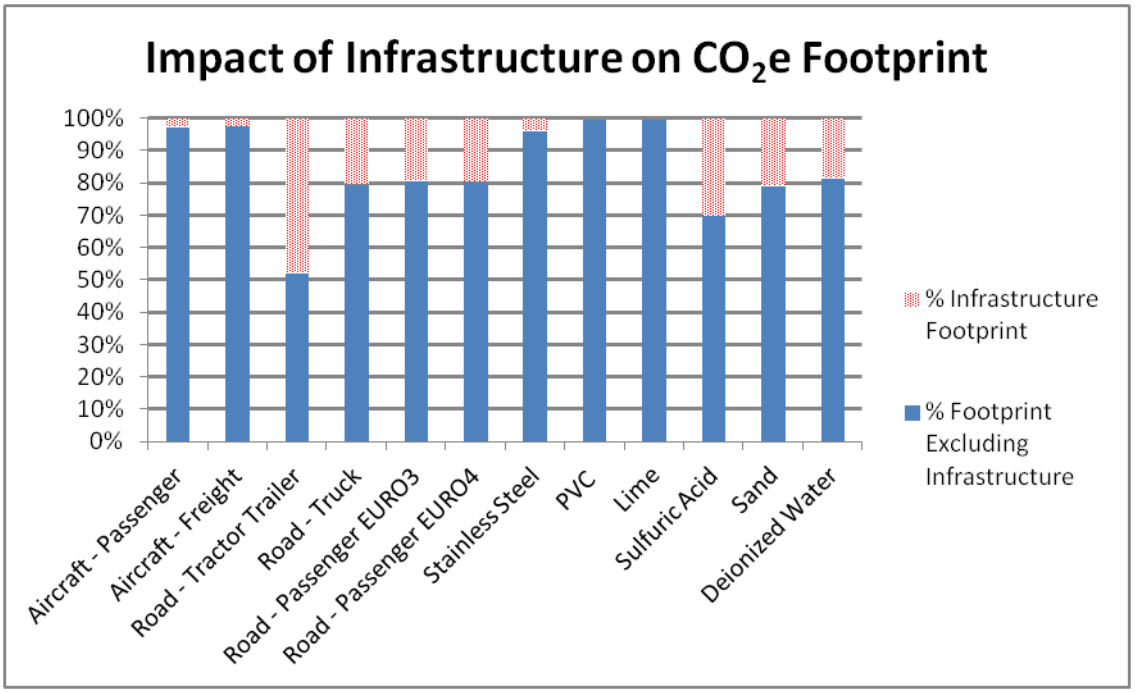


**Figure 2. Impact of "Infrastructure" on SimaPro® $CO_2e$ footprint, selected items.**

### 5.9.2 Variation in SimaPro® for Different Choices for Selected Materials

A sensitivity analysis was performed for five materials to gain insight regarding the variability of results from SimaPro® that might result from different choices by the user regarding SimaPro® processes. Table 7 summarizes the variability of the SimaPro® results for $CO_2e$ (the variability for the other sustainability metrics is presented in the Final Report). The results indicate there is considerable variation in the SimaPro® results depending on the processes selected.

**Table 7. Variability of SimaPro® results for $CO_2e$ for different processes selected.**

| Material | # Options Evaluated | Minimum | Maximum | Average | Median | Standard Deviation |
|---|---|---|---|---|---|---|
| **Steel** | 8 | 0.420 | 2.042 | 1.292 | 1.299 | 0.516 |
| **Vegetable Oil** | 8 | 0.689 | 2.724 | 1.657 | 1.853 | 0.676 |
| **PVC** | 10 | 1.556 | 3.254 | 2.318 | 2.249 | 0.638 |
| **Gravel** | 8 | 0.048 | 13.037 | 3.861 | 2.628 | 3.903 |
| **Cement** | 9 | 0.445 | 1.370 | 0.872 | 0.821 | 0.291 |

Values are in metric tons of $C0_2e$ for 1000 kg of each material (except 1,000,000 kg of gravel)

Key observations include the following:

- A user is faced with making choices to select processes in SimaPro® to represent remedy items, and the decision of which process to select will often not be clear to a typical professional in the remediation industry.
- The SimaPro® results vary significantly depending on the processes selected by the user, with the minimum and maximum footprints from SimaPro® typically different by a factor greater than 2 and sometimes different by a factor of 10 or more.

Comparison of results from SiteWise™ or SRT™ to SimaPro® is therefore highly complex, and is perhaps not possible in an absolute sense because of the many possible choices available for processes in SimaPro® and the associated variability in the footprints calculated by SimaPro®.

## 5.10 SUGGESTED FOOTPRINT FACTORS FOR GENERIC MATERIALS

A chart was developed by the project team (see Table 8) to help guide users in specifying footprint factors for materials that might not be represented in a tool. This chart is based on representative footprint factors based on SimaPro® results for selected materials. The idea of the chart (for a unit of 1 kg of material) is as follows:

- If a material listed in the last column on the chart (Table 8) is not included in the tool, and the user wants to include that material, it is suggested that the user input a generic material in the tool using the footprint factors illustrated on the chart corresponding to that material.
- If a generic material is not included on the chart (Table 8) or in the tool, but a $CO_2e$ per kg can be established for the material, categorize the generic material based on column 2 of the chart (i.e., similarity of $CO_2e$ footprint). Then, input a generic material in the tool using the known $CO_2e$ footprint factor plus the footprint factors for the other footprints (energy, NOx, PM, and SOx) illustrated on the chart for that category of $CO_2e$.
- If a generic material is not included on the chart (Table 8) or in the tool, and a $CO_2e$ per kg cannot be established for the material, categorize the generic material based on similarity to one or more other materials in the last column of the chart and input a generic material in the tool using the footprint factors illustrated on the chart for the corresponding category of $CO_2e$.

