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Responses to External Peer-Review Comments
on
Risk Assessment of Spent Foundry Sands In Soil-Related Applications

U.S. EPA Office of Resource Conservation and Recovery
Economics and Risk Assessment Staff

U.S. Department of Agriculture-Agricultural Research Service

The Ohio State University

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1) Introduction

In 2002, the U.S. Department of Agriculture's Agricultural Research Service (USDA-ARS) implemented the Foundry Sand Initiative to evaluate the reuse of spent foundry sands (SFS) in horticultural and agricultural applications. As part of this effort, the U.S. Environmental Protection Agency (EPA) worked in collaboration with USDA-ARS and Ohio State University (hereafter collectively referred to as "the Authors") to investigate the potential risks associated with such activities, and produced, through contract with RTI International (RTI), a draft report entitled "Risk Evaluation of Spent Foundry Sands in Soil-Related Applications" (Risk Assessment).

Subsequently, the Authors retained Industrial Economics, Incorporated (IEc) to conduct an independent peer review of the Risk Assessment.

The review panel was charged with providing comments on the following:

1. Please comment on the transparency of the risk assessment.
2. Please discuss the adequacy of the risk assessment execution.
3. Please comment on whether the selection of U.S. foundries was representative of the industry and if the characterization of these foundry sands was adequate.
4. Please comment on the methodology used for choosing constituents to evaluate.
5. Please comment on the conceptual models, particularly the plausibility of the sources, pathways, and receptors included.
6. Please discuss the appropriateness of the Manufactured Soil conceptual model, as protective of the other conceptual models.
7. Please discuss whether the screening steps reported in Chapter 4 were appropriately conservative in their application to support the conclusions.
8. Please comment on the appropriateness of the various probabilistic modeling steps employed to develop national-scale screening values.
9. Within the context of a screening risk assessment, please comment on the level of conservatism inherent in the Home Gardener scenario, with special attention to the assumption of independence of the ingestion pathways. Please also comment on the rationale for modeling the 50%tile and 90%tile general population consumption rates, each with a 50% homegrown fraction.
10. Please comment on how soil background, phytotoxicity, and impacts on soil biota were considered in the assessment.
11. Please comment on the clarity of the Risk Characterization section, with special attention to the discussion of uncertainties.
12. Please comment on whether the assessment supports the report's conclusions.

When identifying and selecting experts for the review panel, IEc made an effort to include individuals with expertise in one or more of the areas outlined in Table 1.

Table 1: Areas of expertise sought in potential peer reviewers

Area of Expertise	Description
Human Health Risk Assessment	Expertise in the methods and approaches to conducting human health exposure and risk assessments, including experience creating or reviewing exposure and risk assessment documents and familiarity with multimedia risk assessment.
Spoil/Plant Science	Expertise in the field of soil science, including metals transport in soils and metals uptake in plants.
Groundwater Hydrology	Expertise in the methods and approaches used for modeling the fate and transport of contaminants in groundwater, as well as the effects of soil properties on groundwater movement

The final panel of expert reviewers included (with area of expertise in parentheses):

- Dr. Ken Barbarick, Colorado State University (Soil Science)
- Dr. Mary Fox, Johns Hopkins University (Human Health Risk Assessment)
- Dr. Charles Harvey, Massachusetts Institute of Technology (Groundwater Hydrology)
- Dr. Donna Vorhees, The Science Collaborative (Human Health Risk Assessment)

This comment review and response report focuses on the technical themes presented by the peer reviewers of the SFS risk assessment. Section 2 provides each reviewer's summary, while Sections 3 through 13 address specific reviewer comments. For each comment category, the comments are provided by reviewer, followed by the response.

2) Summary by Reviewers

Dr. Ken Barbarick

I think the report did do a comprehensive risk assessment of the use of spent (recycled) foundry sands. I support their conclusions that their "Home Garden" scenario is protective of human health. I recommend that they include leaching of constituents for the storage pile as a part of the modeling process and that they pursue microbial-community studies to better characterize the impact on soil biota. I do not believe that this report has answered all necessary questions (i.e., the impact on specific soil biota). Several more studies would be needed to also quell the concerns expressed by the Michigan Department of Environmental Quality. I would characterize the report as an excellent start and foundation, but it is not a complete vetting of the potential impacts.

Dr. Mary Fox

Overall approach of screening steps leading to a more refined analysis of selected constituents is sound. Parts of the report are poorly organized and lack clarity, particularly sections of Chapters 3 and 6 and the rationale and approach to the probabilistic modeling. There are problems with implementation of the probabilistic *modeling that compromise the conservatism of the home-produce ingestion pathway and, ultimately, the risk assessment findings and conclusions.*

- *Data inputs for ingestion scenarios (particularly home gardener) must be double checked for accuracy and revised to reflect source data in some cases.*
- *Probabilistic analysis of soil and produce ingestion scenarios must be revised and repeated before concluding that use of manufactured soils will be protective of human and ecological receptors.*

Dr. Charles Harvey

This risk assessment synthesizes a remarkably wide range of data and models of environmental processes. The breadth of the study is impressive, and the assessment makes ingenious use of a variety of existing models and data sets. As an academic researcher, it is easy to suggest that some data sets are insufficient to fully characterize the range of conditions across the United States and that we do not yet understand some physical and biogeochemical processes well enough to construct accurate models. However, many of these complaints would be counterproductive – the point of this assessment must be to construct the best estimates of risks given available data and existing models. Therefore, I will focus this review primarily on basic conceptual issues and on aspects of the evaluation that can be improved with available methods and data. I have chosen to first construct a list of broad comments and to note how these comments relate to the charge questions. I then provide a few specific questions, and finally to come back to the charge questions with specific responses.

Dr. Donna Vorhees

This report benefits from recent research targeting spent foundry sands (SFS) characterization that supports the evaluation of exposure. SFS appears to contain chemical concentrations that are similar to what is found in undisturbed soils under natural conditions. In addition, the Authors explore whether other factors besides concentration might result in more exposure to chemicals in SFS relative to natural soil and conclude that there is limited potential for such increased exposure. Therefore, it is understandable to propose use of SFS for manufactured soil and other beneficial uses. The Authors present a labor-intensive, national-scale risk assessment to determine risk associated with likely uses of SFS. Like all risk assessments, this one is inherently uncertain. The Authors understand this reality and carefully explain many sources of uncertainty both qualitatively and quantitatively in the form of a probabilistic risk assessment for exposure pathways believed to be associated with the highest levels of exposure. But as has been noted by EPA Region 9 in its comments, this risk assessment might serve as a model for similar assessments of materials that might pose greater risk than SFS to ecological and human health. Therefore, the assessment should be viewed in this light and held to a high standard with respect to methodology and documentation. In general, my comments focus on opportunities to improve what is generally a sound and useful risk characterization of the beneficial use of SFS.

Major issues identified by the peer reviewers requiring attention are the following:

1. *The risk assessment should incorporate exposure information from EPA's Final Child-Specific Exposure Factors Handbook (September 2008). This document provides more recent reviews of exposure data and recommendations for point*

estimate and distributions of some risk model inputs than those provided in EPA's 1997 Exposure Factors Handbook.

2. *The probabilistic risk assessment (PRA) complies with much of what EPA recommends in its PRA guidance (U.S. EPA, 2001), but some additional documentation and potentially additional analysis is warranted. I refer to EPA recommendations in my responses to charge questions.*
3. *The risk assessment should provide a brief, succinct explanation of why, despite multiple screening steps, cumulative risks associated with SFS use are below pre-established levels of concern.*

3) Characterization of Foundry Sands

The peer-review comments relating to the initial characterization of foundry sands are grouped into eight subcategories:

a) General Sand Properties;
b) Beneficial Use Characterization;
c) Management of Foundry Sands;
d) Representative Sampling;
e) Constituents Sampled;
f) Detection Limits;
g) Documentation; and
h) Additional Sources of Information.

a) General Sand Properties

Dr. Charles Harvey

Page 1-1, paragraph 2

Why do heat and abrasion render sands unsuitable? To develop a conception of SFS, it would be useful to better understand how it has been altered in the foundry from natural sands so that it is no longer useful.

Response:

Aside from an initial cleaning process, the foundries themselves do nothing to the native sands other than add a variety of materials (e.g., clay, seacoal, binders) to make them suitable for casting. During the casting process, however, the sands are exposed to high temperatures, which cause the grains to fracture. In addition, during mold formation and sand reclamation, the sand grains become abraded as they rub against each other. The fracturing and abrasion ultimately change the grain shape, which makes the sands undesirable for continued casting. A change in the grain shape will prevent the gases to pass through the mold and cause it to crack.

The third sentence of the second paragraph on page 1-1 now reads as follows:

> "However, mechanical abrasion during the mold-making process and sand reclamation, and exposure to high casting temperatures causes the sand grains to eventually fracture. The fracturing changes the shape of the sand grains, rendering

> them unsuitable for continued use in the foundry. The resulting residuals are generally managed as a waste or beneficially used."

b) Beneficial Use Characterization

Dr. Mary Fox

Section 5.3, page 5-5, Probabilistic Modeling of Soil/Produce Ingestion Pathway

Need more explanation for risk assessment approach to soil/produce ingestion pathway. Why not directly estimate risks using the available SFS data? Is it possible to make some experimental manufactured soils to develop data for this part of the risk assessment?

Dr. Donna Vorhees

The Authors should describe past and ongoing use of SFS in more detail. They refer to these uses: "Approximately 25% of the 10 million tons of SFS produced annually are beneficially used outside of the foundry, but only 3.9% of SFS is used in soil-related applications (AFS Survey, 2008)…" The Authors explain in Section 2.4 that they conducted a peer-reviewed literature search regarding metals and organics in SFS. In Section 2.5, they refer to a literature search for field studies of SFS leaching. But they found no field studies related to past or ongoing uses of SFS in amended soil. Beyond the scientific literature, have there been reports by other credible sources of any problems that have arisen from past or ongoing use of SFS in amended soils?

Response:

The Authors found no reports from credible sources of problems arising from past or ongoing use of SFS. The report language has been modified to relate this more explicitly. Also, although geotechnical applications utilize the most foundry sand in the United States, at the time of this evaluation only one company was identified that used SFS in blending operations. When the Authors contacted this company (in Ohio), the company had not reported any problems to us (e.g., plant growth issues). Essentially, the spent sand is used as a replacement for sands that they would normally purchase for soil blending. Since the constituent concentrations in spent sands are similar to those of native sands, one would not expect any problems.

The Authors have revised the discussion on the probabilistic modeling of the soil/produce ingestion pathway to better communicate the risk modeling approach. The intent of this evaluation was to develop risk-based screening criteria for soil-related beneficial uses of SFS, rather than to perform a classic risk assessment. Creating/experimenting with manufactured soil was beyond the scope of this evaluation.

c) Management of Foundry Sands

Dr. Charles Harvey

Page ES-2, paragraph 6

Are the heavily contaminated sands used for brass or olivine sands ever mixed with other sands? In other words, is the distinction between the contaminated SFS left out of

> *this assessment and the safer SFS retained for the assessment always clear? Would foundries ever shift from one kind of sand to another and in the process mix the sands?*
>
> Page 2-4, paragraph 3
>
> *Core butts were removed by sieving. Will these butts be removed before the use of SFS, and if not, could they be a source of contamination in SFS neglected by this assessment?*

Response:

While most foundries only pour one type of metal, some foundries may pour both ferrous and non-ferrous metals on separate lines. In the latter case, it is possible for a foundry to mix these waste streams. The report carefully stipulates which waste streams do and do not qualify as SFS (e.g., spent molding and core sands qualify, whereas broken or unused cores do not), and which foundry and sand types were being evaluated. Although the Authors did sample from non-leaded brass foundries and those that use olivine sand, no mixed waste streams were sampled.

During the casting process, a portion of the core will generally break down to individual grains. This is because the binder thermally decomposes when it comes in contact with the molten metal. But in most cases, the cores do not break down completely and residual pieces remain. In any case, the resulting spent sands contain sand from both molds and cores, but a much smaller portion from cores. It is only those core pieces that do not break down that are removed prior to soil blending. Therefore, the spent sands analyzed for this risk assessment do consider contaminants from the cores because individual grains from the broken cores do mix with the molding sands.

d) Representative Sampling

Dr. Ken Barbarick

> *The selection of the foundries and the characterizations of the foundry sands are adequate. The study used a good distribution of geographical and process-types.*
>
> *The researchers appropriately eliminated olivine sands for testing since they most likely would not be used in a soil mix that grows vegetables or fruits.*

Dr. Mary Fox

> *Information provided in the risk assessment is not adequate to evaluate whether selection of SFS for analysis was representative of the industry. What is the size of the industry? The 43 samples available represent what percent of the industry? Also, the sands analyzed were from foundries in the east, south, and mid-west. No samples were taken from western states. If geographic representativeness is not relevant to developing a national assessment, a justification should be provided.*

Dr. Charles Harvey

> *I have no experience with variability among foundries. However, 43 samples appears to be a small sample size. More samples would benefit the assessment given the differences among natural sands, the metals cast, and the different binders.*

Dr. Donna Vorhees

> *The selection of U.S. foundries appears to be representative of the industry. The characterization of foundry sands appears to have included chemicals that might reasonably occur in SFS and have the potential for causing adverse health outcomes. However, additional documentation is needed to ensure the representativeness of the foundry sampling effort, which is the basis of all risk analyses.*
>
> *The USDA study appears to have collected a reasonably representative sample of SFS material over multiple years. However, not until Section 6.8.2 (point 1) do the Authors clearly describe how the initial set of foundries was selected for sampling. This description aside, industry representatives, rather than USDA scientists, collected samples in years 2 and 3, and only a subset of facilities with data for the first year provided data in subsequent years. Might there have been any selection bias such that facilities with higher chemical concentrations in SFS elected not to report these results or did not provide samples at all? Also, is there any reason to think that foundry operations might be modified in the future in a way that influences SFS properties? I suspect that the Authors considered these questions, but it would be helpful to document this information to provide assurance that this assessment provides an upper bound on potential risks under current and future conditions.*

Response:

The majority of the foundries in the United States are located east of the Mississippi River and in the Midwest. Therefore, the focus was on foundries from this portion of the country. In addition, every effort was made when selecting the foundries to cover the widest range of sands that were amenable for beneficial use in soil-related applications. Both large and small foundries were targeted, along with those using a variety of molding and core sand operations. Green sands were targeted the most since they represent 80% of the metalcasting byproduct volume in the United States and are by far the most logical choice for use in manufactured soils. In this assessment, 83% of the foundries targeted for study used green sands, while the remaining used chemically bonded molding sands. These numbers are representative of industry averages.

e) Constituents Sampled

Dr. Mary Fox

> *I believe the SFS samples used were adequately characterized. It was helpful to have the SPLP leachate data to supplement the TCLP.*

Dr. Charles Harvey

> *The list of metals contains the most likely contaminants except for the neglect of mercury and selenium in the screening model. I do not have the background to comment on potential organic contaminants. However, it is clearly very important to carefully consider all possible organic contaminants, and I hope that one of the other reviewers can bring this expertise to the review.*

Response:

Mercury was not included in the data set because the Authors did not have the analytical capability at the time, but it should not preclude its inclusion in this assessment. As discussed in report section 4.2, a study by Fahnline and Regan (1995) found that mercury concentrations in TCLP leachates from 52 spent sands were very low at < 0.10 mg L^{-1}.

No leaching data were available for selenium. However, the Authors wish to point out that the maximum porewater concentration for pure SFS (0.039 mg L^{-1}, Table B-26) is below both the MCL and tapwater screening level for selenium (0.05 mg L^{-1} and 0.078 mg L^{-1}, respectively). . With respect to the organic contaminants, the Authors considered those organics that would likely be generated as a result of the high-temperature casting process (i.e., EPA priority phenolics, PAHs, and dioxins).

f) Detection Limits

Dr. Charles Harvey

Page 2-5, paragraph 3

"The method detection limit for this data set was calculated by multiplying the standard deviation of the baseline noise by the t-value at the 99% confidence interval." This statement needs explanation and description of the implications.

Response:

This particular statement was misplaced and has been moved in the report to Section 2.4.2, *PAHs and Phenolics*. To clarify, the MDL was calculated by multiplying the standard deviation of six replicate standards by the Student's *t*-value at the 99% confidence interval. Calculating the MDL at the 99% confidence interval allows for the probability that 1% of the samples analyzed, which have a true concentration at the MDL, will be false positives. Additionally, reporting data down to the MDL does nothing to control the possibility for false negatives. The Authors have revised the text in the report as follows, to improve clarity:

> "The method detection limit (MDL) for this data set was calculated by multiplying the standard deviation of replicate standards ($n = 6$) by the Student's *t*-value at the 99% confidence interval. Calculating the MDL at the 99% confidence interval allows for the probability that 1% of the samples analyzed, which have a true concentration at the MDL, will be false positives."

g) Documentation

Dr. Donna Vorhees

Ideally, the final version of this risk assessment will include either (1) the Dayton et al. paper with SFS data, which is referred to as "under review," or (2) reference to the version of this paper that is accepted for publication in a peer-reviewed journal. How well the data represent SFS is a separate question that is addressed in response to charge question #3.

Sections 1.1 and 1.2 refer to a multiyear research project conducted to characterize inorganic and organic constituents in SFS and to assess the potential mobility and uptake of these constituents by environmental receptors. The Authors say that the results of this research are in the public domain, but do not list any citations. Including

> *them all in one place early in the document would briefly convey the scope of the multiyear study.*

Response:

The Authors have added a complete list of relevant citations to Section 1.1., those being Dungan 2006; Dungan and Dees, 2006, 2007, and 2009; Dungan and Reeves, 2005 and 2007; Dungan et al., 2006 and 2009; and Dayton et al., 2010.

h) Additional Sources of Information

Dr. Donna Vorhees

> *In the first paragraph of Section 2.4, the Authors explain that "the foundry industry routinely analyzes their sands for metals and/or organics," but these data were not considered in the assessment because of "inconsistencies between foundries in the sampling and testing protocols." They also refer to a database compiled by Dr. Tikalsky at The Pennsylvania State University, but did not use these data either because "method detection limits varied for similar constituents, and as a result, comparisons could not easily be made between the data." None of the reasons for excluding these data suggests data quality problems, just inconsistencies in how data were collected. Consequently, it is not apparent why the data were completely dismissed. For example, despite differences in sampling and analytical methods, do the data suggest that much higher or lower concentrations of any chemicals were found in the other data sets? Might there be additional COCs? Or are the data sets generally consistent with the USDA data, after taking into account the inconsistencies?*

Response:

The first statement about foundries testing their sands has been removed from the document, as it is somewhat irrelevant. While many foundries do analyze their sands for waste disposal and beneficial use requirements, the Authors did not have access to these data for the purposes of this risk assessment.

With respect to Dr. Tikalsky's database, it should be clarified that it examined 338 foundry sand byproducts, not just spent molding sands. The database did not analyze any additional constituents of concern that were not addressed in the assessment of the 43 spent sands. In fact, the Tikalsky database included very little overall information about the constituent concentrations, and this information was not consistent between the sands. While many of the sands in the Tikalsky database were not suitable for beneficial use in soil-related applications (e.g., chemically bonded sands, shot blast fines), the concentration of metals (total and leachable) and organics in iron, steel, and aluminum moldings sands were comparable with the numbers the Authors obtained when analyzing the 43 spent sands for this assessment. This section of the report has been rewritten as follows to note the similarities between the constituent concentrations in the Tikalsky database and the 43 sands used for the assessment:

> "A database was created by The Pennsylvania State University (Penn State), where industry data on different foundry waste materials were compiled (Tikalsky et al., 2004). This database contains interesting information on total and leachable concentrations of various constituents in foundry byproducts, many of which were not suitable for beneficial use in soil-related applications. While the Penn State

database was not used in this risk evaluation as a result of inconsistent analytical data among the foundry byproducts, a preliminary comparison of the database with the USDA data set revealed that metal (total and leachable) and organic concentrations in molding sands were highly similar."

4) Problem Formulation

The peer-review comments relating to up-front problem formulation are grouped into seven subcategories:

a) Organizational Issues;
b) Selection of Constituents to Model;
c) Highly Exposed/Sensitive Subpopulations;
d) Storage Pile Conceptual Model;
e) Roadway Construction;
f) Dermal Exposure; and
g) Manufactured Soil Conceptual Model.

a) Organizational Issues

Dr. Mary Fox

Page 3-1 to 3-2

Section 3.1.1, 3.1.2 are repetitive of Chapter 2 – not needed in this chapter.

Page 3-7

Section 3.2 Benchmarks and criteria can also be re-located to appropriate sections of the analysis.