**Table 8. Chart of suggested footprint factors for generic materials.**

| Category | $CO_2$ Categorizer (per kg of material) | # of Materials in Each Category | Generic Values for Each Category Based | | | | | Materials Each Category is Based On (in order from greatest $CO_2$ emissions to smallest) |
|---|---|---|---|---|---|---|---|---|
| | | | Energy (MJ) | $CO_2$ eq (kg) | Nox (kg) | Sox (kg) | PM (kg) | Text represents name of option as selected in SimaPro® |
| Very High – 5 | >5 kg $CO_2$ eq | 2 | 100 | 10 | 0.02 | 0.02 | 0.001* | Potassium nitrate, as N, at regional storehouse/RER S |
| | | | | | | | | Virgin GAC_Assembly_1 kg |
| High – 4 | >2-5 kg $CO_2$ eq | 6 | 60 | 3 | 0.006 | 0.008 | 0.001* | Chromium steel 18/8, at plant/RER S |
| | | | | | | | | Anionic resin, at plant/CH S |
| | | | | | | | | PVC pipe E |
| | | | | | | | | Glass fibre, at plant/RER S |
| | | | | | | | | HDPE pipes E |
| | | | | | | | | Regen_GAC_1 kg |
| Medium – 3 | >1-2 kg $CO_2$ eq | 9 | 30 | 1 | 0.003 | 0.005 | 0.001* | Acetic acid, 98% in $H_2O$, at plant/RER S |
| | | | | | | | | Reinforcing steel, at plant/RER S |
| | | | | | | | | Cationic resin, at plant/CH S |
| | | | | | | | | Ammonium nitrate phosphate, as $P_2O_5$, at regional storehouse/RER S |
| | | | | | | | | Sodium persulfate, at plant/GLO S |
| | | | | | | | | Green Sand_1 kg |
| | | | | | | | | Potassium permanganate, at plant/RER S |
| | | | | | | | | Hydrogen peroxide, 50% in $H_2O$, at plant/RER S |
| | | | | | | | | Sodium hydroxide, 50% in $H_2O$, production mix, at plant/RER S |
| Low – 2 | >0.05-1 kg $CO_2$ eq | 12 | 10 | 0.5 | 0.001 | 0.002 | 0.0004 | Soybean oil, at oil mill/US S |
| | | | | | | | | Sodium hypochlorite, 15% in $H_2O$, at plant/RER S |
| | | | | | | | | Iron (III) chloride, 40% at $H_2O$, at plant/CH S |
| | | | | | | | | $CO_2$ liquid, at plant/RER S |
| | | | | | | | | Cement, unspecified, at plant/CH S |
| | | | | | | | | Lime, hydrated, loose, at plant/CH S |
| | | | | | | | | Bentonite, at processing/DE S |
| | | | | | | | | Iron sulfate, at plant/RER S |
| | | | | | | | | Sulfuric acid, liquid, at plant/RER S |
| | | | | | | | | Molasses, from sugar beet, at sugar refinery/CH S |
| | | | | | | | | Pellets, iron, at plant/GLO S |
| | | | | | | | | HCl, 36% in $H_2O$, from reacting propylene and chlorine, at plant/RER S |
| Very Low – 1 | >0-0.05 kg $CO_2$ eq | 3 | 0.2 | 0.01 | 4.00E-05 | 3.00E-05 | 2.00E-05 | Graphite, at plant/RER S |
| | | | | | | | | Gravel, unspecified, at mine/CH S |
| | | | | | | | | Sand at mine/CH S |

*The generic value for PM is based on the average PM emissions of all materials in the top three categories (average of 17 materials)
MJ = megajoule

Use of the footprint factors suggested in this table for generic materials is a significant improvement compared to simply not accounting for any footprint from use of such materials.

## 5.11 IMPACT ASSESSMENT FOR ONE DEMONSTRATION SITE

Per the Demonstration Plan, a life-cycle impact assessment (LCIA) was performed for one of the demonstration sites to illustrate the full scope of SimaPro's™ capabilities. A LCIA is used to evaluate the effect of an activity on a particular impact category such as global warming and acidification. SiteWise™ and SRT™ do not have the capabilities to perform an impact assessment.

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# 6.0 PERFORMANCE ASSESSMENT

## 6.1 QUANTITATIVE PERFORMANCE OBJECTIVES

### 6.1.1 Footprint Contributor Ranking

In general, the rankings are not identical, and as such the DoD tools do not strictly meet this quantitative objective. However, it appears that the contributor rankings derived by SimaPro® may be sufficiently uncertain that a difference in the contributor rankings between a DoD tool and SimaPro® does not necessarily indicate a deficiency in the DoD tool.

### 6.1.2 Result Ratio

This objective is evaluated quantitatively for each sustainability metric (e.g., NOx) by determining the ratio by which the DoD tool result differs from the benchmark result (larger result divided by smaller result, positive in one direction and negative in the other direction). Per the performance objectives, ratios greater than 1.2 are considered significant. There were no remedy alternatives where the footprint totals were within a factor of 1.2 between the DoD tool and SimaPro® for all five sustainability metrics evaluated, suggesting that variations in footprints of greater than 20% are typical (i.e., should be expected) when comparing the DoD tools and SimaPro®. However, with a few notable exceptions (discussed in the report), the DoD tools provide total footprints for remedy alternatives that are generally comparable to SimaPro® results.

- For $CO_2$e and energy, the total remedy footprints from SiteWise™ Version 3 were always within a factor of 1.6 of the results from SimaPro® (i.e., not extremely different) and 10 of the 15 alternatives evaluated were within a factor of 1.2.
- With the exception of Little Rock, for $CO_2$ and energy, the total footprints for each remedy alternative from SRT™ Version 2.3 are always within a factor of 1.7 of the results from SimaPro® (i.e., not extremely different).
- If total footprints for remedy alternatives at the same site are compared, the ranked alternatives based on footprints are mostly (but not always) in agreement between the tools.

Many of the individual remedy components have DoD tool results that differ from the SimaPro® results by more than a factor of 1.2 and high results for some components partially offset low results from other components. In cases where SimaPro® accounts for items that are not accounted for in one of the DoD tools, that clearly is a cause for discrepancy. In other cases, however, it is not clear that results that differ by more than a ratio of 1.2 indicate a deficiency in the DoD tool. There is no clear evidence that the footprint factors used in the DoD tool are invalid. Those footprint factors may in some cases be more applicable to the specific remedy item than the footprint factors used in SimaPro® for the processes selected by the user.

### 6.1.3 Effects of the System Boundary With and Without Infrastructure

The results indicate that for remedy alternative totals the impact of this system boundary varies from "minimal" to "significant." A summary of the percent reduction in the SimaPro® result for each remedy alternative when infrastructure is not included is provided in Table 9.

**Table 9. Impact of infrastructure system boundary on footprint totals.**

| Remedy Alternative | Percent Reduction in SimaPro® Result Without Infrastructure | | | | |
|---|---|---|---|---|---|
| | $CO_2e$ | Energy | NOx | PM | SOx |
| CRREL Alt 1 | 0.76 | 0.68 | 1.49 | 13.77 | 0.42 |
| CRREL Alt 2 | 0.79 | 0.72 | 1.55 | 13.57 | 0.45 |
| CRREL Alt 3 | 0.90 | 0.93 | 1.93 | 12.56 | 0.50 |
| CRREL Alt 4 | 13.56 | 8.96 | 17.79 | 67.02 | 5.30 |
| Alameda G2 | 1.01 | 1.45 | 1.45 | 2.30 | 0.41 |
| Alameda G3a | 2.75 | 2.98 | 4.61 | 23.71 | 1.83 |
| Alameda G3b | 1.43 | 1.70 | 2.43 | 19.31 | 0.60 |
| Alameda G4 | 0.47 | 0.60 | 0.78 | 4.11 | 0.18 |
| Alameda S2 | 25.22 | 38.99 | 26.60 | 50.45 | 40.44 |
| NWIRP Alt 1 | 1.97 | 2.55 | 1.15 | 17.91 | 1.35 |
| NWIRP Alt 2 | 1.65 | 2.23 | 2.06 | 15.01 | 1.27 |
| NWIRP Alt 3 | 3.82 | 4.45 | 3.05 | 28.00 | 2.88 |
| NWIRP Alt 4 | 3.53 | 4.54 | 2.32 | 24.12 | 2.56 |
| NWIRP Alt 5 | 5.72 | 5.47 | 3.83 | 30.57 | 3.60 |
| NWIRP Alt 6 | 11.90 | 13.40 | 7.80 | 28.84 | 18.52 |
| Beale Alt 2 | 8.75 | 8.45 | 4.53 | 17.48 | 16.81 |
| Beale Alt 3 | 11.89 | 14.64 | 5.26 | 22.18 | 18.66 |
| Little Rock | 19.88 | 47.68 | 23.39 | 35.82 | 34.78 |
| Travis Alt 1 | 0.79 | 0.69 | 1.86 | 20.39 | 0.28 |
| Travis Alt 2 | 6.62 | 3.42 | 7.71 | 27.93 | 11.42 |

The greatest boundary effect is generally for PM, where the inclusion of infrastructure generally accounts for more than 10% of the footprint and often accounts for more than 20% of the footprint. For other footprints, the boundary effect is generally less than 5% but is significantly higher (in some cases more than 20%) for some alternatives. The impacts of this boundary condition are typically greater for transport than for materials, so for alternatives where transport dominates the footprint (such as Alameda Alt S-2 and Little Rock) the boundary effect will tend to be quite significant. The evaluation of this performance objective indicates the selection of the system boundary does impact the results for other performance criteria in this study, and therefore, is significant. However, as noted in Section 5, for total remedy footprints adding infrastructure generally had a small effect on remedy footprint totals relative to the overall difference in footprint totals between the tools.

### 6.1.4 Sensitivity Analysis of Selections in SimaPro®

Evaluation of this performance metric indicates that SimaPro® results are sensitive to the processes selected by the user. This is complicated by the naming convention of the processes, which abbreviate countries of origin and boundaries. The evaluation also indicates that the results provided by the DoD tools sometimes do not fall within the range of results the

benchmark tool for a variety of potential processes used to represent specific remedy items. Note that this performance objective would be further complicated by the boundary effect discussed in Section 6.1.3 if that was also considered within the sensitivity analysis. One advantage of the DoD tools is that the selection of inputs for the user is simple and clear.

### 6.1.5 Correlation or Bias

The findings indicate some bias when compared to the SimaPro® results for these pilot projects. In cases where SimaPro® addresses items that one of the DoD tools does not, a clear cause for discrepancy leading to bias is evident. For other items, however, it is not possible to make a general statement regarding systematic bias. As discussed earlier, there are numerous potential variations in the benchmark result due to choices that can be entered regarding process and boundary condition (i.e., SimaPro® results being higher or lower than one of the DoD tools could simply be due to user selections in SimaPro®).

## 6.2 QUALITATIVE PERFORMANCE OBJECTIVES

### 6.2.1 Technical Confidence

It is the opinion of the ESTCP project team that all of the tools provide reasonable results, regardless of whether or not the DoD tool results are within a factor of 1.2 of the SimaPro® results.

- Visual inspection of footprint totals (see full results in Final report) suggests that the tools provide results that are generally comparable.
- Given the potential variability in SimaPro® results for reasons discussed throughout this report, it is not evident that there is more technical confidence in the results of the DoD tools or SimaPro®. However, from the perspective of a typical environmental professional who might apply these tools, the variety of input selection choices in SimaPro® may be overwhelming, and perhaps more significantly, would likely result in undesired variability in results from one user to the next due to different choices made for inputs and system boundary.
- The more clearly defined inputs and associated footprint factors in the DoD tools likely reduce such variability and increase technical confidence in tool application.

### 6.2.2 Comparing Functionality

SimaPro® is essentially a user interface to several LCI libraries and impact assessment methods. Therefore, the functionality that SimaPro® has relative to the DoD tools is either a result of the user interface or the content of the libraries. Specific examples are as follows:

- The SimaPro® user interface provides network-type graphics that help the user better understand the various contributions and the interrelated nature of various contributions.
- SimaPro® provides access to several LCI libraries, some within the public domain and some that are proprietary. Although this functionality has the downside of providing the typical environmental user with a potentially overwhelming number of options, this

functionality also provides an advanced user with a wide variety of processes that are not available in the DoD tools. While the DoD tools could be modified to include all of the public domain LCI libraries, the DoD tools could not incorporate the proprietary libraries without paying a substantial fee. It is possible that the DoD tools might be able to incorporate some aggregate or modified average or statistical range of the individual proprietary processes.

- SimaPro® provides the user with the option of creating assemblies for multiple processes. For example, GAC (a common material used in environmental remediation) is not included in the LCI libraries as part of in SimaPro®. However, based on information available in literature, a SimaPro® user can create a GAC "assembly" using the appropriate quantities of various processes. The DoD tools also do not include this capability. New assemblies would need to be created outside of the DoD tools, documented, and then input into the DoD tools. Similarly, an advanced SimaPro® user can take an existing process in the Ecoinvent library and modify the contributors to that process. For example, if the SimaPro® user wants to use material (e.g., potassium permanganate) and notices that the electricity blend used in the Ecoinvent process of manufacturing potassium permanganate is different than the actual electricity blend for manufacturing the potassium permanganate used at their particular site, the user can make a copy of the Ecoinvent potassium permanganate process and then change the assumptions regarding the electricity blend used in that process. This would be well beyond the capability of a typical environmental user.
- A number of impact assessment methods included as part of SimaPro® are not included in the DoD tools. For example, in SimaPro®, the NOx and SOx emission can be combined to determine the acidification impact and the human respiratory impact.
- A SimaPro® project can be organized in a variety of ways based on the desired organization of the output. For example, in this study, the SimaPro® projects included intermediate assemblies for categories such as electricity, materials, and transportation so that results could be output in these categories. The contribution categories and associated outputs in the DoD tools are set by the tool design.

In general, the above-noted functionality for SimaPro® primarily benefits an advanced SimaPro® user or LCA expert, but may not benefit a typical environmental user expected for most GSR applications.

There are a number of functionality features offered by one or both of the DoD tools that are beneficial to the environmental user that are not offered by SimaPro®. Both DoD tools are tailored for environmental applications. Both DoD tools allow the user to provide the tool spreadsheets to peers, collaborators, or reviewers (e.g., via email). The Tier 1 evaluation offered by SRT™ provides useful calculations for remedies where specific quantities are not yet defined. SiteWise™ also includes calculations useful for environmental remedy applications such as a module to calculate well construction materials, electricity use based on known pump flow rate and head (or motor horsepower, load, and efficiency), and fuel use from oxidizers. The input and output from the DoD tools is organized according to remedy items that would be generally familiar to a typical environmental user. The contribution categories and associated outputs in

the DoD tools are set by the tool design, and this set design and pre-determined organization actually facilitates rather than limits use for the DoD tools for environmental projects.

A specific inconsistency is that the tools do not all use the same sustainability metric to represent GHG emissions ($CO_2e$ which includes GHGs other than $CO_2$ versus just $CO_2$).

### 6.2.3 SimaPro® Project Organization and "Work-Arounds"

SimaPro® was not designed to evaluate the environmental footprints of remediation projects. The Final Report includes a brief description of SimaPro's™ organization, how SimaPro® might be used to evaluate a footprint for a remediation project, and several "work-arounds" that are helpful for using SimaPro® for this purpose.

### 6.2.4 Extent of the Learning Curve

In general, both SiteWise™ and SRT™ are easy to use, and either tool can be learned by a typical environmental professional in less than one day. The DoD tools are Microsoft Excel based, which most environmental professionals are comfortable using. The DoD tools are also designed specifically for application to environmental remedies, which makes them much easier for an environmental professional to understand and apply. By contrast, SimaPro® is not simple for a typical environmental professional to use. There are many decisions for the user to make when using SimaPro® regarding choices for processes (e.g., to represent materials or transportation) and the results may vary considerably depending on selections made. However, the best choice will not be clear to a typical environmental project user (and in some cases there may not be a best choice). The latter issue is highlighted in the discussion of sensitivity analysis for SimaPro® options presented in this report. The choices representing remedy items are easier to navigate and select in SiteWise™ and SRT™.