The problem formulation chapter should reflect the framework shown in Figure 3-4. Rather than describe exposure pathways – this is the place to describe the screening modeling approach. Section 3.3.4 jumps the gun and includes results of screening analyses, listing constituents modeled as a result of screening.

Dr. Donna Vorhees

Provide graphical overview of the assessment. A single graphic that shows steps in COC selection, the deterministic screening analysis, the probabilistic analysis, and the relationship between the deterministic and probabilistic analyses would help improve clarity of the document. Figure 3-4 is a start, but is missing important information about how COCs were selected in a manner that ensures cumulative risks (i.e., risk across exposure pathways and chemicals that together might cause an adverse health outcome) associated with use of SFS do not exceed levels of concern. This understanding is important for states to determine whether use of SFS will meet their risk management goals.

The assessment includes a "problem formulation" section, which discusses the purpose and scope of the assessment and defines the primary question and assessment endpoints to be addressed: "determine whether the proposed unencapsulated uses of SFS have the potential to cause adverse health or ecological effects (for this

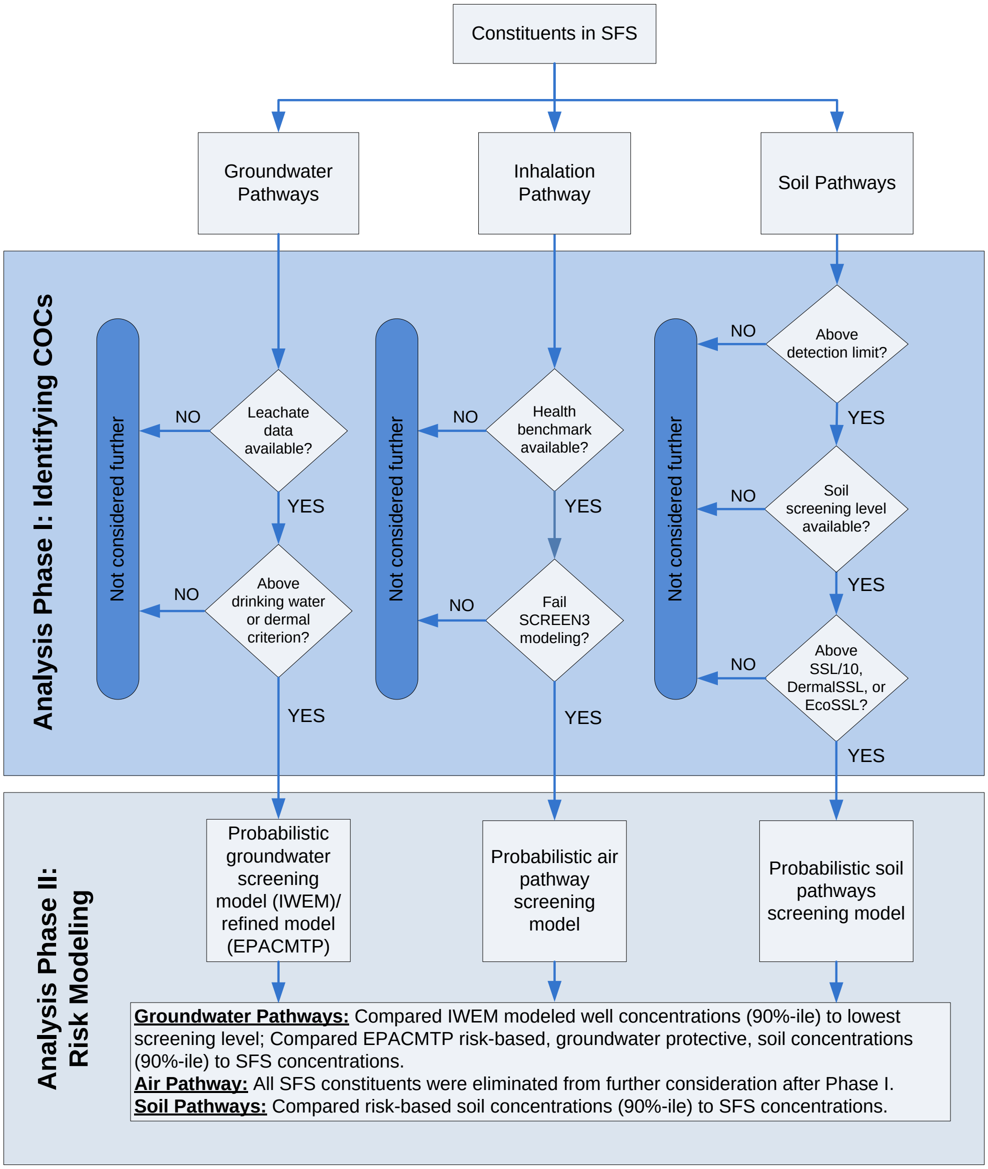
> *assessment, the Authors used the following risk management criteria: 10*$^{-5}$ *risk for cancer effects and an HQ of 1 for noncancer and ecological effects).”*

Response:

The Authors agree that certain portions of each chapter were repeated in the subsequent chapter. However, that was intentional; the goal of these sections was to allow a reader to pick up at the beginning of any chapter without having to go back. In other words, the chapter was meant to stand alone for readers who did not have the time to read the whole document in one sitting.

With regards to the benchmarks and criteria, these data have been removed from Chapter 3, Problem Formulation, and now are presented only in the relevant sections of the analysis.

To better orient the reader, a figure has been added to Chapter 1 to depict the SFS assessment framework and the fact that it is comprised of five key components: (1) SFS Characterization; (2) Problem Formulation; (3) Analysis; (4) Risk Characterization; and (5) Conclusions. In addition, the Analysis Plan (section 3.2) has been rewritten to clearly communicate the goal of the analysis and provide an overview of the steps taken to accomplish this goal. The Authors have also replaced Figure 3-4 with the figure shown below to better depict the relationship between the different stages of analysis. The discussions in section 3.2 have also been revised to provide an overview of the stages shown in the figure.



Groundwater Pathways: Compared IWEM modeled well concentrations (90%-ile) to lowest screening level; Compared EPACMTP risk-based, groundwater protective, soil concentrations (90%-ile) to SFS concentrations.
Air Pathway: All SFS constituents were eliminated from further consideration after Phase I.
Soil Pathways: Compared risk-based soil concentrations (90%-ile) to SFS concentrations.

b) Selection of Constituents to Model

Dr. Mary Fox

The general methodology outlined for choosing constituents consisted of three types of information:

- *Information on completed exposure pathways (see response to #5-6 below regarding gaps in exposure pathways captured by the conceptual models)*
- *Availability of sampling data above the limit of detection*
- *Availability of human or ecological health benchmarks*

This is an acceptable methodology for selecting SFS constituents to evaluate in each stage of the assessment.

Dr. Donna Vorhees

I assume that this question relates to selection of chemicals of concern and not chemicals that should be measured in SFS. In general, the method seems reasonable, but is spread out across Sections 3, 4, and 5, which makes it slightly difficult to follow. On pages 1-2 and 1-3, the Authors indicate that "This report is intended to provide states with a sound scientific basis with which to evaluate the potential risks to human health and the environment associated with the beneficial use of SFS in soil-related applications." This goal could be achieved more easily by succinctly explaining the various screening steps that are described in Sections 3, 4, and 5 that resulted in elimination of chemicals from the list of COCs and, in some cases, elimination of entire exposure pathways.

Response:

As noted above, the Analysis Plan section 3.2 has been greatly enhanced with the addition of new text and a figure that depicts the different stages of the analysis, including Phase I: Identifying constituents of concern. As discussed in the revised report, the Phase I Analysis was used to identify COCs for three potential exposure pathways: (1) groundwater, (2) inhalation, and (3) soil defined as both direct ingestion and indirect exposure via produce. Section 3.2 of the report has been revised to discuss the steps taken to identify the COCs for each of these pathways.

c) Highly Exposed/Sensitive Subpopulations

Dr. Donna Vorhees

The problem formulation does not include discussion of highly exposed or highly susceptible populations, but this discussion appears later in Sections 5.3.2 in the context of the PRA (i.e., home gardeners more exposed than the general population) and 6.3.5 (i.e., discussion of the potential for plants to take up concentrations of cadmium and selenium that pose a concern for human health).

Highly Exposed Populations. The document would benefit from a clear discussion of the population targeted for evaluation – not just identifying the scenario (e.g., home gardener) - but the degree of exposure. The Authors explain that the analysis is intended to be protective of the 90th percentile exposure level, but do not clearly define this criterion until Section 5.1.

Susceptible Subpopulations. The screening analysis does not explicitly evaluate childhood exposures, but the probabilistic exposure assessment includes four age groups for individuals younger than 20 to account for variation in exposure over this time. The problem formulation appropriately discusses the importance of evaluating children separately from adults, given their potentially higher intake to body-weight ratios. These groups do not include the 0–1 year old life stage, and the Authors assume that this exclusion overestimates risk. How is risk overestimated if the intent is to evaluate risk to an individual who is more than 1 year old? If the intent is to evaluate someone from birth, then why not do so? At a minimum, the significance of ignoring this age group should be discussed (i.e., explain that there is no exposure from birth to about six months, when babies typically do not eat solid food, and review what is known about body-weight normalized ingestion rates for babies 6 months to 1-year- old).

Response:

Home gardeners who get fruits and vegetables from soils manufactured with foundry sands are already more exposed than the typical population. In addition, the Authors evaluated risks to children of home gardeners. Since home gardeners and children tend to have higher exposures, the children of home gardeners are likely to be a relatively highly exposed subpopulation, and thus protective of many other highly exposed subpopulations. The degree of this exposure can be seen when compared to that of the general population. The original discussion in Section 3.1.5 has been modified as follows:

> "In addition to these overarching assumptions, the risk assessment of unencapsulated SFS uses was predicated on a number of conservative assumptions intended to ensure that the results could be used to support management decisions with a high degree of confidence. That is, the assessment was intentionally designed *not* to underestimate the potential risks to human health and the environment.
>
> - The exposure scenarios focus on sensitive populations with respect to behaviors that tend to increase exposures. For example, the home gardener scenario represents adults and children that will have a relatively high level of direct contact (e.g., incidental soil ingestion) and indirect contact (e.g., ingestion of home grown produce) when compared to other populations
> - For carcinogenic (i.e., cancer-causing) constituents, the target cancer risk was defined as an excess lifetime cancer risk of 1 chance in 100,000 (i.e., 1E-05). For constituents that cause noncancer health effects, the target hazard level was defined as a ratio of predicted intake levels to safe intake levels—the HQ—of 1
> - The Phase II modeling (explained further in Section 3.2.2, below) used the upper end of the exposure concentration distribution (i.e., groundwater screening modeling used the 90th percentile receptor well concentration, and refined surface and groundwater modeling used the 90th percentile of the exposure distribution) rather than a central tendency measure
> - Exposure assumptions used in the risk modeling were designed to likely overestimate, rather than underestimate, potential exposures. For example, the exposure estimates from ingestion of home-grown produce assumed that the receptor consumes a very large amount of produce because the total produce diet is the sum of multiple produce categories (e.g., root vegetables, leafy greens). This implies that (1) all of these categories can be grown in the 0.1 acre garden in the same season, (2) all of these categories are consumed at relatively high rates, and (3) all these categories are consumed year round
> - For effects to ecological receptors (e.g., plants, animals, soil invertebrates), conservative environmental quality criteria (i.e. EcoSSLs – see section 4.4.3 for more on the conservative nature of these screening levels) were used in defining the target hazard levels
> - The home garden was accessible to all residents, including children at all times; and

> - The addition of SFS manufactured soil (containing SFS at 50% of the soil dry weight) to the home garden essentially replaced the existing top 20-cm layer of local soil."

The Authors also note that the screening levels used in the assessment were developed by EPA using the more protective adult and child exposure factors. The assessment has been modified to reflect this point. Thus, the screening analysis does take more sensitive subpopulations (children) into account.

EPA has invested considerably in the development of distributions of the 1997 EFH, subsequently updated in the 2011 EFH. The 2011 EFH currently represents the best available consumption data. The CSEFH was published in September of 2008, and the data presented therein generally agree with the 1997 and 2011 EFH. The exposure parameters used in this assessment have been updated to reflect the CSEFH and 2011 EFH data.

The Authors acknowledge that evaluating a child starting in year 1 would not overestimate risk for children of that age group. However, applying the constant starting year of exposure for the child receptor does maintain the conservative nature of the assessment, given that exposure could start at any point during childhood (i.e., from 1 year through year 19). The purpose of implementing a start year of 1 is to capture and bracket the risks for two distinct receptor age groups. Evaluating children separately from adults is important given their potentially higher intake to body-weight ratios. Allowing the start age to vary for the child introduces the possibility of the childhood exposures overlapping the adult exposures. For example, if the child's starting year of exposure is at age 15 and the exposure duration is 8 years, the exposure would span both childhood and adulthood. Thus, the clear distinction between the child and adult exposures is not maintained.

With regard to infant exposure, EPA guidance is available to assess exposure via the breastmilk pathway. The COCs for the soil/produce pathway include nickel, manganese, lead, and arsenic. Current studies have not shown any of these constituents to be of significant concern via the breastmilk pathway. When discussing the assumptions built into the Conceptual Model for probabilistic modeling, the Authors have modified the following text in Section 5.3.7.1 to improve clarity and to address the absence of infant exposure modeling:

> "The adult was 20 years old when exposure began, and the child was 1 year of age when exposure began. Application of these start ages maintains the conservative nature of this screening assessment. Infant exposure (i.e., 0 to 1 year of age) via the breastmilk pathway was not evaluated under this modeling scenario given that none of the metals included in the probabilistic modeling phase have been identified in current studies as being of significant concern via the breastmilk pathway."

d) Storage Pile Conceptual Model

Dr. Ken Barbarick

> *An oversight or weakness of the conceptual model is not considering leaching of the components studied from the "storage pile". This process may not pose a risk; however,*

it should be discussed including documentation that is available. A series of column "batch" leaching studies could be utilized to determine the extent to which any constituents are transported. Breakthrough curves could help estimate how many pore volumes of water would need to move through simulated piles to move significant quantities of each component. These data then could be included in the pathway modeling.

Dr. Mary Fox

Regarding Figure 3-2, The Blending Site Model. There is a footnote to the figure explaining that deposition of particles and subsequent contact and ingestion were not quantified because it was assumed that related exposures would be insignificant compared to the manufactured soil (home garden) model. I agree with this for the human receptor, but the justification may not hold for wildlife.

Response:

With respect to Dr. Barbarick' s comment, leaching from a storage pile of SFS represents a much lower risk to groundwater than the home garden because, by definition, the temporary storage pile would remain in place for a relatively short period of time before use. Moreover, it is reasonable to assume that the storage piles would be covered to some degree to prevent the pile from becoming saturated with water (something that would greatly increase the weight of the pile and make transport more difficult). Importantly, because this material has economic value, it is expected that the facility would transport the SFS as rapidly as possible to generate revenue. In addition to these considerations, Section 2.5.4 shows that many constituents were either not detected in leachate sampling, or were detected at levels below health screening criteria.

Some constituents were detected in leachate above health screening criteria, indicating that drinking the leachate directly could result in adverse health effects. For these constituents, the Authors believe that the home-gardener scenario represents a much greater **potential** risk to groundwater because (1) the SFS would remain indefinitely in the garden, (2) the SFS is incorporated into the soil rather than sitting on top of the soil, (3) the garden presents a much larger footprint (approximately 405 m^2) than the temporary storage pile (assumed to be 150 m^2 in size), and (4) the underlying soil in a garden would be expected to have a higher hydraulic conductivity associated with agricultural soils (versus a compacted soil or concrete pad used for the temporary storage of SFS). Also, the Authors have modified the text in Section 3.1.5 as follows to provide additional support for the assertion that the potential for groundwater contamination associated with the use of SFS in manufactured soil by the home gardener represents a much greater **potential** risk:

- "The home garden scenario is likely a much greater risk to groundwater than the other scenarios because (1) the SFS would remain in the garden indefinitely, (2) the SFS is incorporated into the soil rather than sitting on top of the soil, (3) the garden presents a much larger footprint (approximately 405 m2) than the temporary storage pile (assumed to be 150 m2 in size), and (4) the soil underlying a garden would likely have a higher hydraulic conductivity than a compacted soil or concrete pad used for the temporary storage of SFS.

- Because SFS and manufactured soils have economic value[1], blending sites would process the SFS as rapidly as possible to generate revenue. This means that (1) the temporary storage pile would remain in place for a relatively short period of time before soil blending, and (2) the storage pile would likely be managed to protect the material's value and workability (e.g., use of a temporary cover to prevent loss due to runoff, and prevent the pile from becoming saturated with water).
- Commercial blending facilities demonstrate the greatest potential for nearby human inhalation exposures, because they tend to work with larger volumes of feedstock and product (thereby emitting greater volumes of particulates) and conduct operations throughout the year.
- The economics of purchasing, transporting, and applying SFS-manufactured soil would make its large-scale agronomic application untenable – farmers could not afford it.[2] Other potential agronomic uses for SFS (e.g., to improve soil texture) involve application rates that would result in SFS concentrations lower than the assumed 1:1 blend (i.e., the soil is 50% SFS, by weight) in SFS-manufactured soil."

With regard to the commenters' concern over wildlife exposure, a storage pile of SFS represents a much lower risk when compared to the home gardener scenario due to the transitory nature of the pile as discussed above and in the revised risk assessment report. Furthermore, the soil concentrations (50% SFS) in the home gardener scenario should adequately screen for deposition to adjacent soils because it would be unrealistic to think that these emissions would ultimately lead to a soil mix of 50-50 off site.

In addition, the Authors note that the sands are below background levels for many of the trace elements. This reduces the likelihood that sensitive ecological receptors would experience significant effects.

e) Roadway Construction

Dr. Mary Fox

> *With the following exception, the conceptual models capture the relevant sources, pathways and receptors: Figure 3.1 should include roadway construction or construction operations (i.e., moving SFS from storage to road building area) as a source with dispersion in air and deposition to soil as pathways.*
>
> *I am not sure that the assumptions regarding engineering controls on the storage pile for the roadway subbase model are reasonable. Therefore, particulate emissions and runoff should be considered for evaluation. However, the nature of roadway construction is likely temporary or intermittent, which would reduce concern about this source and related pathways. The temporary nature of construction activities is discussed in Chapter 6, but it should be included in Chapter 3 along with the descriptions of the conceptual models.*

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[1] In 2007 manufactured soil sold for approximately \$21.50 yd^{-3} (cost of product and delivery), or about \$22,800 A^{-1} for a 20 cm-deep layer (Kurtz Bros., Inc. 2007).

[2] See previous footnote.

Response:

The Authors agree with commenter that exposures from roadway construction using SFS will typically be temporary in nature, and thus would not expose receptors to the chronic levels of toxins necessary to induce health effects. In response, the Authors have updated Section 3.1.5 of the original risk assessment to state the following:

- "For the temporary storage and use of SFS, indirect exposure pathways (e.g., air emissions to soil deposition to soil-to-plant uptake to ingestion) would be unlikely to produce significant exposures because
    - there would likely be engineered controls to prevent the loss of valued commodities, such as SFS feedstocks or blended soils,
    - few chemical constituents have been shown to biomagnify in terrestrial food webs,
    - the time to reach steady state with respect to plant and animal concentrations would be insufficient, so bioaccumulation would be limited, and
    - releases during roadway construction using SFS would be temporary and intermittent and, as a result, the potential for exposure will be very limited."

f) Dermal Exposure

Dr. Donna Vorhees

> *On Page 3-6, the Authors explain that "Dermal contact for the groundwater and soil pathways was excluded because available data indicate that the contribution of dermal exposure to soils to overall risk is typically small" based on results of a risk assessment conducted 14-15 years ago that reportedly involves only exposure to soil. This is not sufficient justification for excluding the soil dermal and groundwater dermal exposure pathways from further analysis. Did the cited risk analyses include the same exposure pathways and quantitative assumptions, i.e., are they directly relevant to the current assessment? I doubt that the large differences between dermal exposure and other pathways cited in Note #2 on this page apply to a COC such as arsenic in the context of this assessment. Such short cuts might be technically justifiable in some instances, but the goal of this assessment is to provide states with the risk information they need to reach decisions. The best way to do this is to quantify risk from all exposure pathways or to quantitatively demonstrate within the document (not by reference to an older risk assessment with no explanation of its relevance) that the pathway does not warrant further analysis.*

Response:

The Authors agree that when SFSs are used in manufactured soils for home gardens, the potential exists for dermal contact with soils and groundwater contaminated via leachate. For this reason, the Authors have performed additional screening assessments to evaluate these potential exposures for the COCs identified for the groundwater (Section 4.2.1) and soil pathways (Section 4.4.3). The Authors have added new text to the report describing the methodologies used to evaluate dermal exposures to contaminated soils and groundwater, and presenting the results. As discussed in these additions, the soil and water dermal exposures were found to be well below a level of concern for all of the evaluated COCs.