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# 7.0 COST ASSESSMENT

This section addresses the costs of implementing the GSR footprint tool software at a DoD site. There is no direct costs savings that results from applying the software to calculate footprints. Indirectly, it is expected that alternatives with lower footprints (e.g., energy) will frequently have lower costs, but that was not evaluated in this effort.

## 7.1 COST MODEL

Table 10 provides a summary of the estimated costs for obtaining and applying these tools for a typical GSR application at a DoD site.

**Table 10. Estimated costs to apply the tools at a typical DoD site.**

| Cost Element | Estimated Costs: SiteWise™ and SRT™ | Estimated Cost: SimaPro® |
|---|---|---|
| Start-Up<br>Software Cost<br>Training/Learning | <br>Free<br>$400 to $1600* | <br>$3000 to $12,000<br>$2400 to $8000** |
| Annual Maintenance Costs<br>Software Updates | <br>Free | <br>$1500/yr or more |
| Estimated Application Costs<br>Per Project executed by a professional trained to use the software | $3000 to $10,000 | $5000 to $15,000 |

*Assuming a first-time user might require 4 to 8 hours to become familiar with the tools and a range of hourly costs of $100 to $200 per hour; however advanced features take longer.
**Assuming a first-time user might require 24 to 40 hours to become familiar with the tool (self-study or a course from a third-party) and a range of hourly costs of $100 to $200 per hour; however advanced features take longer.

In summary, the DoD tools are available to download at no cost, and a typical environmental engineer requires minimal training to use these tools, whereas SimaPro™ is purchased, requires more extensive training, and typically includes annual maintenance costs.

## 7.2 COST DRIVERS

The major cost drivers for applying any one of these tools, which result in the range of cost estimates provided above for tool application, include the following:

- Project complexity, which particularly increases with the number of different remedial technologies and/or number of remedial alternatives.
- Input parameters not represented in the tool because such input parameters may result in the user needing to research appropriate footprint factors or choosing and documenting appropriate surrogates.
- Availability of data because information is easier to obtain for operating remedies (based on actuals) rather than planned/designed remedies where estimates are required.
- Degree to which results need to be broken down by specific inputs rather than totals.

- Extent of reporting and documentation of results (i.e., a few tables versus a short memo versus a full-scale report).
- Technical experience of the user because the more experience the user has with this tool, the less it will cost to apply. Also, an experienced technical user will most likely require less time to become acclimated with the tool.

A cost driver specific to SimaPro® is the extent to which there are multiple process choices for a remedy component (e.g., type of steel or type of truck transport). SimaPro® requires the user to develop a basis for making a choice and/or performing a sensitivity analysis, which can become overwhelming when there are many choices for different remedy items.

## 7.3 COST ANALYSIS

As detailed in Table 10, the SimaPro® tool is more expensive than the SiteWise™ and SRT™ tools in all of the following categories:

- Cost to obtain the tool
- Learning to use the tool
- Applying the tool to projects

Thus, it only is logical to use SimaPro® over the other DoD tools if there is a perceived technical benefit. The results from this project, however, do not suggest that there is a great advantage to using SimaPro® compared to the DoD tools for footprinting at DoD sites, unless the user specifically wants to incorporate some aspect of analysis that SimaPro® offers that the DoD tools do not include (e.g., sustainability metrics that the DoD tools do not calculate or the results of impact assessments). It should be noted, however, that some impact assessment methods are public domain and can be applied externally to the DoD tools to obtain impact assessment information, if desired. However, this could increase cost of using the DoD tool.

Because there are no cost savings from the use of these tools, there is no attempt to calculate any sort of payback period or return on investment for the use of these tools at a specific site. However, some attempt has been made to compare the cost of using the DoD tools to the cost of using SimaPro® for the entire DoD complex. Assuming 1000 DoD sites have a footprint analysis performed, and analysis with a DoD tool costs approximately $5000 less than analysis with SimaPro®, there is savings of approximately $5M. This number may double (or more) if costs of software purchases and training for SimaPro® across the DoD components are included. The cost of developing both tools and implementing this project is approximately $1M to $2M; therefore, there is an excellent return on that investment across the DoD complex as more footprint evaluations are performed over time.

# 8.0 IMPLEMENTATION ISSUES

The following implementation issues are discussed in the sections below.

- Software availability and documentation
- Ease of use
- Key tool limitations
- Regulatory issues

## 8.1 SOFTWARE AVAILABILITY AND DOCUMENTATION

SiteWise™ and SRT™ are publicly available (i.e., freeware) spreadsheet-based technologies that are specifically designed for soil and groundwater remedies. The tools are easily downloaded from public websites. These tools are well documented. A beneficial feature of the SiteWise™ tool regarding documentation is that all spreadsheet cells are visible including formulas, so every calculation in the tool itself is transparent to the user. A beneficial feature of the SRT™ tool regarding documentation is the option for Scenario Planning, where different futures for carbon offset cost and energy costs are available to users and the importance of different sustainability metrics can be given project-specific levels of importance. It is also easy for users of the DoD tools to send the Microsoft Excel spreadsheet files to other professionals (e.g., via email) allowing for easy exchange of input and results for purposes of collaboration or peer review. This is a significant feature with respect to documentation for specific project applications.

In contrast, SimaPro® is not free and can cost between $3000 and $12,000 to purchase depending on the number of user licenses and features (additional costs can be incurred with service and support, if required). The Benchmark Team found the documentation for SimaPro® difficult to understand given the complexity of the software (see discussion regarding "ease of use" in Section 8.2). The calculations within SimaPro® are not transparent to the user. Unlike the DoD tools, files for SimaPro® are not easily exchanged with other professionals for collaboration or peer review, partly because those individuals also need to purchase the software. In addition, the backup/archive features are not well documented and are complicated by which versions of libraries each user has licensed and maintains (see Section 8.3). This is a significant shortcoming of SimaPro® with respect to documentation for specific project applications, especially for analysis of public projects where it might be expected that the models would be sharable with other parties for review or assessment.

For the DoD tools, the footprint factors are documented in the tool lookup tables and/or the tool documentation. One challenge with SimaPro® is that the user must spend additional time documenting which LCI items were used in a study, and failure to do so in a detailed manner could result in other users being unable to reproduce results. While much of the data accessed via SimaPro® is from public sources, data, such as that from Ecoinvent, are not public and are subject to protections under the software license. In this ESTCP project, various demonstration site inputs for SimaPro® utilized Ecoinvent data that cannot be publically shared to readers. This causes an additional documentation gap for software users that is significant. Licenses for reuse of proprietary database values can be purchased for re-distribution within a third-party tool, but at a substantial cost (thousands of dollars), and these licenses will significantly increase the cost

of a project. Costs for acquiring various types of licenses for subsequent redistribution of Ecoinvent data were evaluated in this project, and ultimately were found to be extremely complicated and costly (particularly compared to the free and fully documented footprint factors used by SiteWise™ and SRT™). Although it is likely there is value to these licenses and the Ecoinvent data for many practitioners, only a handful of Ecoinvent data entries are relevant to the remediation field and the benefits of the additional costs to use or license these items do not appear to outweigh the additional costs for a typical DoD GSR project.

## 8.2 EASE OF USE

Both DoD tools are simple to use and require minimal training. They are both Microsoft Excel based, which most environmental professionals are comfortable using. They are also both designed specifically for application to environmental remedies, which makes it easier for environmental professionals to apply them to GSR projects. For example, the DoD tools readily account for well construction. This activity is not represented in SimaPro®, but could be created by a user and employed on future projects. That is, SimaPro® can become friendlier for use in environmental projects, but significant time would be needed by each user upfront to create user-defined assemblies and processes that are common to environmental projects and already well represented in the DoD tools.

SiteWise™ has some specific features that enhance ease of use. For instance, it is very easy in SiteWisev to specify a sole input item and see the resulting footprints of that specific item in the results. All of the results can be cut from the output files (individual results or summed results) with full precision, allowing for easy post-processing and evaluation of results. Many features were added in Version 3 to further enhance ease of use (e.g., more columns, automatically identify return trips for materials transport, etc.).

SRT™ is designed in a tiered manner to allow the user the flexibility to select the level of effort and detail appropriate for the project at hand. The different tiers (Tier 1 and 2) make it simple to develop estimates for key sustainability metrics associated with a remedy footprint, by calculating inputs based on site-specific data.

There are many choices in the various LCI libraries and the documentation or descriptions provided within SimaPro® are likely difficult for a typical environmental user to interpret and use as a basis for confidently selecting input for a project. External lengthy descriptions are available, but this would take additional time for the reader to obtain these additional descriptions and understand the content. As discussed in Section 7.1, the learning curve is much greater for SimaPro® compared to the DoD tools.

## 8.3 KEY TOOL LIMITATIONS

For the DoD tools, a number of limitations identified in the initial phase of the project were addressed by revisions to the tools. There are clearly differences in footprint factors used by all the tools, but this is not so much a limitation of individual tools as it is a need for standardization between tools. There are some limitations of the DoD tool functionality compared to SimaPro®. For instance, the DoD tools do not incorporate impact assessment in the manner SimaPro® does, and do not include the universe of sustainability metrics that SimaPro® does. However, these are

relatively minor limitations for the typical DoD user for a GSR project. Note that SimaPro® offers many features and processes for general LCA projects that are beyond the functionality of the DoD tools because the DoD tools are targeted to footprint evaluations for environmental remedies.

There were limitations identified in Phase 1 of the study for both DoD tools. Almost all of the SiteWise limitations that were identified in Phase 1 were able to be addressed in Phase 2 of the study. Most of the SRT limitations that were identified in Phase 1 were able to be addressed in Phase 2 of the study. Additionally, there are some program structure restrictions within SRT™ that were identified in this project (e.g., transparency of calculations), and are attributed to the program architecture requirements stipulated by the Air Force (commissioned tool design). These restrictions were, therefore, unable to be revised in Version 2.3. That level of transparency is not always needed for footprint calculations, but for the purpose of this project, the restrictions on the transparency of the internal SRT™ calculations increased the level of effort. In some cases, it required a break-out of components from the overall footprint of a specific module or the entire remedy. For the purpose of this project, the Benchmark Team re-created the SRT™ calculations in a separate spreadsheet (i.e., without the user interface) to breakout the footprint contributions from various remedy components for comparison to SimaPro® footprint contributions. This is possible as the SRT™ User's Guide provides details on program calculations and assumptions. For SRT™ remedies outside of the eight, the remedy-based modules (e.g., bioreactor) sometimes cannot be easily represented in the tool. Finally, the outputs from SRT™ are rounded within the tool, which makes validating tool results more challenging.

As mentioned in Section 1.4, the tools to do not uniformly address (1) footprints (e.g., GHG emissions) due to water use; or (2) quantification of water used, reused, or reclaimed as a resource. Additional details for each tool are provided below.

- SimaPro® can calculate footprints (e.g., GHG emissions or energy use) associated with direct use of potable water like mixing chemicals at the site, and such calculations were included in this project. SimaPro® can also quantify water use associated with various processes (e.g., manufacture of materials), and has the ability to represent re-use of water to offset other footprints. It does not have specific functionality to represent water reclaimed by successful remediation.
- SiteWise™ calculates water treatment footprints (e.g., GHG emissions or energy use) associated with direct use of potable water like mixing chemicals at the site, and such calculations were included in this project. SiteWise™ quantifies water use for production of electricity, but SiteWise™ does not calculate water use for most processes such as manufacture of materials. However, SiteWise™ does allow the user to enter water consumed (or reclaimed by inputting a negative value) within each component and it also allows the user to enter the quantity of water recycled as part of a footprint reduction package. The quantities entered are then included in the output from the tool.
- The current version of SRT™ does not calculate footprints (e.g., GHG emissions or energy use) associated with direct use of potable water like mixing chemicals at the site, and does not assess water use as a sustainability metric. It is anticipated that future

revisions of SRT™ will include conversion calculations to account for: 1) direct water use during remediation; 2) indirect water use in life-cycle processes such as the production of materials; and 3) potentially water reclaimed as an outcome of remediation activities.

SimaPro® has been a valuable resource in this comparison project because of its industry popularity and its acceptance and inclusion of key popular global LCA data sources. However, use of SimaPro® comes with some downsides as detailed below.

- While creating models in SimaPro® is relatively straightforward (albeit with an extended learning curve), exporting and sharing the models with other parties is difficult. Even for parties with a SimaPro® license, the process of sharing model results is burdensome. A main reason for this burden is the volume of information in the libraries contained within SimaPro®. There are two ways of sharing projects. In the export option, all project flows are exported and saved to an archive. Importing the resulting archive in another computer with SimaPro® takes several hours. Each flow (in the case of this project, 16,000 of them) either has to be individually verified for import, or the user needs to decide in advance to automatically import all flows. This may sound like a simple decision but given the way in which data are stored in libraries, accepting all flows can overwrite existing model/flow data on the receiving computer, which is not desirable. The restore from backup option is much faster, requiring only about 15 minutes. Overall, the sharing process is time consuming, and potentially destructive to existing models. Various levels of quality assurance (QA)/quality control (QC) would be needed to ensure no change in local data. Thus, there are significant limitations for SimaPro® with respect to ability to share files for collaboration, peer review, and documentation.
- SimaPro® handles updated data in potentially unexpected ways. Typically the underlying databases in SimaPro® are updated once or twice a year. Because these are not "mission critical" updates, not all users perform them. The impact of these updates is that a project that simply refers to a data source within SimaPro® may give one result for the original database version and a different result for an updated version. This can also lead to problems with repeating results. There are limited ways to identify such discrepancies, although one identification method is when importing projects discrepancies are noted – but a user is typically going to choose to accept "all 16,000 potential changes" instead of seeing specific problems individually.
- SimaPro® is a user interface to LCI data from various sources. The base version of SimaPro® available includes the US NREL LCI database, the European Reference Life-Cycle Database (ELCD), the European Ecoinvent database, and several other sources. The databases often duplicate life-cycle processes, meaning multiple data sources in SimaPro® are available for similar items (e.g., multiple data sources on consuming electricity). This can cause confusion for the user regarding which database values to select. Even within a given LCI database, especially a large database like Ecoinvent, there are several options for similar items. Aside from the geographical factors (i.e., U.S. versus Europe), the timestamps may be significantly different.

- A large majority of data in SimaPro® is from European sources or applicable to European processes (the software itself is made in the Netherlands). While one should expect the production processes nowadays to be comparable amongst economies of the developed world, there are many known discrepancies between U.S. and European production. In other cases there are known reasons why European process data are not representative (e.g., electricity mixes and impacts of energy production). These various factors could bias the result when applying the data to U.S. problems or processes.
- The date of record for data can be quite old. The Ecoinvent database has some information dated from the 1980s and earlier.