Additionally, the Authors have updated the conceptual models depicted in Figures 3-1 through 3-3 to include dermal exposures. The new Analysis Plan (Figure 3-4) also includes dermal exposure.

g) Manufactured Soil Conceptual Model

Dr. Ken Barbarick

The "Manufactured Soil" conceptual model is a highly conservative approach that will be protective of the other conceptual models. A 20-cm deep soil mix with 50% spent foundry sand is highly unlikely. The material and incorporation of a 50% mix to this depth would be expensive.

The "Home Gardener" scenario is the best choice for modeling since it would pose the greatest risk to an individual. The comment in #7 [see comment in 5.e below] regarding $Conc_{MS}$ *should be considered.*

The "Home Gardener" scenario is very conservative; it almost represents a worst-case scenario. The assumptions for the general population consumption and independence of the ingestion pathways are appropriate.

Dr. Mary Fox

I agree that the Manufactured Soil conceptual model can be considered protective of the other conceptual models for human receptors. See above comment about the blending site model and exposures to wildlife from deposition of particles leading to ingestion.

Dr. Charles Harvey

Yes, [the Manufactured Soil conceptual model] appears "protective."

The major sources, pathways, and receptors are included.

Page 1-4, paragraph 3

What does the spatial scale of the risk assessment mean? The size of the garden plots? The extent to which SFS is applied over a geographic area?

Page 3-7, paragraph 1

The statement that SFS will not be used for agronomic purposes is not convincing. It may be true that economics will always limit the use of SFS by farms, but I see no concrete evidence to support this contention. How expensive is SFS, and how much is it worth to improve soils for a farm? If SFS were used for a farm, then clearly a larger plot or garden area would need to be considered for the groundwater and home gardener models.

Dr. Donna Vorhees

The conceptual models are plausible and appear to include relevant sources, pathways, and receptors. However, the Authors should document the sources of information (e.g., stockpile management practices) used to construct conceptual models. Why do the Authors assume that engineering controls will prevent runoff but not fugitive dust? Also, engineering controls are not likely to be used for home gardens as appears to be *assumed in Figure 3-3. Where are direct links between SFS-containing materials (e.g., manufactured soil on a garden/field”) and receptors (e.g., home gardener) that ingest or come into dermal contact with it [Note: This direct contact pathway is shown correctly later in Figure 5-3]? Finally, the conceptual models are somewhat confusing, e.g., the legend suggests that dashed lines are used only for the surface water runoff pathway, but dashed lines are used for other pathways.*

Home gardeners are assumed to be exposed via the following exposure pathways:

1. *inhalation of SFS emitted from soil blending operations*
2. *ingestion of groundwater contaminated by the leaching of SFS constituents*
3. *incidental ingestion of manufactured soil*
4. *ingestion of fruits and vegetables grown in the manufactured soil*

Except for the concern expressed below about exclusion of the dermal contact with soil and groundwater pathways, these exposure pathways are appropriate. There is also the potential for home-produced poultry, dairy, and beef. Did the Authors consider this possibility (e.g., links to several newspaper articles regarding the increase prevalence of backyard chickens can be found at: http://www.backyardchickens.com/LC-links.html), assuming that there is any reason to use manufactured soil for grazing areas?

The Authors focus on SFS use in manufactured soil applied to gardens because this application is expected to result in the highest exposure. Therefore, if exposure to manufactured soil is not associated with significant risk, then other applications also will not be problematic. If the description of possible uses for SFS-containing materials is accurate, then the conceptual model for manufactured soil use appears to be protective of other SFS uses. However, it would be useful to include a section that describes current controls and possible future controls on SFS use, if any, to support this assumption. How much SFS is produced annually? How much might end up in manufactured soil and what fraction of agricultural land used for food production might ultimately have SFS-containing manufactured soil placed on it? The answers to these questions are relevant to the assumption that the home garden pathway represents an upper bound of possible exposure. Could a home gardener also be exposed from what they buy in the supermarket and/or the local community supported agriculture farm?

Independence of Ingestion Pathways. “Sub-pathways include the incidental ingestion of soil, as well as the ingestion of exposed fruits (e.g., strawberries), protected fruits (e.g., oranges), exposed vegetables (e.g., lettuce), protected vegetables (e.g., corn), and root vegetables (e.g., carrots)” (page ES-4). On page 6-31, the Authors argue that “it would be unlikely that a person would consume a high-end amount of root vegetables and leafy greens and apples that were all grown from the same garden.” This statement might be true, but the Authors do not provide any data that substantiates this assumption. Instead, they refer generally to consumption rates being high.

Response:

The Authors acknowledge that Dr. Barbarick, Dr. Fox, and Dr. Harvey find the home gardener conceptual model to be protective. No further response is necessary.

To address the potential for confusion pointed out by Dr. Harvey as it relates to the spatial scale of the risk assessment, the Authors have clarified the question in Section 1.1 (and Section 6.2) as follows:

> "Will the addition of SFS to soil result in an increase in the metal concentrations in soil relative to background levels, and how should the results of the risk assessment be interpreted across varied national soils?"

Regarding Dr. Vorhees questions regarding SFS production and potential use volumes, the 2002 Economic Census estimates that approximately 2,500 foundries operate nationwide. While this number is likely to have declined due to recent economic trends, it is likely still close to the actual number of operating foundries. In U.S. EPA (2008), it was found that the "metal-casting process generates approximately 9.4 million tons of foundry sand annually."

However, this amount would include non-silica foundry sands and foundry sands generated by brass and bronze foundries, etc. In addition, U.S. EPA (2008a) found that SFSs could be used in higher price markets (e.g., fill, concrete), could be located too far from a soil blender to be economically feasible, could be more expensive than competing native soils (e.g., parts of North Carolina) etc. Therefore, the actual amount of SFS available for use in manufactured soil would be much lower. With respect to agricultural use, the subject paragraph has been modified to clarify and further justify the position (see the final bullet in the Response to 4d, above).

Dr. Vorhees points out that the report should document the sources of information (e.g., stockpile management practices) used to construct conceptual models. For example, she asks why engineering controls will prevent runoff, but not fugitive dust The text inset below has been added to the roadway subbase discussion as a footnote to support that runoff controls are a legal requirement and that some of the same management practices will also control fugitive dust as required by the Clean Air Act. In the case of the blending site, fugitive dust emissions were considered as a release mechanism because the blending processes themselves, rather than storage conditions, generate the emissions. Blending operations would also be occurring on a much larger scale and, thus, would pose a higher risk than under the roadway subbase scenario.

> (*footnote text*) "Runoff controls are a legal requirement under the National Pollutant Discharge Elimination System (NPDES) that is part of the Clean Water Act. Most states have been authorized to implement the NPDES stormwater program (http://cfpub.epa.gov/npdes/stormwater/authorizationstatus.cfm), although some areas (e.g., tribal lands) remain under the direction of EPA. The NPDES regulations establish best management practices (BMPs) for any source of sediment, from sites or operations (e.g., construction, agricultural, or industrial), that might impact surface waters. Many of the BMPs applicable to the control of runoff are similarly used to control fugitive dust emissions as required under the Clean Air Act."

With regard to Dr. Vorhees comment concerning the use of engineering controls in a home garden, the footnote on Figure 3-3 has been modified, as shown in the text below, to clarify the assumption that controls would be imposed to protect the gardener's investment in manufactured soils.

> (*footnote text*) "The scenario assumes that the home gardener would impose controls to prevent significant runoff/erosion of manufactured soil from the garden."

The Authors have updated the conceptual model figures and footnotes in Section 3 to better communicate the scenarios.

The Authors also acknowledge that they did not consider the possibility of beef, diary, or backyard chickens in the home gardener scenario. As discussed above, the use of SFS in an agricultural setting is limited due to economic feasibility. Because of the soil-plant barrier, the low potential for uptake of metals that are largely unavailable, and the relatively limited amount of animal products that could be raised on soils amended with SFS, the Authors do not believe that this represents a significant limitation of the analysis.

To address the comment regarding the clarity of the statement "it would be unlikely that a person would consume a high-end amount of root vegetables *and* leafy greens *and* apples that were all grown from the same garden," the Authors have revised the statement as follows:

> "It would be unlikely that a person would consume a high-end amount of root vegetables *and* leafy greens *and* apples that were all grown from the same garden because (1) all types of produce cannot be grown in the same season, (2) there are regional characteristics (e.g., soil type, precipitation) that strongly influence what types of crops can be grown, and (3) there are agronomic limits as to how much produce can be grown, harvested, and consumed that are not reflected in the exposure factor data."

The Authors believe that this revision clarifies the above statement; however, it should be noted that the Authors used data from EPA's Exposure Factors Handbook and, therefore, are confident that the data are appropriate for the intended purpose. We believe that the paragraph and other changes to the report make it clear that, taken together, the consumption rates for fresh produce are conservative (tend to overestimate the actual consumption rates) and appropriate for the purposes of developing a conservative risk assessment screen for the produce ingestion pathway. Further, we explored this conservatism by running the model for alternative scenarios (e.g., general population) to provide quantitative insight into the risk estimates for receptors that represent more typical consumption rates for fresh, home-grown produce.

5) Screening and Modeling

The peer-review comments relating to screening of constituents and pathways are grouped into the following subcategories:

a) Positive Comments;
b) Soil-Blending Site Distances;
c) Groundwater Model;
d) Consumption Model Protectiveness;
e) Constituents Contributed by Soil;
f) Unitized Exposure Estimates; and
g) Transparency Issues.

a) Positive Comments

Dr. Ken Barbarick

Yes, the screening steps were appropriately conservative. Model equations are based on documented modeling research. The elimination of the TCLP test for "Ingestion of Groundwater" pathway is appropriate. The study also provides good justification for which metals were retained to determine risk of exposure.

The study used different screening levels developed at Oak Ridge National Laboratory. The risk assessment execution is solid. The screening levels from Oak Ridge National Laboratory are commonly used and are the best information available. They are sufficiently protective for the risk assessment used in this study.

Dr. Mary Fox

For the most part, the deterministic screening modeling was straightforward and clearly presented.

The air and groundwater screening steps were clearly designed to be conservative, e.g., 95th %ile sampling data were used for modeling and comparisons. Selection of constituents to evaluate in drinking water scenario is conservative. Contaminants were retained because LOD for leachate testing falls above the screening reference levels.

The screening of soil and produce ingestion pathways was trickier because it involved the "dilution" of SFS concentrations due to mixing with other soil components in the manufactured soil and consideration of multiple sub-pathways.

To address the issue of multiple sub-pathways of exposure the Authors divided the SSL health screening benchmarks by 10 to derive an adjusted SSL that allows for multiple pathways of exposure. This is an appropriate and conservative approach.

Dr. Donna Vorhees

The screening assessment is based almost entirely on the conceptual model for manufactured soil use on a home garden because this use is assumed to be associated with the highest degree of exposure. The exception is the use of a soil-blending operation to represent an upper-bound exposure estimate for the inhalation of fugitive dust pathway.

The assessment appropriately includes deterministic methods. The extensive use of screening in lieu of "forward" risk calculations might make risk communication a challenge.

Response:

The Authors acknowledge the above comments. The use of initial screening in lieu of "forward" risk calculations is a standard, accepted practice in environmental health risk assessment, and the Authors do not anticipate risk communications challenges. No further response is necessary.

b) Soil-Blending Site Distances

Dr. Charles Harvey

The calculated risks from inhalation were based on a minimum distance of 500 m between the nearest residence and the source. This choice of value for the downwind distance does not appear to be conservative, especially relative to other selected parameter values. The choice is based on a single areal photograph of a blending facility. It is reasonable to suspect that, if more sites were considered, some would have closer distances to the nearest residence. For a conservative screening calculation, the assessment should use a minimum distance closer to 100 m. For the groundwater model, the choice of a 1 m distance from a garden to a drinking water well appears to have been an attempt to be conservative (however, see comment above). The same philosophy was not used for the choice of the distance between blending site and the nearest house. A distance of 100 m seems like a reasonable, conservative choice.

Decreasing the assumed distance to the closest residence may push the 95th percentile for manganese over the screening concentration. At 500 m, the calculated value of 501 mg/kg is only a factor of two less than the screening concentration (Table 4.4). Such an outcome would complicate the overall assessment. However, it could be very useful for devising future regulations for building blending facilities.

Issues related to manganese poisoning from inhalation have been considered in studies on the dangers of mining dust.

Response:

Dr. Harvey suggests that the assessment should use a minimum receptor distance closer to 100 m instead of the 500 m distance applied in the assessment. However, we believe that the distance of 500 m is appropriate for screening purposes. The goal of the assessment was to model a reasonable maximum exposure (RME) scenario. In defining this scenario, the Authors identified or developed parameter values that were consistent with high-end emission and dispersion conditions, but not “worst-case” conditions. As shown **Table 2**, several aspects of the modeling approach maintained the high-end, conservative nature of the assessment. For instance, modeling was performed using EPA’s recommended conservative screening model SCREEN3. The full range of meteorological conditions and wind directions were examined to ensure that modeling options identified the highest concentrations. This model generated short-term, maximum 1-hour air concentrations. These short-term concentrations were then combined with chronic health benchmarks to develop conservative screening levels. Lastly, these screening levels were compared to the 95th percentile SFS concentrations to ensure that the concentrations did not pose an unacceptable risk to human health. The Authors believe that compounding these high-end modeling elements with a receptor distance of 100 m would result in an unreasonable “worst-case” scenario and not an RME scenario. The Authors would also like to point out that dividing all current inhalation screening concentrations by a factor of 5 (i.e., to reflect a reduction of receptor distance from 500 m to 100 m) would not change the conclusions of the analysis.

Table 2: Parameters for Screening Level Inhalation Assessment

Parameter	Value	Bias	Rationale
Model Selection	SCREEN3	Protective	SCREEN3 is the screening version of the Industrial Source Complex model, version 3 (ISC3), used to calculate short-term, maximum 1-hour air concentrations
Emission rates (g s^{-1} m^{-2})	Calculated based on AP-42	Protective	Calculated using high-end wind speeds and rainfall assumptions
Height of storage pile (m)	4	Neutral	Based on aerial photography
Length of storage pile (m)	15	Neutral	Based on aerial photography
Width of storage pile (m)	10	Neutral	Based on aerial photography
Receptor height (m)	0	Neutral	Representative of breathing zone for child receptor (i.e., ground level)
Urban or rural	Rural	Rural	Rural option selected based on observed surrounding land use
Search for maximum direction	Yes	Protective	Examining all directions ensures that the maximum concentrations will be located
Choice of meteorology	Full	Protective	Under this option, SCREEN3 examines a range of stability classes and wind speeds to identify the "worst case" meteorological conditions, i.e., the combination of wind speed and stability that results in the maximum ground level concentrations
Distance (m)	500	Neutral	Distance to the nearest resident based on aerial photography
Health Endpoints	Chronic	Protective	Benchmarks used to calculate the screening level are based on the worst-case exposure duration, and frequency of 24 h d^{-1}, 365 d yr^{-1} were used for comparison to short-term maximum air concentrations
SFS concentration levels	95th percentile	Protective	95th percentile concentrations of constituents in SFS were for comparison to risk-based screening levels

c) Groundwater Model

Dr. Mary Fox

Numerous subsurface parameters for groundwater modeling were set to model default values. This is outside my area of expertise, but I wonder how these defaults influence the “national representativeness” of the groundwater ingestion pathway.

Dr. Charles Harvey

The groundwater modeling resulted in a result of “zero” for all estimated 90th percentile exposures (Table 5.1). First, “zero” for a chemical concentration appears a little peculiar – “zero” really means that the modeled results are at or below some minimum value that the model can accurately produce.

The more important question about these findings is: why are the values so low? Why does the simulated leachate not reach the well, or why is it so greatly diluted? Some simple calculations are useful for approaching these questions. First, it is useful to consider how long it will take the leachate to reach the well. If we only consider the time to flow through the saturated zone to the well, then the model parameters imply that it will take about a year for a conservative solute to reach the well from the far upstream side of the plot. (In all model runs, the plot was 1 acre (~40 m x ~40 m), the gradient was 0.0057, and the hydraulic conductivity was 1890 m/yr. So, assuming a porosity of 0.25, T = (40 x 0.25)/(1890 x 0.0057) = ~1 year). Thus, the modeled time for one of the solutes (e.g., arsenic) to reach the well will be longer, and perhaps much longer, than a year because the model includes the transport time through the unsaturated zone, and solutes are subject to sorption as parameterized by retardation factors. But, what time duration was modeled? The description states that the "land application unit was operated for 1 year," but for how long was the leachate input simulated, and for what time period was groundwater transport simulated?

Furthermore, what was the screened interval of the well? If concentrations at the bottom of the well were considered, then they would be "zero" because the bottom of the well is on a stream line that extends upgradient to a recharge source beyond the plot. <u>For groundwater concentrations below some depth in the aquifer, putting the well very close to garden plot is, in fact, not conservative</u> –contaminants from the SFS will pass above the depth of the well because the well is so close to the garden plot. (For a stream line to extend from the plot to the bottom of the well, recharge would have to be greater than 2.5 m. For a porosity of 0.25 again, and approximating stream lines as parallel, the recharge rate that will reach the bottom of the 10 m aquifer in one year is, 10 x 0.25 = 2.5 m. None of the realizations should have such a large recharge rate, and hence, solute should not reach the bottom of the well in any of the realizations.) If only top levels of the aquifer are considered, then concentrations will rise more quickly after creation of the garden plot because leachate will reach the well quickly near the top of the aquifer. The "protective" approach would be to use the maximum concentration with depth.

In summary, there simply isn't enough explanation of the model to understand whether the "zero" concentrations are a robust finding, or whether they result from a peculiarity of the model setup. This report does not make a convincing case that the groundwater modeling has been carefully considered. For example, hydraulic conductivity is the largest source of uncertainty in most groundwater models, yet in this probabilistic assessment that parameter is set to a constant value. In fact, it appears that this assessment would be better served by employing a simpler approach— that a sophisticated groundwater model may be unnecessary. Simple approximations of pore-water velocities and retardation factors would produce equally valid outcomes, and such an approach would be more transparent.

Page 5-4, last bullet point

Why were the concentrations of antimony, beryllium, cadmium, and lead modeled at half their detection limits? The detection limit would be the appropriate "protective" value.

Response:

The Authors used fixed default values for the seven key parameters listed in Section 5.2.1 of the original risk assessment. These model defaults, as well as the default input distributions, are from national distributions, as explained in U.S. EPA (2002a). These parameters were peer reviewed along with the model, as discussed in U.S. EPA (2002a). Thus, the Authors believe that these default values are appropriate and representative for the nationwide, probabilistic risk assessment conducted here.

In response to Dr. Harvey's questions about the modeling results, the model returns zero when the modeled concentrations are less than 10^{-20} mg L^{-1}. Footnote 'a' of Table 5-1 has been revised to clarify this threshold. IWEM ran the scenario 10,000 times, and each iteration was modeled for 10,000 years or once peak receptor well concentrations were identified, whichever came first. The 10,000 model iterations would randomly choose different well screen depths within the shallow aquifer. The aquifer was located between depths of 5.18 m and 15.28 m below the ground surface.

The Authors agree with Dr. Harvey that the combination of short distance to receptor well and randomly chosen well depth (i.e. "screen interval") may not lead to conservative results. To test the effects of this combination on exposure concentrations, additional probabilistic screening modeling was performed at well distances of 15m, 30m, 50m, 75m and 100m. Numerous changes have been made to Section 5.2 (Screening Probabilistic Modeling of the Groundwater Ingestion Pathway) of the report to reflect the rationale behind the additional modeling, how it was performed, and the results.

Also, a complete review was conducted of the probabilistic screening modeling of the groundwater pathway. The review evaluated the use of IWEM as detailed in the report (e.g., choice of garden size, well distance, operational life, etc) to see if any changes would result in more accurately representing the SFS home garden scenario. The review was designed to also identify alternative peer-reviewed and publically available groundwater models, if any, that could more accurately represent the SFS home garden scenario. As a result of the review IWEM was retained as the groundwater model of choice, but several changes were made to how it was used. Specifically, the size of the home garden was reduced to 0.1 acre to more closely reflect home garden sizes, and the operational life of the garden (used by IWEM to track the duration of metal's leaching from the garden) was increased to 40 years. Section 5.2 (Screening Probabilistic Modeling of the Groundwater Ingestion Pathway) of the report has been modified to reflect the changes in modeling methodology and results. A complete description of the review process and its findings is found in Appendix A of this Response to Comments document.