## 8.4 REGULATORY ISSUES

Emissions of GHGs and other impacts resulting from soil and groundwater remediation are becoming a greater concern for regulatory agencies. Regulatory agencies are still evaluating how and whether to include considerations of GSR to interpret footprint results as well as how to consider them within the GSR process and the remediation process as whole. EPA and several states have issued guidance, factsheets, and/or have implemented GSR programs. This topic has also been a recent focus of ITRC guidance and an American Society for Testing and Materials (ASTM) subcommittee. Findings from this project and tool revisions will improve footprint calculation and enhance the understanding of factors that affect these calculations, which will facilitate acceptance of future GSR evaluations.

The uncertainties and variation in the results outlined in this report argue for standardization between tools, and particularly the use of the footprint factors used in the tools, to alleviate any skepticism from regulators regarding use of these tools. Also, the results of this study indicate that the DoD tools allow for easy transmission of the files to regulators (or contractors for the regulator) for review. The ability for the regulator to obtain the files and confirm the analyses is a significant advantage provided by the DoD tools.

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# APPENDIX A

# POINTS OF CONTACT

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# APPENDIX A (continued)

# POINTS OF CONTACT

| | | | |
|---|---|---|---|
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# APPENDIX B

# SUMMARY OF SITEWISE™ IMPROVEMENTS IMPLEMENTED DURING THIS PROJECT

| Revisions that Impact SiteWise™ Footprint Results | |
|---|---|
| **Observations by Benchmark Team for SiteWise™ Version 2** | **Revisions Implemented in SiteWise™ Version 3** |
| Inconsistencies were noted with respect to whether life-cycle impacts were calculated for all fuel burning equipment. | Life-cycle impacts are now calculated for all activities requiring fuel use. The criteria pollutants calculated by the tool (NOx, PM, and SOx) are calculated as either on-site or off-site, and a total criteria pollutants impact is also reported in summaries. |
| SiteWise™ did not include footprint factors for several materials that are commonly used in remediation. | A list of commonly used materials in environmental remediation has been developed by the project team and impacts associated with manufacturing these typical materials have been analyzed. From this effort, five generic materials were added to the materials list; these selections include "very low," "low," "medium," "high," and "very high" impact materials (see Section 5.11). |
| There was limited robustness in the calculation of NOx, SOx and PM. For materials, only $CO_2$e and energy are calculated. | Criteria pollutants (NOx, PM, and SOx) are now included for material use. Previously only energy use and $CO_2$e were calculated for material use. |
| Comparisons made for materials indicated many significant differences between SiteWise™ and SimaPro® results, and SiteWise™ did not include asphalt which is a commonly used material. | Several materials were updated with more accurate footprint factors. These include: virgin GAC, steel, and vegetable oil. Additionally, asphalt was added to the materials list. Footprint factors for laboratory analysis, water and wastewater treatment, tillage, generators, and area stabilization were updated with better sources to provide more reasonable estimates for total impact of each activity. |
| For equipment/material transportation, SimaPro® has the option to allow shared truckloads to account for cases where equipment or material will be transported by a common carrier rather than a dedicated truck. SiteWise™ did not have that option and thus required an assumption that all road transportation is done via a dedicated truck. | Equipment road transportation input is now separated into dedicated-load road transportation and shared-load road transportation. Shared-load road transportation calculations (new for this version) use a ton-mileage approach. Dedicated-load road transportation now also has the option for the user to select for empty return trips to be automatically calculated. |

| Revisions that Impact SiteWise™ Footprint Results (continued) | |
|---|---|
| **Observations by Benchmark Team for SiteWise™ Version 2** | **Revisions Implemented in SiteWise™ Version 3** |
| Electricity emissions were generally (but not always) larger in SimaPro®. Some specific issues that were identified are as follows:<br><br>• SiteWise™ used 2005 eGRID summary table for much of its data. More recent data are available.<br>• SimaPro® includes the energy and emissions results for resource extraction and transmission (i.e., pre-combustion). SiteWise™ does not include energy or emissions for resource extraction or transmission.<br>• For energy use, SiteWise™ assumes that for every unit of electricity used onsite, three times that amount of energy was used to generate that electricity at an offsite facility. By contrast, SimaPro® has specific footprint factors for energy used to generate a kWh of electricity from a particular fuel source.<br>• PM is not calculated for electricity.<br>• Although SiteWise™ allows for the selection of a custom blend of electricity, the user must do all calculations outside the tool to determine what the footprint factors are for the custom blend. | For impacts due to electricity generation, SiteWise™ Version 3 includes the following changes.<br><br>• eGRID 2012 v1.0 (calendar year 2009 data) summary tables are used instead of 2005 data as footprint factors for $CO_2$, $CH_4$, $N_2O$, CO2e, $NO_x$, and $SO_2$ by state.<br>• Transmission and distribution losses from eGRID 2012 v1.0 are now added to resource extraction (i.e., life-cycle impacts which have already been used in SiteWise™) to determine the final energy and emissions associated with electricity generation.<br>• Heat input data and total electrical generation data by state from eGRID 2012 v1.0 are used to develop efficiency factors for electrical generation by state. This addresses all primary forms of electrical generation reported in eGRID (coal, oil, hydro, natural gas, biomass, nuclear, wind, solar, and geothermal). Efficiency factors are supplied for each resource by state—where available—and also as national average efficiency by resource. Efficiency factors are calculated as the ratio of the each state's net annual electrical generation (from all sources, including nuclear, solar, wind, etc.) to the state's annual heat input, with equations for renewable resources satisfying the First Law of Thermodynamics.<br>• PM emissions are included in addition to the existing NOx and SOx emissions. Total PM emissions are sourced from the 2008 National Emission Inventory by state and merged with data from eGRID 2012 v1.0 to develop PM footprint factors by state.<br>• In the event that a user wants to use a custom blend of energy sources, a separate worksheet is included to assist in the calculation of impacts and efficiency of a custom feedstock blend. The user can then manually input the results into the Lookup Table for a different region under the "other" category. |

| Revisions that Impact SiteWise™ Usability or Formatting | |
|---|---|
| **Observations by Benchmark Team for SiteWise™ Version 2** | **Revisions Implemented in SiteWise™ Version 3** |
| In many cases, the six columns available in the SiteWise™ inputs sheets were not sufficient. In particular multiple trips for transport of personnel or equipment or materials are often combined by user due to limited spaces for input. | The number of columns in SiteWise™ has been increased from 6 to 12 to allow for more inputs to be included per component. In addition, for equipment transportation, SiteWise™ has an option to include the footprint for an empty return trip. This eliminates the need for an additional column with a zero weight load to account for the empty return trip. |
| Tab names for SiteWise™ (i.e., Remedial Investigation, Remedial Action Construction, Remedial Action Operation, and Long Term Monitoring) may not be appropriate for each type of remedy. | Tabs for SiteWise™ have been renamed "Component 1, …, Component 4" rather than names for the various phases of the remediation process. These four component tabs are now identical; with each allowing the user the option to specify component duration. The user can provide the names for each component in the Input Sheet under the Site Info tab. These names are carried through the results presentation as headers in the output figures and graphs in addition to the output sheets. This adds flexibility for the user. |
| In the input sheet, values would need to be changed in both the "Look Up Table" tab and the "Look Up Table Defaults" tab in order for these changes to be preserved when an alternative is generated and then subsequently re-imported into SiteWise™. Unfortunately, this would change the look up table defaults for all other alternatives generated using that input sheet. | The Lookup Table values are preserved when an alternative is generated; it does not permanently alter the "Lookup Table Defaults" nor does it change with subsequent runs. |
| The generation of the alternative function would only save the input and summary output sheets but not the calculation sheets. | The generation of the alternative includes all of the calculation sheets in the generated folder with all links broken in addition to the Input Sheet and Summary Sheet. |
| SiteWise™ could not determine grout/steel and other material use from linear feet of wells installed. This had to be determined outside of model. | A separate worksheet has been added to calculate the amount of materials consumed for each well type. This sheet requires the user to input information such as well diameter, borehole diameter, and other well dimensions. The tool calculates the amount of materials consumed, allowing the user to manually input the information into the main input sheet. Impacts from these additional materials are now included in the results. |
| In some cases, the user may have a known value for the setting of a variable frequency drive (VFD) motor but SiteWise™ had no method of calculating the energy consumption from that data requiring the calculation to be done outside the tool. | For pumps and other electrical units equipped with VFDs, an additional calculations line has been included within the Input Sheet to assist in the calculation of electricity usage based on VFD settings. |
| On output sheets, the footprint factors and the actual emissions values were denoted by the same cell color, making it more difficult to readily view results. | On output sheets, the footprint factors and the actual emissions values are denoted by a different cell color to make it easier to readily view results. |
| On the output sheets, the different sheets had different formats depending on what results they are reporting. | Each output sheet has the same format regardless of what results they are reporting. This makes post-processing of results easier. |
| It would be useful for the tools to provide information regarding the amount of total electricity used and the percent of that which is from renewable sources. SiteWise™ did not report the amount of electricity from renewable sources. | Electricity use and percent electricity from renewable sources is now reported. |

| Revisions that Impact SiteWise™ Usability or Formatting (continued) | |
|---|---|
| **Observations by Benchmark Team for SiteWise™ Version 2** | **Revisions Implemented in SiteWise™ Version 3** |
| When comparing alternatives, it would be useful to have a single chart that indicates the relative value for all metrics. SiteWise™ has a separate chart for each metric but did not have one chart for all metrics. | The Final Summary spreadsheet now includes a chart of normalized comparisons of impacts between alternatives. This chart is intended to be used in conjunction with the qualitative impacts table also included in the Final Summary spreadsheet. |
| The scales for the charts within SiteWise™ would set automatically based on the data. This was fine for the maximum but this would sometimes cause the minimum to be a value other than zero and this would sometimes exaggerate the differences among alternatives. | Vertical axes for all charts throughout SiteWise™ have been set for a minimum of zero. |
| Headings that are changed in the input sheet did not transfer to the output sheets, making locating input specific emissions more difficult. | Notes inserted into any cell in the Input Sheet are now saved when that Outputs are generated. These notes are preserved when the alternative is reloaded in the Input Sheet. |
| It would be useful to have compatibility between Versions 2 and 3 of SiteWise™ to allow users to upload a Version 2 input sheet into Version 3. Since SiteWise™ downloads are free, there is no need to have Version 3 input sheets upload to a Version 2 program. | Version 3 Input Sheet loading is backwards compatible with Version 2 inputs (i.e., Version 3 can be used to load Version 2 generated Input Sheets). Pop-up notes direct the user within the tool on how to properly update the Version 2 inputs for Version 3 output generation. This is necessary because some key calculation infrastructure has changed between the Versions (e.g., the user must now specify electricity resource mix by state instead of by region). |
| User notes had to be kept outside of the SiteWise™ input sheet. It would be useful to have a spot within SiteWise™ to keep notes. | A Notes tab has been included in the Input Sheet for documenting changes in the Lookup Table. |
| It would be useful to have a method for tracking changes made in the lookup table. | Changes in the Lookup Table are now automatically highlighted. |
| It would be useful to inform the users of the need to make edits to the lookup table upon selection of a custom input factor. | On the Input Sheet, with any selection of a custom input factor, the user is notified by a pop-up note that the Lookup Table must be edited. |

Suggested future SiteWise™ improvements include the following:

- Development of a User Guide for SiteWise™ Version 3 to accompany the public release of SiteWise™ Version 3. This will be funded by NAVFAC EXWC.
- Validation of footprint factors using objectives including reputability, robustness, relevance, recency, and possibly other criteria to decrease variation of results between DoD and EPA tools and to avoid duplication of efforts resulting from multi-tool analyses.

# APPENDIX C:

# SUMMARY OF SRT™ IMPROVEMENTS IMPLEMENTED DURING THIS PROJECT

| Revisions that Impact SRT™ Footprint Results | |
|---|---|
| **Observations by Benchmark Team for SRT™ Version 2.1** | **Revisions Implemented in SRT™ Version 2.3** |
| The electricity footprint factor used for the SRT™ application is a default national average rather than one based on the local or regional grid. | State-specific values have been provided to calculate a local electricity mix and explained in Guide and Tool help buttons. |
| The bioremediation substrate $CO_2$ footprint factor for SRT™ is a factor of 5 to 10 higher than the corresponding footprint factor used in the SimaPro® analysis, and the oxidant $CO_2$ footprint factor for SRT™ is a factor of 2 to 5 higher than the corresponding footprint factor used in the SimaPro® analysis. | The footprint factors for bioremediation substrate and oxidants were revised to reflect recent research, and calculations and footprint factors within the tool were reviewed and revised where necessary. |
| The rates for drilling fuel consumption are determined differently in different modules and should likely be clarified (e.g., ISCO=10 gal/day and monitoring wells=32 gal/day). | Default drilling rates now assume the same rig type is used across all technologies. To aid the User, values for alternate equipment have been provided within the User Guide. |
| The SRT™ drilling footprints are generally lower than the SimaPro® drilling footprints by a factor of 2 or more for all parameters. The SRT™ footprints for all parameters except sulfur oxide (SOx) are lower than the corresponding footprints from SimaPro for backfill transportation and soil disposal transportation. | Fuel efficiency for on-road and non-road activities were updated. Diesel emission footprint was revised to distinguish between on-road and non-road activities, affecting mainly NOx and PM10. Emissions due to landfill activities (i.e., transport and soil spreading) were incorporated for excavation and PRB technologies. Clarifying language was added to the User Guide along with Help buttons in theTool. |
| Energy required to manufacture PVC is not being properly represented. | Footprint factor was updated and Tool calculations modified to include energy footprints from all materials including PVC. |
| The footprint factors for gasoline and diesel reference NREL but it is unclear if these are life-cycle values or just fuel combustion values. | The Tool default footprints have been updated so that only combustion processes contribute for the energy sources tracked in the Tool. A supplementary list of footprint contributors not accounted for in the defaults has been supplied in the User Guide and Tool Help buttons in the Tool. |
| The SRT™ personnel transportation footprints for $CO_2$ and energy are higher than the corresponding SimaPro® footprints by a factor of 2 to 5, while the footprints for airline transportation are more than an order of magnitude less than the corresponding SimaPro® footprints. | Updated the footprint assumptions associated with air travel and vehicle travel. References are documented in the User Guide. |
| Footprint factors for energy, NOx, PM10, and SOx should be consistently applied. It appears inconsistent to include energy, NOx, PM10, and SOx for on-site fuel use, transportation, electricity, PVC, and steel but not for other significant materials or activities, such as emulsified vegetable oil (EVO) or oxidants. | Calculations in the Tool were revised to include the energy footprints of all materials. Documentation provided in User Guide and Tool Help buttons. When available, additional materials footprint factors were identified and updated. The Tool architecture has been updated to allow the User to add previously unavailable factors for tracked materials. |