The modified screening modeling found that arsenic exceeded the lowest available screening level in the wet and central tendency climates. Arsenic was therefore retained for more refined study. Complete descriptions of how the refined study was conducted, and the results, have been added to the report in Section 5.3 (Refined Probabilistic Modeling of the Soil/Produce and Groundwater Ingestion Pathways) and Appendix J (EPACMTP Groundwater Modeling). The results of both the probabilistic screening modeling and refined modeling have also been included in constituent-specific subsections, as well as discussions of uncertainty, in Chapter 6 (Risk Characterization).

The Authors agree that it is useful to consider how long it would take for SFS manufactured soil constituents leaching from the garden to reach the receptor well. If exposures via groundwater do not occur in the same timeframe as exposures via surface pathways (e.g. ingestion of homegrown produce), then it may be more appropriate to assess potential health impacts separately.

Additional modeling was performed, including the use of retardation factors as Dr. Harvey suggested, to determine if surface and groundwater pathway exposures would occur within the same timeframe. The results of this modeling demonstrated that peak exposures from surface pathways would not overlap with peak exposures via groundwater. References to this additional modeling, or the implications of the results (i.e. not aggregating surface & groundwater exposures), have been added to pages ES-5, ES-7, 3-13, 5-29, 6-13, and 7-3. The following language was also added to Section 5.3.5:

> "An analysis was performed to evaluate anticipated arrival times to determine if the exposure through the soil ingestion pathway would overlap with exposure through the groundwater pathway. To determine the approximate timeframe when the peak groundwater exposure might occur, estimates were made of the time at which the contaminant plume would arrive at the receptor well and the time when the contaminant plume would finish passing the well. Arrival of peak concentrations would only occur somewhere within this time period. These estimates were based upon two additional outputs from the unsaturated zone transport simulation: 1) first arrival time of leachate at the water table and 2) cessation time of leachate arrival at the water table. Retardation effects were used to account for horizontal travel to the receptor well. The results of this analysis are summarized in Table 5-3.

Table 5-3. EPACMTP Arrival Times of Plume at the Receptor Well for Arsenic

Percentile	Arrival Time Zone (year)	
	Beginning	End
90 %	29	200
80 %	61	200
70 %	100	202
60 %	150	220
50 %	201	272
40 %	203	345
30 %	207	457
20 %	229	663
10 %	398	1112

> Based on the analysis, (see Appendix J for more details), it is unlikely that peak surface and peak groundwater exposures will occur within the same timeframe. For example, the earliest estimated timeframe for arrival of arsenic from the garden spanned from 29 to almost 400 years following the application of the SFS. It is therefore likely that the peak well concentrations will not occur until well past the timeframe for peak surface pathways exposures, and perhaps even past the timeframe of residency (i.e., exposure duration of the gardeners who originally applied the SFS manufactured soil). Therefore, separate screening levels were developed for the groundwater and soil pathways."

In addition, a detailed description of this additional modeling, and the results, has been added to Appendix J (EPACMTP Groundwater Modeling) of the report.

With respect to the treatment of nondetects, the Authors assumed that there would be some distribution of concentrations between zero and the detection limit. Because the midpoint of the two extremes of such a distribution would be half the detection limit, the Authors determined that replacing nondetects with half the detection limit would be appropriate. This also is consistent with both U.S. EPA (1989) and U.S. EPA (1991). The Authors have modified the text of Section 5.2.1 to state the following:

> "For arsenic, the higher of the 95th percentile leachate concentrations found by either SPLP or the ASTM leachate methods (0.018 mg L^{-1}) was modeled. Antimony, beryllium, cadmium, and lead were not detected in any samples, and were therefore modeled at half their detection limits in accordance with U.S. EPA (1991b). Thus, their modeled leachate values were 0.02, 0.01, 0.005, and 0.055 mg L^{-1}, respectively."

d) Consumption Model Protectiveness

Dr. Mary Fox

I believe the Authors took reasonable steps to develop models to represent the range of site conditions in the continental United States. This included using regional meteorological data, modeling multiple soil types and climate conditions and defining SFS use feasibility zones.

The home-gardener scenario as described is probably conservative, but not necessarily a "significant overestimation (page 6-31)." Independence of ingestion pathways is an appropriate assumption.

The stated reason for modeling the general population was concern that the home-gardener scenario was overly conservative. I do not share that view. However, it is useful to have a range of estimates to represent other populations with moderate intakes.

Dr. Donna Vorhees

The Authors assume that manufactured soil is 50% SFS and explain that a higher percentage would not be feasible because it would be cost-prohibitive for a home gardener (i.e., see note 5 on page ES-6, which indicates that blends "are more likely to include 5-10% SFS" for this reason), and the manufactured soil would not have the characteristics needed to grow plants (See Dayton et al. manuscript, in review). Still, over time, manufactured soil could be used repeatedly in a single location, so it makes sense to consider the potential for a higher percentage contribution of SFS. The assumption that SFS comprises 50% of manufactured soil is not certain, but does seem to provide an upper bound given soil requirements for growing plants.

Response:

The Authors have replaced the phrase "significant overestimation" with the phrase "as an overestimate" in the revised document.

The Authors also note Dr. Vorhees' finding that the 50% SFS assumption provides an upper bound for manufactured soil. No further response is necessary.

e) Constituents Contributed by Soil

Dr. Ken Barbarick

> *One suggestion is to include the soil contributions to $Conc_{MS}$. No doubt the contribution would be small in most cases; however, including this information provides a more thorough analysis.*

Response:

The Authors note that the scope of this assessment was to look at incremental risks due to exposures to SFS constituents in soil-related uses. Thus, the constituent concentrations contributed by soil are outside the scope of this assessment.

f) Unitized Exposure Estimates

Dr. Mary Fox

> *The rationale and approach to the probabilistic modeling of the soil/produce ingestion pathway (Section 5.3) is not clear. Why were unitized exposure estimates preferable to health risk estimates? More background on development and uses of unitized exposure estimates is needed. Why was 1 mg/kg chosen as the assumed concentration?*
>
> *Methodology for developing unitized exposure estimates needs to be explained more thoroughly including a specific example and references to other EPA uses of unitized exposure or risk estimates. Why is this approach necessary or preferred? How does the assumed concentration of 1 ppm relate to actual manufactured soils or what would be expected?*

Response:

The Authors agree that the introductory discussion on the soil/produce ingestion pathway does not provide sufficient background for the modeling and, in particular, some of the terminology in the beginning of Section 5.3 has caused confusion. The term "unitized" in this context refers to the use of a fixed, initial concentration of a metal or metalloid constituent in SFS that was used as input to the Monte Carlo modeling simulations. The Authors have revised Section 5.3 to summarize the individual steps taken to develop the target soil concentrations from the unitized risk distributions and have added a new section (Section 5.3.1) that provides a detailed description of the probabilistic modeling framework and explains why fixed concentrations—rather than sampled concentrations—were used as input to the model simulations. Application of the unitized approach for this assessment was appropriate because the modeling system is linear with respect to concentration and a "unitized concentration" of 1 mg/kg could be used to calculate the allowable concentration of specific metal constituents in SFS (i.e., representing minimal risk). Importantly, calculating allowable constituent concentrations in SFS provides the states with a frame of reference with which to address the variability of chemical concentrations and characteristics of foundry sands. Thus, the "unitized" concentration of 1 mg/kg was chosen arbitrarily as the initial concentration with which to scale to an acceptable concentration in SFS, defined by EPA as a 90th percentile hazard for the soil/produce ingestion pathway below a value of 1 (note that any other fixed concentration would serve the same purpose). In addition to these changes, the Authors have added the following footnote to Section 5.3 to demonstrate other EPA uses of this unitized approach for risk assessments.

> (*footnote text*) "Similar unitized approaches have been applied under previous U.S. EPA risk assessments. For example, the unitized approach was applied in the Risk-Based Mass Loading Limits for Solvents in Disposed Wipes and Laundry Sludges Managed in Municipal Landfills. This risk assessment and the unitized approach have been extensively reviewed internally and externally by the OMB and the final rule based on this risk assessment, Solvent-Contaminated Wipes, was publish July 31, 2013 (78 FR 46448-46485)."

g) Transparency Issues

Dr. Mary Fox

> *Software used and specifications of the probabilistic modeling including number of iterations and type of sampling (Monte Carlo or Latin Hypercube) should be provided in the main text or as an appendix. This information is needed for transparency. A complete evaluation of the probabilistic modeling cannot be conducted without this information.*
>
> *Joint probability approach for determining the combination of site conditions evaluated in the probabilistic modeling is not well described in Chapter 5 or Chapter 3. How is the joint probability approach implemented within the modeling framework?*

Dr. Charles Harvey

> *Also, as a more specific comment, the report should better illustrate the Soil/Produce Ingestion Pathway model (Section 5.3). This model is an important part of the overall assessment and is bewilderingly complex. A simple way to bring some clarity to the model presentation is to illustrate a mass balance for the model. The flow chart of mass fluxes for the conceptual model is intricate, and as presented, it is impossible for the reader to determine the magnitude of the different fluxes. A mass balance for the model would illustrate how much mass of a particular contaminant is applied, and then how much of this contaminant is transported through the different pathways. This would give the reader some notion of the importance of the different pathways. Also, constructing a mass balance is absolutely key to validating a model —the mass fluxes must sum to the mass loss. Thus, presentation of the mass balance would also provide some confidence in the workings of the model. This balance continues to hold when mean values across all realizations are used, and showing the average values may be the best way to illustrate the mass balance, although augmenting the averages with their standard deviations would improve the illustration.*

Dr. Donna Vorhees

> *The assessment includes documentation of models, data, and assumptions used to perform all analyses, except as otherwise specified in responses to charge questions.*
>
> *The assessment briefly describes EPA models such that all work could be independently reproduced. Some additional discussion of the 3MRA model would be helpful for the*

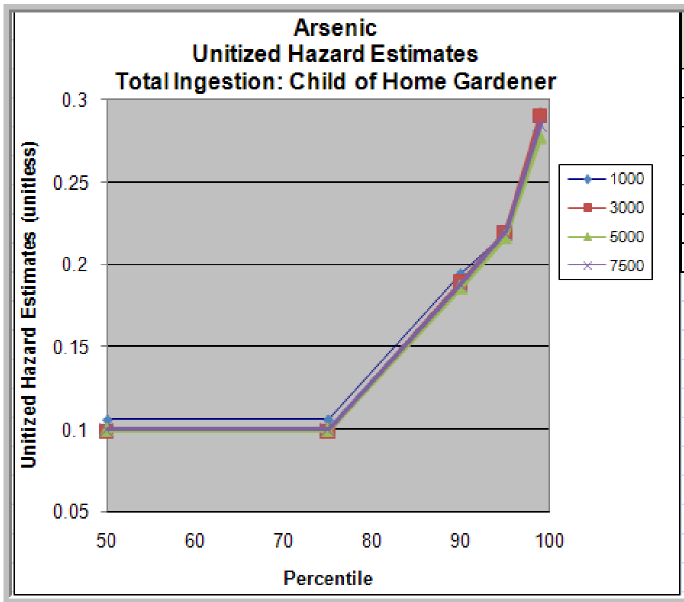
> *reader to understand the modeling in greater detail. However, it is possible for a reader to consult EPA guidance regarding the model, as well as the software itself.*
>
> *I could not find discussion of numerical stability of PRA model outputs. Does the 3MRA model provide any quality assurance output to check for such stability? If so, provide a summary in this assessment.*

Response:

Dr. Harvey's request for a mass-balance equation and Dr. Fox's questions speak to the probabilistic model documentation. As noted by Dr. Vorhees, further discussion of the models is available in U.S. EPA (1999a, 1999b, and 2003c). However, to improve transparency, the Authors have revised Section 5.3 and added a new Section 5.3.1 to better communicate the methodologies and modeling that was implemented within the probabilistic framework. Additional language was also added to Section 5.3.4 to direct readers to a detailed description of the refined model's mass balance structure in Appendix G.

The choice of 7,500 iterations in this analysis was based on the Authors' historical knowledge of conducting Monte Carlo simulations using these models for EPA risk assessments. In response to peer-review comments on stability, the Authors evaluated this assumption by performing a stability assessment for the home gardener scenario. The results shown below for arsenic demonstrate that performing 7,500 iterations adequately ensures the stability of the results at the percentiles of interest (50^{th} and 90^{th}).

The Authors have included the arsenic example in Section 5.3.1, and have described the stability test and present the results shown in the following table. The table shown in the figure presents the absolute percent changes between samples. As demonstrated by this figure, the model is stable before 5,000 iterations for the mean, variance, and at the 50^{th} and 90^{th} percentiles.



Value	Percent Difference		
	1000-3000	3000-5000	5000-7500
50th percentile	6.5	0.6	0.5
75th percentile	6.5	0.6	0.5
90th percentile	2.7	1.5	0.9
95th percentile	0.4	1.3	1.1
99th percentile	0.7	4.3	2.5
mean	2.5	0.03	0.6
variance	2.7	4.0	2.6

6) Risk Characterization and Uncertainties

The peer-review comments relating to characterization of the risks and their related uncertainties are grouped into eleven subcategories:

a) Findings/Conclusions;
b) Soil Properties, Background, Phytotoxicity, and Soil Biota;
c) Sensitivity Analysis;
d) Variability versus Uncertainty;
e) Inconsistencies with the Exposure Factors Handbook;
f) Child-Specific Exposure Factors Handbook Not Used;
g) Data Collection Uncertainty;
h) Toxicity Value Uncertainty;
i) Consumption Rate Uncertainty;
j) Cumulative Risk; and
k) Clarity.

a) Findings/Conclusions

Dr. Ken Barbarick

The "Risk Characterization" section is very clear. The weight of evidence approach for (a) risk screening modeling and (b) uncertainties associated with state-of-the-science research provided the best assessment.

The document does a thorough job of providing and interpreting information without hidden assumptions or preconceived notions. The risk assessment is "transparent."

The assessment does support the report's conclusions that spent foundry sands can safely be used as an up to 50% manufactured or garden soil mix.

Dr. Mary Fox

I believe the assessment was conducted as the Authors report. The overall approach is reasonable. The formulae appear correct and models (SCREEN3, IWEM, 3MRA, ISCST3) used are appropriate. However, as detailed in answers to subsequent questions there are data limitations and issues with implementation of the probabilistic modeling that compromise the Authors' claims of conservatism and the assessment conclusions.

I cannot endorse the risk assessment findings and conclusions as presented in the peer-review draft. The probabilistic modeling analysis needs to be revised considering these comments and repeated.

Dr. Charles Harvey

The study also uses a "weight-of-evidence approach," and claims (p. 1-4) that it is "useful to consider exactly what this means," but does not appear to present a definition that clearly distinguishes this approach from simply conducting a good study. As best I can tell, the "weight-of-evidence" approach means a comprehensive study that brings *together all useful lines of evidence. But, I am left wondering if there might be something more to this phrase.*

The report makes a strong argument that SFS use is safe. However, the report would ultimately be more compelling, and certainly more useful, if it focused on providing the best description of the distribution of risks.

Rather than present only 90th percentile hazard estimates (e.g., Table 5.8), the assessment would benefit by presenting the entire histogram. Using histograms instead of point estimates has a number of advantages, as follows: (1) It would remind the reader that the estimates are the result of a Monte-Carlo simulation and give the reader a visual representation of the spread of the resultant distribution. (2) In the current presentation, there is no indication of the skewness of the distribution – above the 90% cutoff, just how large are the values? As a hypothetical example, if the distribution is very skewed then more than half of the health risks could lie above the 90% cutoff, and hence the approach taken in this assessment would miss the real danger. (3) Using the 90% cutoff is arbitrary. The full histogram offers the possibility of estimating other point measures.

Dr. Donna Vorhees

Yes, the assessment supports the overarching conclusion that beneficial use of SFS can occur without significant risk to human health. However, the issues raised in response to other charge questions require attention.

The assessment provides a clear discussion of how risk-based screening levels were developed, including a discussion of uncertainties that influence interpretation of results. I also understand the utility of screening levels as opposed to "forward" risk calculations in this context where states and others might want to compare chemical concentrations associated with individual samples of SFS or SFS-containing materials to "acceptable" concentrations. However, as noted in response to other charge questions, this section could more succinctly address the general question of whether the assessment, in its entirety, ensures that cumulative risks are below levels of concern.

The Authors conclude that "the results of the home gardener risk screening modeling should be considered as a significant overestimation of the actual risks associated with SFS use." This conclusion might be true but is not substantiated adequately in the assessment as discussed in response to charge question #8.

Overall, the execution of the risk assessment is adequate and excels in some respects. My responses to all charge questions highlight opportunities to improve the document.

Response:

The Authors acknowledge that several of the commenters found the conclusions to be accurate. No further response is necessary to these statements.

While Dr. Fox states her inability to agree with the conclusions due to specific issues, the Authors have attempted to address all of these issues in the revised draft. Because most of these issues were transparency issues, and the remaining reviewers agreed with the conclusions, the Authors believe that the conclusions are scientifically supportable.

With respect to Dr. Harvey's first comment, the Authors acknowledge that the term "weight of evidence" may not be the typical description of risk results, and thus, it has the potential to confuse readers. Such terms have been modified to refer to "lines of evidence," which is both accurate and more typical of risk assessment documentation.

The Authors do not believe that providing histograms of the unitized risk estimates per Dr. Harvey's other request would be as useful. These distributions could not be converted into a screening value for states to use and would be confusing to all but the most technical readers. Thus, while taking a point estimate at the 90th percentile may be considered arbitrary by some, it is a deliberately high-end value that allows the Authors to provide to the states a useful screening value that is protective of human health and the environment. Additionally, the Authors did create a range of screening values by using three different consumption rates, which allows for some flexibility among risk managers.

In regard to Dr. Vorhees comments regarding cumulative risk and the "significant overestimation" language, these are addressed in 6.j below and 5.f above (respectively).

b) Soil Properties, Background, Phytotoxicity, and Soil Biota

Dr. Ken Barbarick

The report presents a very thorough scrutiny of soil fertility, nonessential elements, and potentially toxic compounds.

The soil background and phytotoxicity are adequate. The impacts on general soil biota needs more detailed study. For example, earthworms are mentioned as a group in terms of potential risks. Earthworms are a very diverse group of organisms who will more than likely respond differently to the potential risks associated with spent foundry sand additions to soil. This study probably did not have the resources to look at specific groups of biota, however. Shifts in microbial communities should be studied to determine if the "Home Gardener" scenario encourages shifts between major microbial groupings such as bacteria and fungi and if particular individual species of organisms are favored or harmed by the additions of the spent foundry sand. Good references for this approach are the following: Ritchie et al. (2000), and Schutter et al. (2001).

Dr. Charles Harvey

The assessment describes a broad and representative sampling of the research literature.

Finally, in several places, the report emphasizes that background concentrations of metals in SFS do not appear to be much higher than in natural soils, and therefore, the use of SFS poses no danger. This may be true, but this statement should be tempered with several caveats. First, SFS could contain artificial organic contaminants left after heating the binding agents. Second, the metals could be in a less recalcitrant state than in natural soils.

Dr. Donna Vorhees

The comparison of SFS concentrations to USGS background concentrations in Figures 6-1 through 6-4 is useful, although I suggest that axes on paired plots should be

> *consistent to facilitate the comparison. Treatment of nondetect results should be specified on these plots and any other data manipulation that might influence the comparisons.*

Response:

Dr. Barbarick makes several good suggestions as to future research that could be conducted on the topic of soil biota. However, the risk assessment was designed to use available data, and conducting field studies on soil biota is well beyond the immediate scope of this study.

The Authors agree with Dr. Harvey that SFS could contain certain organic contaminants and metals in a less recalcitrant state. For this reason, the study considers background concentrations, the analytical data on potential releases, field and laboratory studies on ecotoxicology, screening comparisons between SFS and health and environmental quality criteria, and probabilistic risk modeling in developing the risk characterization. As suggested by Dr. Harvey, simply comparing SFS concentrations with background concentrations would not provide adequate information to support a risk characterization. However, the Authors believe that the lines-of-evidence approach used to combine and consider all of these data supports the conclusions of this study.

The Authors understand Dr. Vorhees point about matching axes; however, we believe that axes as presented convey the information as intended. The purpose of these figures is to convey information about the concentration distribution for each set of data and, therefore, we believe that using axes that allow the shape of the distribution to be visualized is warranted.