| Revisions that Impact SRT™ Footprint Results (continued) | |
|---|---|
| **Observations by Benchmark Team for SRT™ Version 2.1** | **Revisions Implemented in SRT™ Version 2.3** |
| The SRT™ was unclear and inconsistent on which process in the life-cycle of materials and energy sources were the primary contributors to the corresponding energy and emissions footprint. | The Tool default footprints have been updated so that only combustion processes contribute for the energy sources tracked in the Tool, and only production values contribute for the raw materials tracked in the Tool. A supplementary list of footprint contributors not accounted for in the defaults has been supplied to the User, where possible. Clarifying language was added to the User Guide along with Help buttons in Tool. |
| The SRT™ includes $CO_2$ footprint footprint factors for oxidants, zero valent iron, bioremediation substrate and activated carbon. However, SRT™ does not include energy, NOx, PM, or SOx footprint footprint factors for these materials. | Calculations in the Tool were revised to include the $CO_2$ footprints for all materials. Where available, additional materials footprint factors were identified and updated. |

| Revisions that Impact SRT™ Usability or Formatting | |
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| **Observations by Benchmark Team for SRT™ Version 2.1** | **Revisions Implemented in SRT™ Version 2.3** |
| The SRT™ tool and associated manual are not clear on whether GHG footprints are reported as $CO_2$ or $CO_2$ equivalents. | $CO_2$ footprint is calculated and reported as tons $CO_2$, not equivalents (i.e., GHGs other than $CO_2$ are not included). This clarification was added to the Guide and Tool help buttons. |
| There is an error in the manual for "P&T Variables & Calculations" under PVC. | The equation was reviewed and the User Guide updated to reflect the correct calculation. |
| Button "Calculate Natural Resource Service" on "Input Soil" and "Input Groundwater" needs to be checked "No" in order to obtain certain calculations in next sheets. These calculations appear to have no relation to the "Natural Resource Service." The "No" to "Calculate Natural Resource Service" should be "No" by default. | Default preserved as "Yes" to encourage project managers to consider the natural resource effects of the remediation process. Language has been added to the Tool and User Guide clarifying that if set to "Yes," subsequent cells must be filled. |
| There is no room available for the User to make notes that clarify user inputs. | Comment field added to each editable page. |
| More clarification in the Help buttons would facilitate Tool use. Some Help buttons are not fully displayed. | Added several buttons clarifying the input processes. Reviewed all existing buttons and made consistent and visible. |
| User Guide is somewhat redundant and needs content restructuring and additional guidance on software use. | Default values and references for each technology were consolidated into a single Appendix B. Content was restructured to facilitate use. The "Quick Start" and "Technology Checklists" were incorporated into the User Guide. Clarifying language and lookup tables explaining modifications implemented in SRT™ Version2.3 was added. |

There were additional parameters (e.g., water use) that could not be evaluated by SRT™ for this project, and which are deferred for possible future implementation. Suggested future revisions include the following:

- Calculate $CO_2e$ rather than $CO_2$ for the sustainability metric representing GHG emissions.

- To the extent possible given the structure and intent of the tool, incorporate remedy items not currently represented in the tool (e.g., water use, for total amount used and for emissions generated from the consumption of water).
- Develop an “alternate module” for soil and groundwater that will allow the user to apply various forms of equipment use, materials, transportation, and other activities without specifying a technology.
- Validation of footprint factors using objectives including reputability, robustness, relevance, recency, and possibly other criteria to decrease variation of results between DoD and EPA tools and to avoid duplication of efforts resulting from multi-tool analyses.
- To the extent possible, augment the output to better quantify the specific contributors to the total footprints within each technology module.

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# APPENDIX D

# GLOSSARY OF SELECTED KEY TERMS

Definitions are provided below for key terms used throughout this report. These definitions describe how the terms are used within this report.

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| Bias | Bias is present if one of the tools generally calculates footprints that are higher than the other tool, for one or more sustainability metrics. |
| Boundary | Determines the extent of the processes to be included in the Life-cycle assessment (LCA) study. In this report the specific boundary evaluated pertained to inclusion or exclusion of infrastructure (see definition of infrastructure below). |
| $CO_2e$ | Greenhouse gas (GHG) emissions reported in carbon dioxide ($CO_2$) equivalent ($CO_2e$). This includes $CO_2$ plus other GHGs such as methane. The gases other than $CO_2$ are converted to an equivalent amount of $CO_2$ based on relative global warming potential versus $CO_2$, and the results for all the GHGs are then summed together. SimaPro® and SiteWise™ perform calculation of $CO_2e$, but Sustainable Remediation Toolkit (SRT™) is representative only of $CO_2$. |
| Footprint | The quantitative result for one of the sustainability metrics. For instance, the footprint for energy use might be 1.5 million megajoules (MJ) for a specific remedy alternative. |
| Footprint Factor | A factor that converts an input or process into a footprint. For instance, a footprint factor will indicate how much nitrogen oxide emissions (NOx) is emitted per gallon of diesel fuel combusted. |
| Infrastructure | A type of system boundary considered in this study. "Without Infrastructure" considers only the direct resource usage of a process. For example, truck transport footprints calculated "without infrastructure" only account for footprints associated with fuel used during the transport process. However, footprints calculated "with infrastructure" account for other contributions to footprints associated with the transport process such as the construction of the truck and maintenance of the road network. |
| Impact Assessment | Describes environmental impacts (e.g., acidification, smog) that result from footprints. SiteWise™ and SRT™ do not include impact assessment calculations. |
| Input | Values and choices entered into one of the tools that form the basis of the footprint calculations. In SiteWise™ and SRT™ the input includes (but is not limited to) selections (e.g., type of material, type of equipment) and quantities (e.g., mass, volume, time). In SimaPro® the input includes (but is not limited to) processes (e.g., a specific representation of truck |

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| | transport for a specific mass and distance, a specific representation of material production for a specific mass). In SimaPro® a combination of processes can be grouped into "assemblies." |
| Life-Cycle | When considering "cradle to grave," the life-cycle includes environmental impacts from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling. |
| Process | An item in a SimaPro® database that represents an activity (e.g., transport via airplane) or production of a material (e.g., production of steel) which serves as a basis for footprint calculations. |
| Qualitative | Qualitative refers to analysis and conclusions without reference to calculated values (informed assertions). |
| Quantitative | Quantitative refers to analysis and conclusions based on calculated values. |
| Result Ratio | One footprint result divided by another footprint result, where the larger number is in the numerator and the smaller number is in the denominator (i.e., result ratio is always greater than or equal to 1.0). |
| Sensitivity Analysis | In this study refers to evaluation of different footprints calculated by SimaPro® when different processes are selected to represent a specific material. |
| Sustainability Metric | A specific category for which quantitative footprints are calculated. In this study there were five sustainability metrics (energy use, $CO_2$e or $CO_2$, NOx, particulate matter less than 10 microns [PM10], and sulfur oxide emissions [SOx]). |
| Work-Around | An approach used to overcome a technical or usability limitation in one of the tools being evaluated. |

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