As mentioned in 5.c above, the Authors have added discussion regarding the treatment of nondetects to Section 5.2.1 of the revised document.

c) Sensitivity Analysis

Dr. Donna Vorhees

> *The assessment incorporates appropriate sensitivity analyses and describes them clearly.*

Response:

The Authors acknowledge the comment. No further response is necessary.

d) Variability versus Uncertainty

Dr. Donna Vorhees

> *The assessment incorporates discussion of correlations; see response to charge question #9 for additional discussion regarding correlations.*
>
> *The assessment includes clear descriptions of distributions used in the PRA. However, the Authors made no attempt to differentiate variability and uncertainty. This level of effort is not necessarily warranted if conservative risk-based screening results are well below cumulative risk levels of concern. Some distributions were truncated. Truncation steps are not likely to strongly influence results of the analysis, and truncating at zero for inputs that cannot be negative is certainly reasonable as long as one accounts for the*

> *effect on parameters of the truncated distribution. Other truncation steps are not so easily defined. For example, is a reasonable maximum value for a homegrown produce ingestion rate really estimated by doubling the sum of the mean and 3*standard deviation? If not, what is the next best value? It seems far less complicated to leave distributions as they are with very low probabilities assigned to extreme values. The Authors could always use sensitivity analyses to examine the influence of extreme values.*
>
> *A puzzling aspect of the PRA is the fact that only some inputs are defined with distributions. Why quantify variability and/or uncertainty for only some model inputs when data are available to develop distributions for others? The following sections describe information that is available for inputs that either were treated as point estimates in the PRA or were defined with distributions that could be improved.*

Response:

As implemented, the Monte Carlo simulation does not distinguish between uncertainty and variability, and because the output distribution primarily represents the variability in the input parameters, the Monte Carlo approach addresses what is generally referred to as Type A uncertainty (the uncertainty associated with variability) (Hoffman and Hammonds, 1994). In essence, distributions were selected to represent variability (e.g., exposure factors) and in some cases, to also represent the uncertainty in the true parameter value (e.g., depth that manufactured soil is incorporated into native soil). The uncertainty around the true mean (or other percentile risk) and variance of the risk distribution are not addressed in the sense that the statistical descriptors for each input parameter remain constant throughout the simulation, and the model output is a single distribution of risk for each constituent. Type B uncertainty—the uncertainty associated with a lack of knowledge—was not addressed separately from variability. Type B uncertainty is distinguished from Type A uncertainty by conducting the Monte Carlo simulation in two dimensions; this makes it possible to estimate a confidence interval around the probability density function (PDF) and therefore allows the uncertainty in the overall result to be quantified. The Authors have revised Sections 5.1 (Introduction to Probabilistic Modeling) and 6.8 (Uncertainty Characterization) to ensure that the distinction between uncertainty and variability is made clear within the context of this risk assessment.

The Authors agree that it is highly unlikely that the truncation of selected parameters will have a significant influence on the risk results. The Authors do recognize that the truncation of parameter distributions is an ongoing topic of discussion, and that truncation is only warranted to prevent extreme (e.g., 1,500 lb individual body weight) or impossible values (e.g., negative numbers), as the commenter pointed out. In response to the commenter's question regarding the method chosen to establish the maximum value, this is based on a normally distributed parameter. The value equal to the mean plus 3 standard deviations is 99.865 (i.e., above the 99th percentile). Recognizing that the distributional shape for most environmental exposure factors approximates lognormal, the "protection factor" of 2 was added to ensure that a reasonable maximum value is achieved. This approach to setting maximum values for Monte Carlo risk assessment modeling was originally used during the development of the 3MRA modeling system that was reviewed by EPA's Science Advisory Board (http://yosemite.epa.gov/sab/sabproduct.nsf/0/99390EFBFC255AE885256FFE00579745/$File/SAB-05-003_unsigned.pdf), and has been used by EPA in other multimedia risk assessments, notably, the land application of biosolids. The Authors believe that this convention provides reasonable high-end values for the distribution and, importantly, the maximum values were assigned after the distribution was fit and the mean, standard deviation, and various percentiles were determined. Although the “correct” value to assign as the maximum is a known unknown, a quick comparison for one of the produce categories strongly suggests that this method does, in fact, produce a reasonable maximum value that is highly unlikely to underestimate the “true” maximum value. For instance, a 70 kg adult would consume 741 grams (WW) of exposed vegetables per day using the maximum value calculated using this convention. This is roughly the equivalent of eating two large salads every day that consist exclusively of vegetables grown in a home garden, and is 341 grams higher than the recommended daily intake (400 grams per day) of fresh vegetables, a mark that the vast majority of Americans fall well below. Given the inherent conservatism in the approach described in the document (e.g., the average consumption rate for home-grown produce was 105 grams [WW] per day), the maximum consumption rate values are considered to be reasonable and appropriate for this risk assessment.

The Authors agree that, for certain types of risk assessments, the separation and quantification of uncertainty *and* variability are desirable and necessary for the decision-making process. However, for screening-level assessments that are designed to provide conservative estimates of risk (i.e., the bias is designed to overestimate risk), the value of this additional information is generally not justified by the level of resources required to develop the necessary input data, run the model simulations, and analyze/present the results. For analyses (such as this SFS risk assessment) that cover a significant proportion of the contiguous United States, it is difficult to separate variability from uncertainty (Nauta, 2000), and a two-dimensional probabilistic approach would have presented a real challenge in terms of time and resources. Although a two-dimensional Monte Carlo framework can provide additional insight into uncertainty by separating variability and uncertainty, a one-dimensional probabilistic approach was used that commingles variability and uncertainty into a single dimension (Mokhtari and Frey, 2005). Thus, the risk distribution from the model simulation represents a best estimate of the distribution of risk for a unitized constituent concentration, accounting for multiple sources of uncertainty and variability, especially the variability in the input parameter values. For the purposes of screening the potential for adverse health effects associated with the use of SFS-manufactured soils in home gardens, the Authors do not believe that explicitly separating uncertainty and variability would constitute a material improvement in the risk screening estimates.

Finally, the Authors point out that the PRA includes some inputs that are represented by single values rather than point estimates. Some are given explanations provided in the appendices (e.g., EPA-recommended values). In virtually all of the chemical risk assessments conducted over the past 20 years, human health benchmarks (widely acknowledged as a significant source of uncertainty) are represented by a point estimate rather than a distribution. Similarly, chemical and physical properties are often given as a single best estimate, even though it is recognized that there is variability associated with various measurement techniques. Moreover, some input parameter values were chosen specifically to produce conservative estimates of potential health risks, which, as stated in the document, was the primary goal of the PRA. It should also be noted that, because multimedia models such as 3MRA are sensitive to a relatively small number of input parameters (e.g., source concentration, ingestion rates), distributional data are not developed for the entire suite of input parameters; this typically includes parameters to which the model is not particularly sensitive, as well as parameters that exhibit relatively small variance.

Thus, given the objectives of the probabilistic risk screening, as well as value-of-information considerations associated with separating uncertainty from variability, the Authors believe that the models have been parameterized appropriately.

e) Inconsistencies with the Exposure Factors Handbook

Dr. Mary Fox

Some data inputs do not correspond to the source data referenced (see response to question 9, below)

More care should be taken in defining minimum and maximum values on distributions used in the probabilistic modeling. For example, for the body-weight distributions, the mins and maxs found in Appendix I (Table I-2) do not reflect the Exposure Factors Handbook *data referenced (see comparisons below). It is especially important to choose conservative (and reasonable) maximums for probabilistic modeling particularly for body weight and averaging time, which appear in the denominator of exposure/dose equations. Generally speaking, when defining body weight and averaging time for a conservative scenario, lower values should be chosen. For greater transparency and reproducibility, inputs should reflect the source data.*

Table 1a. Comparing Data in Table I-2 with EFH Data – Body Weight Minimums

Units = kg	Min Table I-2	Min EFH Table 7-4 (5th%ile)	Min EFH Table 7-5 (5th%ile)
Adult	15	50.8	46.2
		Min EFH Table 7-6 (5th%ile)	Min EFH Table 7-7 (5th%ile)
Child 1	4	9.6 – 16	8.8 - 15.3
Child 2	6	18.6 - 26.8	17 - 29.8
Child 3	13	30.7 - 55.9	32.2 - 48.5

Table 1b. Comparing Data in Table I-2 with EFH Data – Body Weight Maximums

Units = kg	Max Table I-2	Max EFH Table 7-4 (95th %ile)	Max EFH Table 7-5 (95th %ile)
Adult	300	106.3	117.5
		Max EFH Table 7-6 (95th %ile)	Max EFH Table 7-7 (95th%ile)
Child 1	50	14.4 – 25.4	13.4 – 26.6
Child 2	200	30.1 – 61.0	29.6 – 60
Child 3	300	67.5 – 92.1	64.3 – 78.1

Note: EFH tables 7-2 and 7-3 are also referenced, but these contain data on means and not the tails of the distributions.

Exposure duration – Table I-2 lists the maximum value set for exposure duration at 100 years – longer than the 70-year lifetime assumption reportedly used for cancer risk comparisons and longer than data in the table referenced (maximum value in EFH Table 15-168 is 57 years).

*Table I-3 Child 3 exposed fruit – I believe there is a typo or calculation error. On page I-3, it reads that the maximum was set at twice the 99th%ile. By my calculation that should be 5.9*2=11.8 g and not 18 g.*

Dr. Donna Vorhees

Cooking and Preparation Loss. Cooking and preparation loss data from USDA (Table 1 in USDA [1975] Food yields summarized by different stages of preparation. Agriculture Handbook No. 102*. U.S. Department of Agriculture, Agricultural Research Service, Washington, DC) could have been used to define distributions for this variable. This publication is the source for the mean net cooking loss, mean net post-cooking loss, and mean paring and preparation loss (for fruits) values reported in Tables 13-6 and 13-7 in EPA's 1997* Exposure Factors Handbook*.*

The exposure durations and averaging times are aligned. The PRA allows for variability in body weight, and some toxicity values might incorporate a body-weight assumption of 70 kg. If so, I doubt that this inconsistency would have much influence on risk estimates.

Response:

The Authors describe how stochastic or distributed input data for each exposure factor were collected and processed in Appendix I, Section I.2.2. Exposure-related parameter values were updated with data from the *Child-Specific Exposure Factor's Handbook* (CSEFH; U.S. EPA, 2008b) and the 2011 update to the *Exposure Factors Handbook* (2011EFH; U.S. EPA, 2011). These data (i.e. from the CSEFH and 2011EFH) were used to fit distributions for Monte Carlo analysis as described in this section. The minimum and maximum values are based on the methodology developed for the 3MRA modeling system and, because the CSEFH and 2011EFH data were used in fitting the distributions, the minimum and maximum values should not exactly match those presented in the CSEFH and 2011EFH. Appendix I has been revised to ensure that the basis for the minima and maxima is made clear. Similarly, the appendix discusses the basis for the exposure duration distribution (see U.S. EPA, 2000) and corrects the typographical error identified by the commenter for the exposed fruit maximum value. The Authors used the recommended EPA values for cooking and preparation losses.

The Authors agree that the inconsistency in using health benchmarks derived assuming a 70 kg adult with variable body weights does not have a significant effect on the risk estimates. This is a widely acknowledged issue in the PRA.

f) Child-Specific Exposure Factors Handbook Not Used

Dr. Mary Fox

Section 5.3.6.2, page 5-15, Exposure Model Inputs

The Authors should consult Child-Specific EFH to ensure they are using the currently accepted values for child intakes, etc. (In many cases, the data in the 1997 and more recent Child-Specific EFH may be the same.)

Dr. Donna Vorhees

*More important, the risk assessment makes no reference to EPA's most recent guidance for evaluating childhood exposures (*Child-Specific Exposure Factor's Handbook*, September 2008, Final). All analyses should be re-visited and updated as appropriate after considering the relevant data, analyses, and recommendations in this guidance document.*

Body Weight. The Authors use body-weight data from EPA's 1997 Exposure Factors Handbook*. Body-weight data representative of the U.S. population have been collected more recently as part of the CDC's NHANES study. EPA developed distributions for children through age 21 using NHANES data from 1999-2006 (See Chapter 8 in EPA's 2008* Child-Specific Exposure Factors Handbook*). Additional NHANES data could be obtained to evaluate adults.*

Soil Ingestion. The Authors define soil ingestion with point estimates, but distributional information is provided in EPA's 1997 Exposure Factors Handbook. *as well as the 2008* Child-Specific Exposure Factors Handbook*.*

Response:

The Authors agree that new child-specific exposure data are now available. Also, in 2011, U.S. EPA published an update to the Exposure Factors Handbook (U.S. EPA, 2011). As discussed in 6e above, exposure-related parameter values used in this assessment have been updated to reflect data in the CSEFH and 2011EFH. Modeling was rerun and the report was modified accordingly.

g) Data Collection Uncertainty

Dr. Mary Fox

Page 2-24, Discussion of TCLP and SPLP

Usefulness of data "unresolved" potentially not representative of complex soil mixture settings. Is this an important uncertainty to include in uncertainty discussion? Is there any further information about this uncertainty (e.g., are the data expected to over- or underestimate contaminant concentrations from leaching in more complex settings)?

Dr. Charles Harvey

I found the writing and organization in this section reasonably clear. The discussion of uncertainties should be broadened to include important uncertainties that are very difficult to assess from the available data. The section should discuss uncertainty associated with using 43 SFS samples to represent all SFS that would be provided by

> *large-scale projects. The report section should also highlight the possibility of organic contaminants not considered in the assessment.*

Response:

The Authors acknowledge that calling the usefulness of leachate data "unresolved" may confuse readers. With respect to TCLP and SPLP, the Authors meant to say that simple leach tests cannot capture actual leaching behavior under every conceivable set of conditions. The Authors do not regard this as a significant source of uncertainty; however, because the aggressive leaching conditions of TCLP and the acidic conditions represented by the SPLP provide conservative estimates of the leaching potential relative to the typical environmental conditions for the use of SFS manufactured soils. For example, the home gardener would adjust the soil pH to near neutral as a normal part of growing home produce. The Authors have added the following paragraph to Section 2.5.4 to address this concern:

> "The TCLP and SPLP represent standard tests that are widely used by the EPA and other regulatory agencies to evaluate the potential for constituent release into the subsurface. With few exceptions,[14] the aggressive conditions used in the TCLP described above are thought to provide a very conservative screen for leach potential. The scenario that the TCLP mimics, however, is not representative of SFS use in manufactured soil because the level of acidity will overestimate constituent release. In addition, the organic component of manufactured soils (e.g., composts, peat moss, pine bark, biosolids) would likely sorb elements released from the molding sand (Basta et al., 2005; Kumpiene et al., 2008). The SPLP conditions that mimic acid rain are more relevant than TCLP for evaluating the conditions considered in this report.
>
> [14] Recent research indicates that the TCLP may not provide an adequately conservative test for arsenic in mature landfills characterized by alkaline pH, low redox potential, biological activity, long retention time, and organic composition of mature landfills (e.g., Ghosh et al., 2004)."

Concerning sample representativeness, a discussion is provided above under 3.d. Also, the Authors have added the following sentence to Section 6.8.2 (Uncertainty Characterization, State-of-the-Science on SFS), in a paragraph regarding the representativeness of available SFS data.

> "Nevertheless, it is unknown if the SFS samples from these 39 foundries are statistically representative of SFS from all iron, steel, and aluminum foundries. The related data may, therefore, overestimate or underestimate the range and distribution of SFS constituent concentrations."

Finally, the Authors have added the following text to Section 2.5.3 to address the potential for additional organic contaminants.

> "While every effort was made to target the widest range of organic constituents that are of concern from an environmental and human health standpoint, it is possible that additional non-hazardous and hazardous organics were present in the SFSs and not addressed in this risk evaluation."

h) Toxicity Value Uncertainty

Dr. Mary Fox

Page 4-3

Split Table 4-1 into sections for cancer and non-cancer benchmarks —add the health effect of concern for non-cancer benchmarks

Dr. Donna Vorhees

Except for lead and its associated CDC benchmark blood concentration, chemicals of concern selected in the assessment do not have toxicity values that are specific to susceptible subpopulations (e.g., PAH age-dependent adjustment factors). However, the Authors should discuss the potential for increased susceptibility among certain subpopulations in general, how they checked for this potential in evaluating risk from use of SFS in manufactured soil and other applications, and the results of their evaluation.

Toxicity Values. EPA's PRA guidance:

> "does not propose probabilistic approaches for dose-response in human health assessment and, further, discourages undertaking such activities on a site-by-site basis" (EPA 2001).

I assume that this is why EPA chose not to quantify uncertainty in toxicity values. But EPA should at least discuss uncertainty associated with chemical toxicity values in the risk assessment to facilitate interpretation of risk results.

Response:

With respect to Dr. Fox's request that Table 4-1 be broken down into cancer and noncancer with health endpoints listed, the table has been modified.

Toxicity values were chosen based on the Office of Solid Waste and Emergency Response (OSWER) hierarchy (OSWER Directive 9285.7-53). The Authors acknowledge that toxicity values are developed with uncertainty factors that account for variability among humans. While this is not a perfect substitute, they are designed to account for sensitive subpopulations. A discussion on uncertainty associated with chemical toxicity values has been added to Section 6.8.1 to facilitate interpretation of risk results. Further discussion of sensitive subpopulations is given in 4.c, above.

i) Consumption Rate Uncertainty

Dr. Mary Fox

I could not locate the data on fraction of home-grown produce grown in manufactured soil (home gardener scenario). This information is key to evaluating the conservatism of this scenario.

Regarding the produce consumption modeling, the assessment uses consumption rate data from national surveys conducted in the late 1980s —this information is dated but remains in use.

Gardeners will grow produce that they like and will consume it in season, as well as preserve it in various ways to be eaten in winter. Further, the probabilistic model inputs include no intake (minimums of 0 grams). The Authors do make a good point that a home gardener may not grow all five of the produce types, but likely grow 4 of the 5 types. Another key consideration in evaluating the home gardener scenario is the fraction of produce assumed to be home grown. I could not locate that number, so my evaluation of the conservatism of this scenario is incomplete.

Dr. Donna Vorhees

Assumption that the Consumption Rate for Homegrown Produce is ½ the General Population Consumption Rates. This assumption is too simplistic. EPA (1997) provides some seasonally corrected consumption rates. Even where such adjusted data are not available, one can estimate adjustment factors that can be used to estimate seasonally adjusted consumption rates (See Section 6.5.6.2 in Volume 5 of EPA's 2005 Baseline Human Health Risk Assessment for the GE/Housatonic River Rest of River.*)*

Homegrown Produce Consumption Rates. A particular strength of this assessment is its reliance on recent research regarding plant uptake of metals for soil amended with SFS. Unfortunately, this research is ultimately combined with consumption rate data for home-produced food that is nearly 20 years old. EPA (1997) cautions those who use these data that they may be outdated, but the Authors of this assessment are silent on this topic. Unfortunately, I am not aware of more recent, systematically collected consumption rate data for home-produced food that are representative of the U.S. population. However, I have attached a recent National Gardening Association (NGA, 2009) white paper that suggests that home gardening is on the rise. I am not familiar with the NGA survey beyond this report and cannot attest to its accuracy. Plus, it looks forward rather than backward in time and does not provide consumption rate data needed to quantify exposure. However, findings from the report mirror a trend that I've observed anecdotally in the northeast and suggest that the uncertainty associated with 20-year old consumption rate data warrants at least some discussion in the assessment. The Authors refer to the consumption rates as "conservative" based on comparison to a 1993 USDA risk assessment, but this comparison is irrelevant. In addition, the Authors argue that

> "In the probabilistic modeling conducted for this assessment, the total consumption rate of home-grown fruits and vegetables for the adult at the 90th percentile risk level was approximately 500 g (WW) d^{-1} for an average adult. In addition, it is not possible to harvest most garden crops for more than a short period when the crop is ripe, which considerably limits potential exposure to garden foods. Given the size of the garden required to support such a diet, the costs of delivering SFS would likely reduce the actual exposure to manufactured soil containing SFS by several orders of magnitude due to the limited garden area. Thus, the results of the home gardener risk screening modeling should be considered as a significant overestimation of the actual risks associated with SFS use."

The NGA white paper reports that the average size of a home garden is 600 square feet and that a well-tended garden produces ½ pound of produce per square foot, or about 300 pounds per year. This equates to about 380 g/d for a 1-person household or about

> *90 g/d for a 4-person household. Again, these quantities are based on mean garden size, not upper-percentile garden sizes, and they do not include consumption of produce grown on other agricultural land where SFS might be used. I imagine authors from the USDA would have additional and perhaps better sources of data to estimate this quantity, and I strongly recommend that this discussion be included. Consumption should also be described in terms that people understand. For example, the 90th percentile consumption rate of 500 g/day corresponds to 2 or 3 garden tomatoes per day. (Note: the garden size assumed in the assessment is 111–180 acres, while the NGA [2009] reports that 6% of home gardens are greater than 2,000 square feet without specifying a maximum value. Nevertheless, as the Authors note, their assumption of garden size greatly overestimates the size of home gardens.)*
>
> *Future assessments of SFS or other materials proposed for beneficial use should extend beyond research regarding environmental mobility and uptake and include studies to improve our understanding of important human exposure variables, such as consumption rates of homegrown produce.*

Response:

With respect to the fraction of homegrown produce grown in manufactured soil, the Authors have modified Section 3.1.4 to be clearer about the scenario.

> “Although manufactured soil could be used in corporate and residential landscaping (e.g., resurfacing construction sites), the home gardener would potentially receive a much higher exposure to SFS constituents under the following assumptions
>
> - The home gardener incorporates a significant amount of manufactured soil into the home garden
> - The home gardener frequently works in the garden, thereby increasing the opportunities of dermal contact and incidental ingestion of SFS manufactured soil, and
> - A significant portion of produce consumed by the home gardener would be taken from the garden consisting of SFS manufactured soil.”

With regards to the fraction of produce assumed to be homegrown, the Authors point to Sections 5.3.6.1 and 5.3.6.2, pages 5-14 through 5-15, of the original risk assessment. There, it is stated

> “Exposure through the ingestion route was estimated by multiplying the concentration of the constituent in the soil or food item by the consumption rate of the individual. […] USDA was concerned that the distributions used to estimate consumption rates might result in overly conservative consumption rates of home-grown produce. To further investigate this, two additional sets of runs were added for comparison: one using point estimates of 50th percentile annual produce consumption rates for the general population, multiplied by 50% to account for crop growth periods and climate limitations to crop harvest periods (reducing the effective consumption rate to home grown produce); and a set of runs using the 90th percentile annual produce consumption rates for the general population, similarly multiplied by 50%.”

U.S. EPA (2011) provides "homegrown consumption" rates that represent the quantity of produce consumed from the home garden. This may or may not represent 100% of total consumption of these items, but clearly represents the amount of home-grown produce consumed. Thus, the issue of "proportion" regarding the amount of produce consumed from the home garden is not relevant; these consumption rates represent the amount of produce grown in the home garden that is consumed; that is, the consumption rates are specific to the fraction of the diet that is from the home garden and do NOT reflect total consumption of produce. The consumer could be eating additional produce from other sources, but, because the scenario is defined for home grown gardens and not commercial gardens, additional exposure to constituents in SFS is presumed not to occur (i.e., the person is assumed NOT to collect and eat a significant amount of produce from other home gardens). The Authors have revised the bulleted text description of the three sets of modeling runs in Section 5.3.7.2 to clarify this point, as follows:

- "**Set 1:** Home gardener, modeled distributions of consumption rates (for home gardeners) – the produce consumption rates specific to home grown produce;
- **Set 2:** General population, 50th percentile (for the general population) consumption rates – the median produce consumption rates for the general population were multiplied by 0.5 to derive a value specific to home grown produce; and
- **Set 3:** General population, 90th percentile (for the general population) consumption rates – the high end produce consumption rates for the general population were multiplied by 0.5 to derive a value specific to home grown produce."

Dr. Vorhees suggests that an alternative to the 50% home-grown rate used for the general population scenarios would be to estimate seasonally adjusted consumption factors as was done in U.S. ACE and U.S. EPA (2005). However, for a screening-level risk assessment intended to support decisions involving SFS across a significant portion of the contiguous United States (see Figure 3-5), the use of seasonally adjusted consumption factors would introduce additional uncertainty and provide little value given the level of resources required to develop seasonal consumption rates, modify the model code to derive seasonal estimates for biotransfer factors, and re-run the simulations. The Authors believe that the use of empirical soil-to-plant biotransfer factors for broad categories of produce (e.g., exposed vegetables) represent a much greater source of uncertainty than the simple 50% adjustment provided by USDA to support a comparative set of modeling runs. More importantly, EPA continues to recommend the use of EFH2011 data in the absence of newer study data. In fact, an earlier trend analysis that used data from the state-based Behavioral Risk Factor Surveillance System (BRFSS) found that fruit and vegetable consumption by American adults was essentially unchanged from 1994 through 2000, and that a low proportion of Americans ate five[3] or more fruits and vegetables per day (Serdula et al., 2004). As discussed in the problem formulation, the purpose of the screening risk assessment was to evaluate the potential for adverse health and ecological effects associated with the use of SFS in specific manufactured soil applications (e.g., incorporation into home gardens). The Authors acknowledge that there are sources of uncertainty in the screening risk assessment

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[3] This equates to approximately 400 grams per day for an average adult.

(as with any risk assessment) and that additional data development activities and modeling could be performed to reduce those uncertainties. However, the Authors would like to emphasize that the assumptions and parameterization of the model were intentionally conservative to ensure that potential risks would *not* be underestimated. Thus, additional activities would only be undertaken if they materially improved the quality of the information used to support the decision-making process for the states. The Authors firmly believe that the screening level risk assessment is appropriately conservative (i.e., fit for purpose) to support defensible conclusions regarding the use of SFS in manufactured soils.

Regarding Dr. Vorhees' suggestion of the National Gardening Association 2009 white paper as a useful reference, the Authors appreciate the suggestion and have used the suggested paper to inform modifications to the home garden conceptual model (see report Section 5.2.1).

Finally, as discussed in 5.d above, the Authors have replaced the phrase "significant overestimation" with the phrase "as an overestimate" in the revised document.

j) Cumulative Risk

Dr. Mary Fox

Section 4.1, page 4-1

More justification is needed to support separate (not cumulative) evaluation of pathways. Inhalation and ingestion – what are the critical health effects underlying health benchmarks for each constituent of concern for each route of exposure? Ingestion: What is known about leaching to groundwater? How long does it take? Quantify/describe the difference in time-scale. Inhalation and ingestion in combination would also seem plausible for residents near a soil blending plant.

Section 4-4, page 4-11

Some SFS constituents do not have tox benchmarks (so they are not included in the assessment) – is this discussed as possible source of underestimation of risk in limitations or uncertainty section?

Dr. Charles Harvey

Page ES-3, paragraph 2

The assessment should document the claim that inhalation and ingestion cause different health impacts – I was not aware that this is true across the range of contaminants considered here. Furthermore, the effects of ingestion on different time scales could be cumulative. For example, I am unaware of any research that indicates arsenic ingestion over different timescales is not cumulative. I suspect that rapid exposure from produce followed later by exposure from groundwater could be cumulative.

The assessment should document the claim of independence of ingestion pathways. I am not aware (across the range of contaminants) that inhalation and ingestion cause different health impacts (e.g., lead?). Furthermore, the effects of ingestion on different time scales could be cumulative, so groundwater and produce may not be independent pathways. For example, I am unaware of any research that indicates arsenic ingestion over different timescales is not cumulative.

Dr. Donna Vorhees

I assume that "appropriately conservative" means that cumulative noncancer hazard indices do not exceed 1 and cumulative cancer risks do not exceed 1E-5 for any receptors. In all likelihood, the screening steps were appropriately conservative, but, as explained in response to charge questions #1 and #6 [see comments below], the Authors should clearly and succinctly document quantitatively how screening steps throughout the report ensure that SFS use will not be associated with cumulative risk levels of concern.

Specifically, demonstrate briefly but quantitatively why SFS use is not associated with cumulative risk levels of concern despite:

1. *Screening out chemicals that were never detected (this step should not be problematic because the authors checked for and addressed detection limits that exceeded screening levels),*
2. *Screening out chemicals that do not have health benchmarks,*
3. *Assuming independence among some exposure pathways (exception is the evaluation of cumulative ingestion exposure to soil and homegrown food),*
4. *Applying the target hazard index of 1 to single chemicals associated with each exposure pathway despite the fact that each exposure pathway involves exposure to chemical mixtures,*
5. *eliminating some exposure pathways from quantitative evaluation (e.g., dermal contact with soil and groundwater and inhalation of fugitive dust [although predicted soil screening concentrations for the dust pathway are sufficiently high relative to SFS concentrations that this pathway should not contribute negligibly to cumulative risks]),*
6. *Use of 95th percentile concentrations instead of maximum detected concentrations to screen for chemicals of concern (it is common practice in EPA's Superfund program to use the maximum detected concentration for this purpose, but practices might vary among different federal and state programs), and*
7. *assuming that the groundwater ingestion pathway did not require further evaluation because estimated exposures for five modeled constituents were below EPA's MCLs [While this assumption may be practical, MCLs are not all necessarily risk-based].*

This comment is related to the graphic suggested in response to charge question #1. More attention needs to be paid to the concept of cumulative risk, referencing relevant EPA guidance (e.g., U.S. EPA 2000, 2003, 2007).

The Authors assumed independence of groundwater, soil, and fugitive dust exposure pathways for the following reasons: "Each of the three pathways listed above was evaluated through a screening model to see if any pathway (or alternatively, any constituents) could be eliminated from further analysis. It is important to note that these pathways are likely to operate individually on a human receptor, not cumulatively. First, inhalation of materials will generally cause different health impacts than ingestion of those materials. Therefore, the inhalation pathway should be evaluated separately from the ingestion pathways. Second, exposures via groundwater ingestion occur on a significantly different time-scale from ingestion of produce and soil. Thus, the groundwater pathway can also be evaluated separately. Given the individual nature of these pathways, they were each evaluated in turn." The Authors provide no justification for assuming that the fugitive dust pathway and ingestion pathway for soil should be

> *separate. Would one really expect different health effects for the COCs in this assessment? What about the fraction of fugitive dust that is ultimately ingested rather than inhaled (i.e., that fraction that enters the airway and is cleared via the mucociliary escalator before entering the gastrointestinal tract)? I will leave it to those who are expert in groundwater modeling to comment on the timescales, but it seems that exposures to SFS in groundwater and soil could occur at the same time and place if SFS-containing materials are used in the same place over time.*

Response:

The Authors acknowledge that some chemicals may interact in a mixture, causing different health outcomes than would result from individual exposures. Additionally, the Authors acknowledge that individuals may be exposed to the same chemical through multiple pathways. Since additive risk across constituents and pathways is a possibility, the Authors have addressed each of the commenters' concerns below, beginning with Dr. Vorhees' seven enumerated points.

Regarding Dr. Vorhees' first point, that constituents were screened out when not detected, the Authors point out that these constituents were addressed when the detection limits exceeded screening levels.

Dr. Vorhees' next point concerns chemicals that do not have health benchmarks, a comment echoed by Dr. Fox. The Authors note that EPA continually strives to assess health benchmarks for a growing array of constituents and mixtures. However, without further toxicological work, which is beyond the scope of this assessment, the Authors cannot evaluate risks from these constituents and mixtures. The Authors have modified the language in several places to transparently state the limitations of the assessment, including the quantitative evaluation only of those constituents for which benchmarks are available, and to explicitly state the uncertainty inherent in this limitation. The Authors have also added the following text to Section 5.3.8.1:

> "The exposure scenarios and pathway evaluations were developed to produce highly conservative estimates of risk; that is, the methodology was designed to overestimate the actual risk to ensure that an ample margin of safety was built into the analysis."

The third potential concern Dr. Vorhees raises, as does Dr. Harvey, is the Authors' assumption of independence across exposure pathways. EPA agrees that the rationale in the report does not adequately explain the relevance of focusing on three basic pathways, and why cumulative risks were not fully evaluated. The Authors have modified which Soil Screening Levels (SSLs) are used in Phase I: The assessment now uses Residential SSLs that, on a constituent-specific basis, can address two or more exposure pathways (i.e., in addition to soil ingestion, they can also address dermal exposure to soil, inhalation of fugitive dust, or both). Also, additional analysis was performed, and documented in report Section 5.3.5.3 and Appendix J, demonstrating that surface pathway exposures and groundwater exposures would not occur in the same time-frame. Refined modeling therefore did not aggregate surface pathway and groundwater exposures. The Authors have revised several sections in the report to clarify how the assessment addressed cumulative risks in Phase I, while focusing Phase II modeling on three basic exposure pathways identified during the development of the exposure scenarios (as shown in the conceptual models). To summarize

> Phase I screening used the SFS data and available screening criteria and models to determine which constituents, if any, should be considered for probabilistic risk modeling. Inhalation exposure and groundwater exposure were screened individually. However, soil pathways screening also included dermal and inhalation exposures, to the extent that constituent-specific data were available. If the constituent failed any one of the screening steps, it was subjected to a more rigorous modeling approach to further screen the constituent on the basis of potential health or ecological risk. Even aggregating exposures, Phase I screening demonstrated that no constituents required refined inhalation or dermal modeling. Phase II modeling focused, therefore, on human exposure via incidental soil ingestion and ingestion of home-grown produce, and ecological exposures via direct contact. Additional analysis demonstrated that groundwater exposures and surface pathway exposures would not happen in the same time-frame, and these exposures were therefore evaluated separately.
>
> Although some constituents can elicit similar toxicological responses (e.g., neurotoxicity), neither the screening nor the modeling stages of the analysis aggregated exposures across multiple constituents. The Authors consider the overall design of the assessment sufficiently conservative as to make further assessment of cumulative risk unnecessary. For example, the exposure scenarios and pathway evaluations were developed to produce highly conservative, reasonable maximum exposure estimates of risk, to ensure that an ample margin of safety was built into the analysis. This approach ensures that the results of this analysis can be used to confidently determine if soil-related uses of SFS will be protective of human health and the environment. The risk assessment is therefore an efficient approach to providing decision makers with information on the potential for adverse effects to the most highly exposed individuals and ecological receptors that could come in contact with SFS constituents.

Dr. Vorhees is correct in her next point, assessing that exposures modeled in this assessment are chemical mixtures, and not individual chemicals. Although HQs of 1 are only for individual chemicals, the quantitative human health benchmarks available to the Authors are also based on the toxicity of individual chemicals. Thus, without the further research into risks of combinations of chemicals, this approach will continue to pose the potential to underestimate or overestimate risks. This uncertainty is now discussed in more detail in Section 5.3.8 Human Health Effects Modeling. Additionally, the Authors note that it is possible for one foundry sand to have higher concentrations of constituent A and lower concentrations of constituent B when compared to another foundry sand. This creates difficulty in conducting a unitized model effort and developing screening levels for individual constituents as was done here.

The fifth point in Dr. Vorhees' list of cumulative risk considerations is that the Authors do not include dermal and inhalation exposures in cumulative risk estimates. However, as the commenter correctly points out, the inhalation screening values are orders of magnitude higher than those for ingestion, and thus are unlikely to contribute significantly to overall risk. Also, as discussed in Section 4f, the Authors have performed additional screening evaluations of dermal exposures which, like the inhalation evaluation, included screening values at least an order of magnitude higher than those for ingestion.

The next suggestion Dr. Vorhees proposes is that the Authors use maximums instead of 95th percentile concentrations. The Authors first point out that maximums were used for dioxins, furans, and PCBs, and that maximums for all elements are presented in the final summary tables alongside the 95th percentile. For the remaining constituents, many were not detected in any sample, and thus would not have changed the evaluation. For those constituents that were detected but passed the screen at the 95th percentile, only one would not have passed the screen at the maximum. Zinc would have failed for ecological risk (123 mg kg^{-1} versus an EcoSSL of 120 mg kg^{-1}). However, as discussed in report Appendix C, a zinc screening level of 300 mg kg^{-1} is protective of soil fertility. Thus, it would be unnecessary to model zinc.

Dr. Vorhees seventh and final enumerated consideration for cumulative risk is that the potential for cumulative risk in the groundwater pathway should not be screened away by comparing to the MCLs because they are not health-based levels. The Authors agree that MCLs are not necessarily based solely on risk. For precisely this reason, the Authors also compared leachate to tapwater screening levels from the regional screening tables.

The Authors agree with Doctors Fox, Harvey, and Vorhees that greater justification was needed for the assumption that exposures via surface pathways (i.e., incidental ingestion of garden soil, and ingestion of home-grown produce) would not occur in the same timeframe as exposures via groundwater. As discussed in 5c above (and documented in report Section 5.3.5 and Appendix J), additional modeling was performed that validates and quantifies this assumption.

Finally, the Authors wish to reiterate that concentrations of most constituents in SFS are below the same concentrations in naturally occurring soils. Thus, the cumulative risks experienced here would differ very little from those posed by native soils.

k) Clarity

Dr. Mary Fox

I think Chapter 6 contains most of the relevant information to characterize the assessment and put the results in context. However, the clarity is compromised by some organizational issues—there are some sections that appear out of place and some sections that don't seem well integrated into the discussion at all.

Section 6.2, Key risk assessment questions

The fourth question (nutritional health and essentiality) doesn't seem to be directly addressed in the chapter.

Section 6.3.5

This section is not well-integrated into Chapter 6. How does this discussion of highly exposed populations relate to uncertainty or the assessment overall? Does it relate to how ecological risks were evaluated?

Section 6.4

The information in Section 6.4 seems more appropriate as part of the preceding section on Overarching Concepts.

> Section 6.5 through 6.7
>
> *These substance-specific sections are good summaries of the assessment information. I would substitute "Summary" or "Integrated Summary" for "Weight of evidence" because weight of evidence is risk assessment jargon that can mean different things to different readers.*
>
> *The Authors present Section 6.8, Uncertainty Characterization, as a high-level overview for risk managers/ policy makers and therefore do not re-hash assumptions and uncertainties in detail. The information presented is useful; however, as a technical reader, I was looking for more. I would like to see a "Data and Research" section where the Authors comment on data quality, data gaps, and the feasibility/desirability of a validation study or other research needs.*

Response:

The Authors acknowledge that the discussion in Chapter 6 could be clearer. The Authors believe that changes made throughout the report and, specifically, in Chapter 6, improve the clarity and accessibility of information in this chapter. However, the Authors do not believe that additional changes are warranted, as suggested by the following responses.

- While nutritional health and essentiality are not discussed as prominently as the risk results, they do appear throughout the chapter. For example, in Section 6.7.2.4 the nutritional role of manganese is discussed.
- As discussed in 6.a, above, "weight of evidence" has been changed to "lines of evidence."
- The Authors believe that the data quality and data gaps have been examined in detail in the risk characterization and that the risk assessment that was developed to support safe management of SFS in manufactured soils is appropriate and adequate for the purpose. Ongoing work may identify additional research needs as they pertain to other applications of SFS.

7) General/Other

The peer-review comments not related to the previous categories are grouped into four subcategories:

a) Non-Technical Abstract and Public Label;
b) Technical Inaccuracies/Editorial Comments;
c) Application to States; and
d) Risk Assessment versus Risk Management.

a) Non-Technical Abstract and Public Label

Dr. Ken Barbarick

> *The American Foundry Society's request for an Abstract (I would recommend 1 page or less) and their suggested final statement at the bottom of page 2 of their response are reasonable requests. I also support their recommendation to call the material "recycled*

> *foundry sand." This change puts a more positive spin on the nature of the material and how it could be re-used.*

Response:

The Authors agree that an abstract or non-technical summary of this document would be useful. While outside the scope of this report, the Authors will consider providing such a document in the near future.

b) Technical Inaccuracies/Editorial Comments

Dr. Ken Barbarick

> *The American Foundry Society's comments point out some technical inaccuracies concerning the foundry processes and materials that should be corrected.*

Dr. Mary Fox

> Page ES-7
>
> *Statement is made that composition of SFS may reduce bioavailability of lead, but no reference is provided.*
>
> Section 3.1.5, page 3-6
>
> *Assumptions on indirect exposure pathways from temporary storage and use of SFS—reference needed to support the claim about biomagnification*
>
> Page 4-16, Table 4-9
>
> *Adjustment to the SSL should be presented. Why is SSL for lead shaded in gray?*
>
> Page 4-17, first paragraph, sentence 4
>
> *Check spelling for 'arsenic'*

Dr. Charles Harvey

> Page 1-4, paragraph 5
>
> *Needs editing – "… the characteristics of individual metals, such as the soil-plant barrier,..."*
>
> Page 3-13, paragraph 1
>
> *Needs editing – "It was also clear that certain scenarios were more significant in some scenarios than in others."*

Dr. Donna Vorhees

> *The document is generally clear and well-organized, although it would benefit from more succinct text in some places. For example, the statement that SFS is assumed to comprise 50% of manufactured soil appears 11 times in Sections 1 through 5 alone.*

Response:

The Authors acknowledge the technical inaccuracies pointed out by the American Foundry Society and have corrected these in the revised risk assessment.

The statement regarding the biomagnification of chemical constituents in terrestrial food webs refers to the lack of published studies that demonstrate this phenomenon. With the exception of certain persistent organic pollutants, such as dioxins and PCBs, the Authors are not aware of any studies demonstrating biomagnification for multiple trophic levels (e.g., from soil invertebrates up through top predators). The Authors have clarified the related language.

The SSL for lead was not adjusted. Thus, it should not have been gray. The Authors have corrected this error in the revised risk assessment.

The misspelling of arsenic on former page 4-17 has been corrected in the revised risk assessment.

The sentence on former page 1-4 has been edited to be clearer. As discussed previously, the Analysis Plan section 3.2 has been rewritten and the sentence noted on the former page 3-13 is no longer in the document.

Finally, the Authors have attempted to reduce statements regarding the assumption that SFS make up 50% of the manufactured soils modeled.

c) Application to States

Dr. Ken Barbarick

The report submitted by the Michigan Department of Environmental Quality studied the data for possible impacts and concluded that the material possibly could be used with restrictions. I believe the report actually adequately addressed the issues raised by the Michigan Department of Environmental Quality.

Dr. Donna Vorhees

The PRA modeling steps are generally appropriate to develop national-scale screening values. However, more work is needed to comply with EPA recommendations for PRA documentation and EPA's most recent recommendations for evaluating children's exposure. In addition, the Authors should consider adding a section that explains how states might modify the analyses to incorporate state-specific information, thus reducing the uncertainty in applying results of a "national-scale" model to specific locations.

Application of National-Scale Screening Values and PRA to Individual Regions/States. The assessment accounts for variability in chemical mobility in the environment and in soil background concentrations across the United States. This accounting of regional variability is essential for a national-scale analysis. To provide states with as much flexibility as possible in applying findings in a manner that ensures compliance with their own risk management goals, the Authors could include a section explaining how states could substitute their own data (e.g., soil characteristics and chemical concentrations) into the PRA model and other screening models.

> *In addition, some states have defined soil background concentration data sets that could be presented in this assessment along with the SFS data, USGS data, and other data briefly discussed in Section 6.8.2, item #2 (e.g., see "Background Levels of Polycyclic Aromatic Hydrocarbons and Metals in Soil" at http://www.mass.gov/dep/service/compliance/riskasmt.htm).*

Response:

The Authors acknowledge that a site-specific or state-specific risk assessment could be conducted for the beneficial use of SFS in the future. Including guidance on how states could use the methodology to conduct state-specific evaluations is beyond the scope of this report. However, by being as transparent as possible in describing the methodologies and data used in this assessment, it was the Authors' intention to facilitate future application of the methodology by other interested parties. For example, the Authors point to the fact that states can easily use totals sampling and leachate testing to compare their actual SFS to the 95th percentiles that were found not to pose excess risks in this report. In addition, as Dr. Vorhees correctly points out, some states have already developed state background soil levels for comparison. While the Authors encourage states to make use of the best, most specific data available to them, and will continue to assist states in future analyses, such work is outside of the scope of this document. However, as described in 7.d, below, this may be addressed through a non-technical fact sheet and training.

d) Risk Assessment versus Risk Management

Dr. Ken Barbarick

> *The EPA Region 9 comments point out the mixing of Risk Assessment and Risk Management approaches. I agree that this needs clarification and the report should focus on Risk Assessment.*

Dr. Charles Harvey

> *The study arrives at a strong conclusion (ES-8): "…no evidence was found that the specified uses of non-olivine SFS produced by iron, steel, and aluminum foundries evaluated in this report could pose significant risks to human health or the environment when used in manufactured soils, soil-less media, or road base." This statement (and other statements) is more than objective descriptions of the risks of using SFS; it is a value judgment about whether the risks of the anticipated uses of SFS are acceptable. As such, the conclusion combines both a quantification of the risks and an assessment of whether these risks are acceptable. The document would be easier to follow if clearly separated these two steps. However, I was not convinced that the study fully considered the second step, the judgment that risks are acceptable. For example, would the risks be acceptable under all types of SFS use? Is the choice of the 90-percentile risk appropriate, or should risks in the top decile, that are potentially much higher, also be considered? Do the risks need to be weighed against the benefits?*
>
> *I think the document would be easier to follow, and would remain just as valuable, if it simply stated the purpose of providing a good assessment of the risks and then adhered to this narrower purpose.*

Dr. Donna Vorhees

> *There is a tone of advocacy at several points in this document that are not typically found in risk assessments, nor are they helpful as they stray from the topic at hand. For example: "Given their inherent properties and low cost, SFSs present a significant opportunity for the manufacture of soil and soil-less media" (Page 3-4). From a technical perspective, it appears that the work was performed in a scientifically objective manner, but such statements do not instill confidence that the risk evaluation was conducted objectively in the minds of those who are unfamiliar with the details of the technical evaluation. I suggest that the Authors consider deleting them.*

Response:

The Authors have modified several sentences in the report that could be interpreted as evidence that the analysis was not performed in a scientifically objective manner. However, it should be pointed out that the analysis was intended to provide an objective description of *all* properties and characteristics of SFS, including those that can be valuable in soil manufacturing and application.

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Appendix A:

IWEM modeling review, alternate model search, and recommendations for evaluating the SFS home garden scenario groundwater pathway

Appendix A) IWEM modeling review, alternate model search, and recommendation for evaluating the SFS home garden scenario groundwater pathway

A1.0 Background

The Peer Review Draft Spent Foundry Sands (SFS) evaluation used EPA's Industrial Waste Evaluation Model (IWEM) to estimate human exposure to contaminants leached from a SFS-amended home garden via contamination of groundwater in a nearby drinking water well.[4] IWEM was chosen because it is a peer-reviewed, publically available model that has successfully supported regulatory decisions, and it can model a waste management scenario that is similar to the SFS home garden scenario. Specifically, IWEM's land application unit (LAU) waste management scenario had been run as the waste management scenario most similar to the SFS home garden scenario.

External peer-review comments on the draft SFS evaluation led EPA test the IWEM-generated SFS home garden scenario receptor well concentration estimates. This subsequent testing raised the concern that the choice of the LAU waste management scenario, and input parameter values used when modeling the LAU scenario (e.g., waste management unit operating life), may have underestimated closest well concentrations for the SFS home garden scenario. It was also possible that IWEM was not the most appropriate model: another model may more accurately estimate closest groundwater exposures in the SFS home garden scenario.

A2.0 Purpose and Objectives

To address these concerns, EPA first conducted a thorough review of the groundwater exposure modeling performed for the Peer Review Draft SFS evaluation, to fully understand the implications of input parameter choices used when implementing the LAU waste management scenario. Second, EPA compared the various waste management scenarios available within IWEM (i.e., in addition to LAUs, IWEM is able to model landfills, surface impoundments, and waste piles), including input parameter choices, to identify which scenario and input parameter choices would most accurately estimate groundwater exposures for the SFS home garden scenario. Third, a search was conducted to identify whether there are any peer-reviewed and publically available groundwater models, of good standing in the regulatory arena, which could be used to more accurately represent the SFS home garden scenario groundwater exposure pathway in a national-scale assessment.

This appendix presents the evaluation findings and recommends the most appropriate model and approach to evaluate the SFS home garden groundwater pathway. **Section A3** discusses in detail the review of the Peer Review Draft SFS IWEM modeling, and comparison of IWEM waste

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[4] IWEM supports two levels of analysis: Tier 1 (a screening-level analysis using default data values based on national distributions for many parameters) and Tier 2 (a site-specific analysis based on location-adjusted values for the most sensitive waste- and site-specific parameters). The SFS evaluation was based on Tier 2, using three locations to represent variability in meteorological conditions. Thus, "IWEM" in this memorandum refers to that Tier 2 analysis.

management scenario options. **Section A4** discusses the models identified and considered as alternatives to IWEM. Based on results of the review, scenario comparison, alternative model search, IWEM remains the preferred model for supporting the SFS assessment. **Section A5** provides the recommendations on how best to estimate receptor well concentrations for the SFS home garden scenario.

A3.0 Review of SFS home gardener scenario modeling, and IWEM waste management scenario comparison

The numerical engine for IWEM is EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP). The review of the Draft SFS Risk Assessment groundwater exposure modeling included analyzing how IWEM employs EPACMTP to model the LAU scenario. This analysis uncovered a number of differences between the SFS home garden scenario and IWEM's LAU scenario. To develop a better understanding of key underlying IWEM modeling assumptions and limitations, EPA investigated a number of critical modeling choices (i.e., inputs and options available in IWEM) and issues identified by EPA, including:

1. **Well Under Garden Scenario:** The residential receptor well closest to the SFS home garden could arguably exist under the home garden, which IWEM does not allow. The SFS evaluation initially placed the well 1 meter from the edge of the garden, the smallest distance to the receptor well that IWEM allows.

2. **Square Pulse and Conservation of Mass:** The Draft SFS risk assessment assumed that the SFS would be applied in a single application and remain in the home garden (with SFS constituents available for release), so that contaminant mass would be released until all of the available mass had been depleted, and the concentration would presumably lessen over time. In contrast, the LAU implementation in IWEM/EPACMTP assumes that contaminant mass is applied regularly to an area at a constant rate over a finite time period, resulting in a leaching pattern that is constant over the time period and then stops, reflecting the end of land application and depletion or removal of the source (i.e., a "square pulse" source). The IWEM LAU implementation defines the end of this square pulse through a finite "operational lifespan" (with a default of 40 and a maximum of 200 years). In short, the IWEM implementation of EPACMTP models all LAUs as temporary (i.e. "pulse") sources, with a constant leaching concentration during the "operational lifespan," and a leachate concentration of zero for all modeled years after that time.

3. **Operational Lifespan and Timestep:** EPA wanted to better understand how operational life and the initial time step for "testing" receptor well concentrations interact when modeling a pulse source. Specifically, does EPACMTP use the operational lifespan as an initial time step to choose when to "test" receptor well concentrations? When a user specifies the LAU's operational life, does IWEM force EPACMTP to use the default 40-year value as the initial time step regardless of the user's specified value? In this case, EPA wanted to ensure that the peak groundwater concentration does not pass the receptor well before the well is "tested," especially for receptor wells close to the LAU.

4. **1-Year Operational Lifespan:** The SFS evaluation assumed a single application of manufactured soil amended with SFS while constructing a home garden, which was represented in IWEM by assuming an LAU operational lifespan of 1 year. EPA wanted more information on the impacts of this assumption on the model results.

Key components and implications of these issues are addressed in the following sections: the well under the garden scenario (**Section A3.1**); the use of a square pulse and conservation of mass (**Section A3.2**); LAU operational life and initial EPACMTP time step (**Section A3.3**); and how receptor well distance and LAU operational life assumptions interact to influence model results (**Section A3.4**). The analyses presented in these subsections were designed to test whether any of the IWEM assumptions/limitations used in the Draft SFS Risk Assessment modeling, or combinations thereof, could underestimate SFS home gardener receptor well concentrations.

A3.1 Residential Well Under the Garden

The residential well was assumed to be 1 meter from the edge of the unit rather than directly under it. IWEM/EPACMTP does not permit the well to be located under the source, so it is not possible to test this assumption using EPACMTP. However, it is unlikely that this limitation would be associated with a significant difference in predicted well concentrations. Specifically, a well located under the center of a garden would be exposed to less contamination than one at the downgradient edge, because the well in the center would receive contaminated infiltration from only the upgradient portion of the garden instead of all of it. Also, because the well depth was varied during the IWEM SFS runs, there is a good possibility that the well would be exposed to more clean water under the garden at greater well depths than it would at the short (1 m) distance from the edge of the unit, because the plume would not have had time to mix into the aquifer. Therefore, locating the well 1 meter from the edge of the garden is a conservative assumption when compared to locating the well directly under the garden.

A3.2 Square Pulse and Conservation of Mass

One concern with the SFS garden scenario is the apparent disparity in how mass is applied and released when comparing the SFS scenario with the conceptual model of how an LAU is implemented in IWEM/EPACMTP. In the SFS home garden scenario, it is reasonable to expect leachate concentrations to decrease over time after a single application. By contrast, the conceptual model of the LAU in IWEM/EPACMTP uses a “square pulse” LAU source term, in which the leachate concentration remains relatively constant until the source is depleted (when it drops to zero). However, the observed leaching behavior of arsenic, a solubility-controlled constituent, is in many waste disposal environments more consistent with the IWEM “square pulse” conceptual model than the single-application-followed-by-decay scenario posited for the home garden. Furthermore, the “square pulse” LAU source term is a conservative simplifying assumption with respect to establishing screening level criteria for mass loading. Mass can be conserved under the “square pulse” scenario by considering the available mass and infiltration rate to limit the pulse length.

In addition, the nonlinear sorption transport module in EPACMTP, used for metal simulations in the unsaturated zone, applies a similar simplifying square pulse assumption to all source term conceptual models as a trade-off for computational efficiency. Nonlinear transport is a complex computational problem which is compounded when conducting Monte Carlo simulations; a square pulse is a necessary and appropriate simplification to maintain reasonable computational times. Regardless of the characteristic shape of the leachate concentration profile over time, IWEM/EPACMTP would represent the correct total mass loading with an equivalent square pulse. Therefore, the square-pulse assumption is considered a reasonable simplification that does not alter the results significantly.

A3.3 Operational Lifetime and Initial EPACMTP Time Step

IWEM/EPACMTP does not use the operational lifetime of an LAU (or any other WMU) to determine the time stepping strategy for identifying the peak or average concentration at a receptor well during flow and transport simulations. The adaptive aspect of EPACMTP's time stepping strategy is based primarily on the transport simulation results from the unsaturated zone and the fate and transport characteristics of the contaminant. Specifically, the unsaturated zone transport modules generate a time series of concentrations at the water table. That time series captures both the arrival time of the leachate "front" at the water table and the time at which leachate no longer arrives. Those two times are used to define the maximum duration of the contaminant pulse. The contaminant pulse's onset and ending times, in conjunction with knowledge about sorption and decay of the contaminant in the saturated zone, are used to predict when the contaminant will likely arrive at the receptor well and when the plume is likely to pass by that location. The prediction of arrival time is tempered with a safety factor to reduce the risk of predicting an arrival time that is too late, thus missing the peak. IWEM/EPACMTP discretizes the time interval until the predicted arrival time and steps through that time interval linearly to identify the peak concentration. Thus, the likelihood of IWEM missing the peak concentration due to an inappropriately long time step is small, and is unrelated to operational lifetime.

A3.4 Well Distance and Operating Life Assumptions

The remaining issues revolve around the operating life (1 year) and well distance (1 m) assumed for the SFS home garden scenario and how these interact. These variables are connected, and because both of these values are small, they combine to generate a 90th percentile result that is low when compared to results obtained with a higher well distance or a more typical "operating life" assumption (like the default 40 years). For these reasons, these variables were treated together in this analysis, which focused first on well distance at the 1-year operating life and then on the effects of increasing the operating life. Implications for modeling EPA's SFS scenario are then discussed.

IWEM was used to model several well-distance permutations of the SFS home gardener scenario. Results were analyzed graphically and numerically by visualizing and summarizing the peak concentration values for each run. These values are generated as standard outputs during a Tier 2 analysis by IWEM in the *.SAT output file that is generated during each model run. Original *.SAT files were saved along with their associated IWEM run/project files (*.wem and *.mdb). Analyses were performed using the Python programming language and widely used open-source scientific computing libraries.

A3.4.1 Characterize Modeled Exposure Results at Various Well Distances for As^{+3}

IWEM was initially run 23 times, modeling trivalent arsenic (As^{+3}, the primary risk driver for the SFS risk analysis), and varying only the well distance for each run. A list of assumptions and well distances used in this modeling is provided in **Table A-1**. The resulting 90th percentile peak concentrations reported for the 23 runs are displayed in **Figure A-1** and **Table A-2**.

Results demonstrate a rapid increase in concentration with distance in wells less than 5m from the source, with the highest peak concentration occurring at a well distance of 30 m. The 30 m peak concentration is more than 5 orders of magnitude higher than the peak concentration at the 1 m well distance. These results are somewhat counterintuitive, as one would normally expect higher groundwater concentrations closer to the source.

These unexpected results were investigated further by evaluating the well concentrations at different screen depths provided in the IWEM outputs.

Table A-1. Assumptions and Variables Used in Initial SFS Simulations

Parameter Name	**Value**
Source type	Land application unit (LAU)
LAU operational life	1 year
Well distances (m)	1–15 (inclusive, at 1-m intervals), 30, 50, 75, 100, 150, 200, 250, 300
Subsurface environment	Unknown (sets default values for groundwater pH, depth to water table, aquifer hydraulic conductivity, regional hydraulic gradient, and aquifer thickness)
Soil type	Unknown
Location	Seattle, WA
Constituent	Arsenic III, CAS ID 7440-38-2
Leachate concentration (mg/L)	0.0156 (95th percentile of SFS leachate measurements)
Number of Monte Carlo realizations	10,000

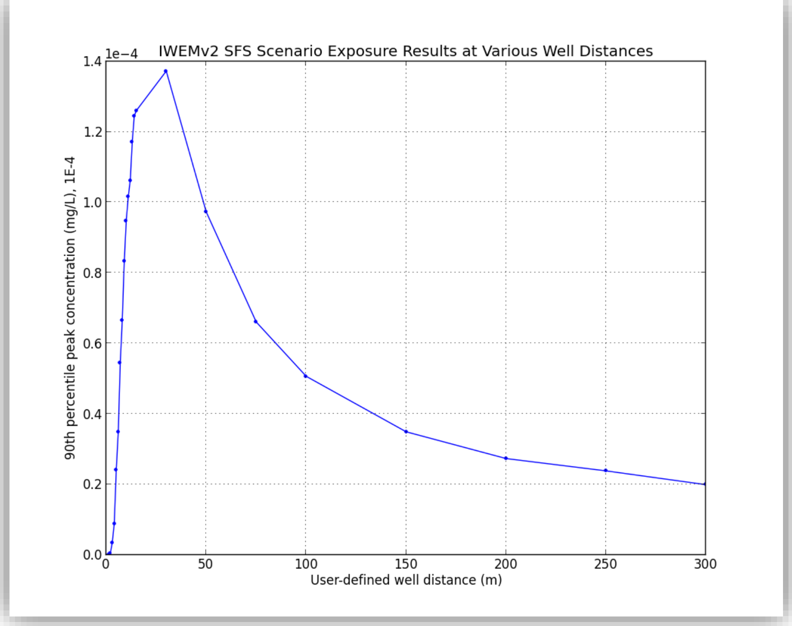

Figure A-1. 90th Percentile Peak Well Concentration with Well Distance: Initial SFS Simulation, Home Garden Scenario, As^{+3}

Table A-2. 90th Percentile Peak Trivalent Arsenic Concentration with Well Distance: Initial SFS Simulation, Home Garden Scenario, As^{+3}

Well Distance (m)	90th Percentile Peak Concentration (mg/L)
1	4.6E-10
2	3.3E-07
3	3.4E-06
4	8.9E-06
5	2.4E-05
6	3.5E-05
7	5.4E-05
8	6.7E-05
9	8.3E-05
10	9.5E-05
11	1.0E-04
12	1.1E-04
13	1.2E-04
14	1.3E-04
15	1.3E-04
30	1.4E-04
50	9.7E-05
75	6.6E-05
100	5.1E-05
150	3.5E-05
200	2.7E-05
250	2.4E-05
300	2.0E-05

Figure A-2 shows eight curves: four depict various percentile statistics of the peak concentration based on the model results for all well depths, while the other four depict the same percentile statistics from the results with well depth constrained to a range of 0 to 4 meters. The key observations are that (1) the 90th percentile values at well distances less than 30 m are significantly lower than the peak concentration values at greater well distances when all depths are considered and (2) this effect does not occur for percentiles of 95 and above or for 90th percentile values constrained to 0–4 m well depths. This suggests that the extremely low concentrations for the lowest well distances occur because the plume has not mixed very deeply within the aquifer, and the random well depth within the aquifer is sampling clean groundwater below the contaminant plume. When only shallow well depths are considered (i.e., 0–4 m), the results follow a continuously decreasing trend with well distance similar to what would be expected in a typical groundwater plume.

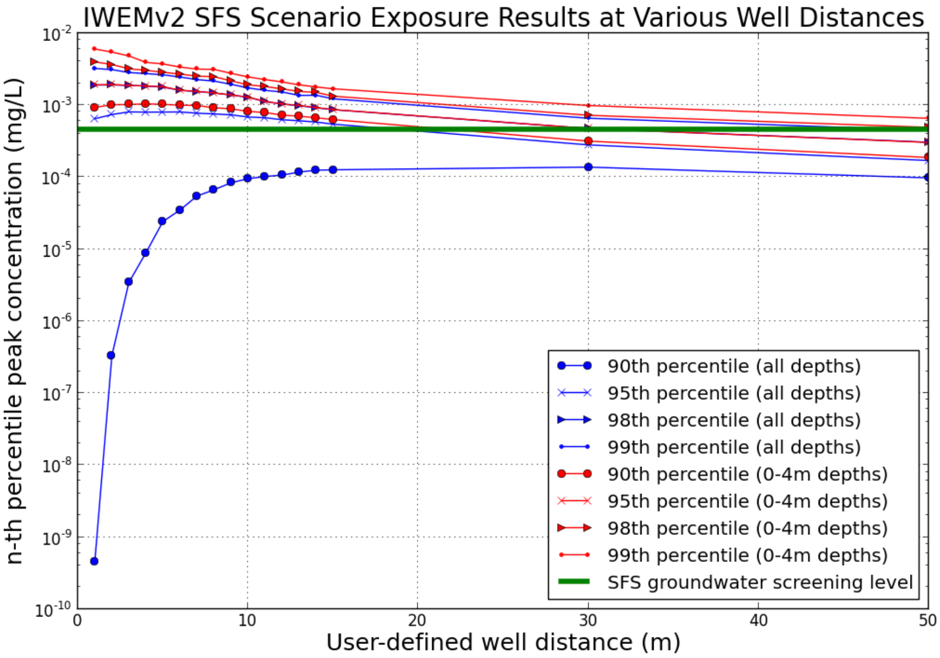

Figure A-2. Effect of well depth on IWEM SFS As^{+3} results for different well distances. (Green line = 4.5×10^{-4} mg/L groundwater screening level.)

Figure A-2 also shows the 4.5×10^{-4} mg/L Tapwater screening level for arsenic (10^{-5} cancer risk) as a green solid horizontal line. Note that the Tapwater screening level occurs in the midst of the groundwater concentrations modeled by IWEM and between the 90th percentile values for all well depths and all other percentile runs plotted in Figure A-2. Most of the values at or above the 95th percentile, in the 0–4-meter depth range, and at a distance of about 20 meters or less from the edge of the unit are above the 4.5×10^{-4} mg/L Tapwater screening level.

A3.4.2 Characterize Modeled Exposure Results for Different Operating Lifetimes and Well Distances for As^{+3}

The EPACMTP LAU model used in IWEM includes a parameter termed “operating life” that is defined in the IWEM User’s Guide (p. 6-12) as “the number of years the WMU is in operation, or, more precisely for the purpose of IWEM, the number of years the unit releases leachate.” The operating life therefore represents the period of time the unit is releasing leachate, which in the case of the LAU, is a single, constant concentration release over time or “square pulse.” The leaching concentration remains constant until all the waste is removed from the unit, at which the leachate concentration drops to zero.

The operating life variable therefore defines the leaching period for the LAU; it does not relate to the number or frequency of waste applications, as EPACMTP does not explicitly model application rate. Therefore, an assumption of a 1-year operating life for the SFS home garden is equivalent to assuming that the SFS-amended soil is removed after one year. This is inconsistent with the SFS home garden scenario: the operation of a typical home garden where soil amendments are left in place in perpetuity after the initial application.

To investigate the sensitivity of the model results to operating life, IWEM also modeled As^{+3} at operating lifetimes close to the 200-year maximum and the 40-year default for this parameter, which are representative of the As^{+3} depletion time, which is 195 years at an initial As^{+3} whole waste concentration close to the 95th percentile and 44 years at an initial concentration close to the 50th percentile, based on percentiles reported for SFS wastes.[5] Results are shown in **Table A-3**,

The home garden was also run as a landfill sized to be equivalent to the SFS LAU (1-acre, 0.2-m thick layer of 50% SFS and 50% soil). This was because IWEM/EPACMTP models landfills as a depleting source. Whereas the modeling duration of the LAU model is governed by the LAU's operational life, IWEM/EPACMTP depletes the waste concentration in a landfill, extending the modeled duration until the mass of constituent is exhausted, yielding an essentially steady state transport result. Otherwise the EPACMTP landfill operates very similarly to the LAU, and is subject to the square leachate pulse assumption for nonlinear sorption of metal constituents. Table A-3 also includes landfill modeling results.

Table A-3. Effect of Well Distance, Operating Life, and WMU Type on As^{+3} Receptor Well Concentrations for a 1-Scre WMU

Well distance (m)	90th Percentile As^{+3} Peak Concentration (mg/L)			
	1-year LAU	40-year LAU	195-year LAU	Landfill
1	4.6E-10	1.3E-02	1.3E-02	1.3E-02
15	1.3E-04	1.1E-02	1.1E-02	1.1E-02
30	1.4E-04	8.9E-03	9.1E-03	9.0E-03
50	9.7E-05	7.2E-03	7.7E-03	7.5E-03
100	5.1E-05	5.1E-03	5.7E-03	5.5E-03

Leachate Concentration (Cl) = 0.0156 mg/L, 95th percentile leachate concentration.

Table A-3 shows that, for As^{+3} in SFS, there is essentially no difference in results between the 40- and 195-year LAUs and the landfill, with the highest concentrations occurring at the 1 m well, and that all results run for the longer "operating life" are more than an order of magnitude higher than the Tapwater screening level.

Figure A-4 shows the various percentiles of concentration for various depths and operating lives. The results for the 1-year LAU scenario show the anomalously low values for the closer well distances as discussed above.

Figure A-5 plots the IWEM output data to show concentration by depth and distance. The 1-year LAU results show significantly lower (about 2 orders of magnitude) values than either the 40-year or 195-year LAU runs, which can be attributed to the wastes not being left in place long enough to fully develop the contaminant plume and reach peak groundwater concentrations. Figure A-5 also shows that the 40-yr and 195-year plumes are very similar for As^{+3}.

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[5] If a 50:50 mixture of soil and SFS is considered, the depletion times for 95th and 50th percentile waste concentrations would be 97 and 22 years respectively. Note that IWEM/EPACMTP does not consider whole waste concentrations in any of its WMU release calculations.

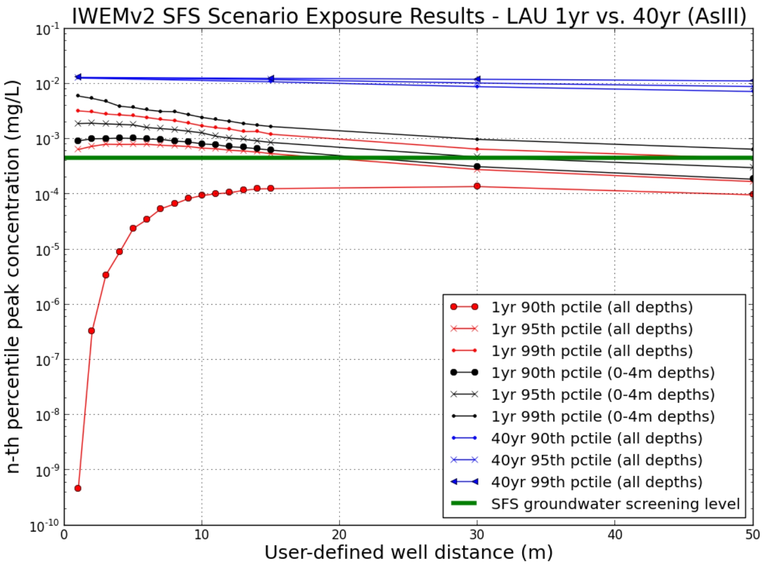

Figure A-4. Comparison of 1-year and 40-year operating lifetimes for the LAU SFS home garden scenario for As^{+3} results. (Green line = 4.5×10^{-4} mg/L Tapwater screening level.)

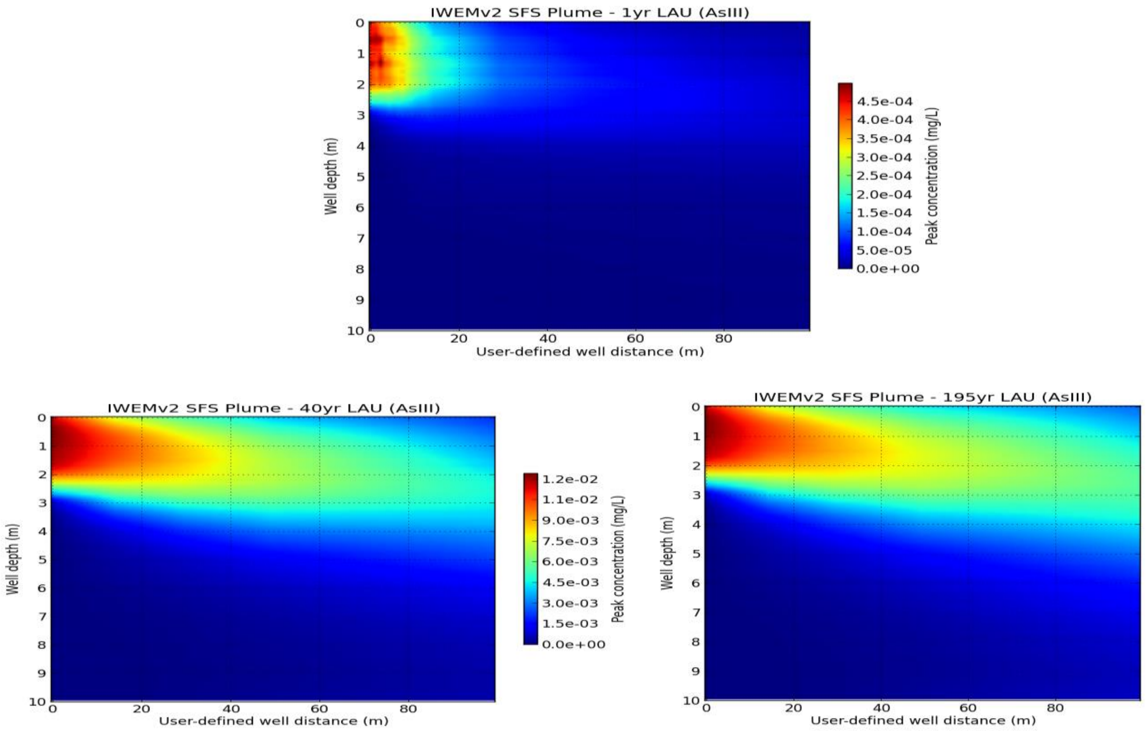

Figure A-5. As^{+3} concentration plots (by well distance and depth) for 1-year (top), 40-year (middle), and 195-year LAU (bottom) simulations (with all other parameters set the same). Note that concentration scale is different (lower) for 1-year simulations to show "plume".

A3.4.3 Characterize Modeled Exposure Results for Different Operating Lifetimes and Well Distances for Other Metals

In addition to As^{+3}, the SFS groundwater risk assessment modeled four metals (antimony, beryllium, cadmium, and lead) using one-half their respective detection limits. These constituents were modeled using the same LAU model conditions used for the original modeling scenario conditions (1-year operating life and 1-m well distance), as well as the same range of well distances (1m, 15m, 30m, 100m) and operating lifetimes (1-year, 40-year, 200-year) as investigated for As^{+3}. These constituents were also modeled using the IWEM/EPACMTP landfill model with the depleting source scenario. Results are shown below.

Table A-4 provides results for antimony, which behaved similarly to arsenic, with the 1-year results being about an order of magnitude below the rest, and the 40-year, 200-year, and landfill results being essentially equivalent.

Table A-4. Effect of Well Distance, Operating Life, and WMU Type on Antimony Receptor Well Concentrations for 1-Acre WMU

Well distance (m)	90th Percentile Antimony Peak Concentration (mg/L)			
	1-year LAU	40-year LAU	200-year LAU	Landfill (0.2 m deep)
1	3.5E-03	1.6E-02	1.6E-02	1.6E-02
15	2.3E-03	1.4E-02	1.4E-02	1.4E-02
30	1.6E-03	1.2E-02	1.2E-02	1.2E-02
50	1.0E-03	9.9E-03	9.9E-03	9.6E-03
100	5.6E-04	7.3E-03	7.4E-03	7.0E-03

Leachate concentration (0.02 mg/L) equal to one-half the detection limit.

Table A-5 provides results for beryllium, for which the 1-year 90th percentile concentrations were zero at all well distances, suggesting that this was a strongly sorbing constituent with a large attenuation in concentration in the vadose zones. This is also reflected in the approximate order of magnitude difference between the 200-year LAU and the landfill results with the landfill giving the higher groundwater concentration.

Table A-5. Effect of Well Distance, Operating Life, and WMU Type on Beryllium Receptor Well Concentrations for 1-Acre WMU

Well distance (m)	90th Percentile Beryllium Peak Concentration (mg/L)			
	1-year LAU	40-year LAU	200-year LAU	Landfill (0.2 m deep)
1	0.0E+00	2.9E-07	8.6E-07	1.3E-04
15	0.0E+00	2.0E-05	6.6E-05	2.0E-03
30	0.0E+00	1.6E-05	5.6E-05	1.9E-03
50	0.0E+00	1.1E-05	4.7E-05	1.6E-03
100	0.0E+00	4.4E-06	2.8E-05	1.2E-03

Leachate concentration (0.01 mg/L) equal to one-half the detection limit.

The results for cadmium (**Table A-6**) and lead (**Table A-7**) show a behavior very similar to arsenic and antimony, with very little difference between the 40-year LAU, 200-year LAU, and landfill results but with lower concentrations for the 1-year LAU results, particularly for the 1 m well distance, and especially for cadmium.

Table A-6. Effect of Well Distance, Operating Life, and WMU Type on Cadmium Receptor Well Concentrations for 1-Acre WMU

Well distance (m)	90th Percentile Cadmium Peak Concentration (mg/L)			
	1-year LAU	40-year LAU	200-year LAU	Landfill (0.2 m deep)
1	1.3E-11	4.1E-03	4.1E-03	4.0E-03
15	4.1E-05	3.5E-03	3.5E-03	3.5E-03
30	5.0E-05	2.8E-03	2.9E-03	2.9E-03
50	3.9E-05	2.3E-03	2.5E-03	2.4E-03
100	2.2E-05	1.6E-03	1.8E-03	1.8E-03

Leachate concentration (0.005 mg/L) equal to one-half the detection limit.

Table A-7. Effect of Well Distance, Operating Life, and WMU Type on Lead Receptor Well Concentrations for 1-Acre WMU

Well distance (m)	90th Percentile Lead Peak Concentration (mg/L)			
	1-year LAU	40-year LAU	200-year LAU	Landfill (0.2 m deep)
1	1.1E-03	4.4E-02	4.5E-02	4.4E-02
15	1.8E-04	1.6E-02	3.5E-02	3.8E-02
30	8.4E-05	9.3E-03	2.6E-02	3.2E-02
50	5.3E-05	6.1E-03	2.0E-02	2.6E-02
100	2.7E-05	3.0E-03	1.2E-02	1.9E-02

Leachate concentration (0.055 mg/L) equal to one-half the detection limit.

A3.4.4 Conclusions Regarding Operating Life and Well Distance

Based on the analyses above, it is evident that concentration does not behave as expected for a 1-year "operating" life, with maximum peak concentrations 30 m from the garden in this scenario. However, for a more reasonable operating life (e.g., 40 years), maximum peak concentrations do occur at the closest well distance as expected.

A4.0 Alternative Model Evaluation

A search was conducted to identify models that could potentially serve as suitable alternatives to IWEM for supporting the evaluation of the SFS home garden groundwater pathway. Ideally, the models would need to be capable of (1) estimating leachate concentration and (2) simulating the transport of metal constituents to groundwater drinking wells. The only models that were considered as alternatives to IWEM were peer-reviewed, publically available, and used to support regulatory decisions.

Nonlinear Sorption Isotherms

A nonlinear sorption isotherm is an expression of the equilibrium relationship between the sorbed concentration of a metal (or other constituent) and the aqueous concentration for a representative set of subsurface system conditions. Nonlinear sorption isotherms are important when modeling metals because metal sorption coefficients (Kds), which influence metal fate and transport, are significantly affected by metal concentration in the aqueous phase. In general, metal mobility tends to be higher (and thus, Kds lower) as leachate concentrations increase. Therefore, as leachate concentrations decrease during unsaturated zone (soil) transport, metal mobility also tends to decrease (and Kds tend to increase).

The use of nonlinear metal sorption isotherms enables EPACMTP to model nonlinear behavior in the unsaturated zone module for a wide array of subsurface conditions. For the sorption isotherms used in IWEM EPACMTP, these conditions are defined by parameters that include the pH of the aqueous system, concentrations of adsorbents, natural organic matter, anthropogenic organic acids, and other characteristics appropriate for particular waste streams. IWEM includes ensembles of nonlinear isotherms that have been compiled for hundreds of combinations of these parameters for more than 20 metals for selection and use in the probabilistic modeling framework.

Table A-8 summarizes the capabilities and characteristics of the models identified for consideration. Based on a model comparison, IWEM remains the preferred model for supporting the SFS evaluation; specifically, the model's capabilities (e.g., probabilistic modeling[6], nonlinear metal sorption isotherms—see text box), and history (extensive peer-review record, long history of supporting regulatory decisions) were clearly superior to the alternatives. For example, EPACMTP, the numerical engine for IWEM, was also evaluated separately as an alternative to IWEM. However, given the resources needed to parameterize and execute EPACMTP, IWEM provides an efficient, cost-effective, and scientifically defensible screening tool; EPACMTP is recommended for refined modeling for constituents that fail an IWEM analysis. In addition, none of the other identified alternative models offer the probabilistic (i.e., Monte Carlo) modeling framework used in IWEM, and only one model combination, the SEasonal SOIL (SESOIL) compartment model coupled with the groundwater model Analytical Transient 1-, 2-, and 3-Dimensional Simulation of Waste Transport in the Aquifer System (AT123D), includes nonlinear isotherms and is associated with State and EPA remediation efforts. However, the criterion of being publically available was not fully met by this combination of models: although the source code for SESOIL and AT123D is free, the user interface is not, and is available only through commercial vendors.

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[6] With limited input of setting and source characteristics, IWEM provides the user with user-friendly access to EPACMTP, which contains nationwide aquifer, soil, rainfall/infiltration, and metal sorption data sets, and a probabilistic modeling framework capable of representing variability and uncertainty in model inputs for a specific site area, region, or the entire United States.

Table A-8. Comparison of Alternative Models

Model	Description	Usability	Processes	Probabilistic Modeling Framework	Nonlinear Sorption Isotherms
EPACMTP[a]	EPACMTP is a full-featured groundwater flow and transport model with probabilistic modeling capabilities with a long history of supporting EPA regulatory development for the management and disposal of hazardous wastes. Designed to simulate subsurface fate and transport of contaminants released from land disposal sites. Predicts groundwater exposures in domestic drinking water receptor wells Simulations are performed using probabilistic input specifications based on nationwide data.	Parameterizing and executing EPACMTP can be challenging, but the model includes resident databases that allow the model to be used for nationwide assessments using Monte Carlo simulation techniques; it is not intended for site-specific applications. The Monte Carlo module of EPACMTP allows you to take into account the effect of parameter variability on predicted ground-water concentrations.	Advection, hydrodynamic dispersion, linear or nonlinear sorption, and chain-decay reactions. In cases where degradation of a waste constituent yields daughter products that are of concern, EPACMTP accounts for formation and transport of up to six different daughter products.	Yes	Yes

Model	Description	Usability	Processes	Probabilistic Modeling Framework	Nonlinear Sorption Isotherms
PRZM-GW (Pesticide Root Zone Model for Ground Water)[b]	EPA's Office of Pesticide Programs detailed, numerical solution model which is typically used to model pesticide leaching. The model can be used to support screening (Tier I) and refined (Tier II) drinking water assessments.	Model represents vulnerable private drinking water wells in the vicinity of agricultural environments. The saturated zone of the conceptual model is a shallow unconfined aquifer with a water table depth that corresponds to the scenario location. Well-screen extends from aquifer surface to 1 m below surface, but this length is adjustable. Provides six standard scenarios that represent regions known to have vulnerable GW supplies. For Tier I assessments, it is recommended that simulations be run with all six scenarios. A simulation can be run for up to 100 years. Tier II refinement options include (1) development of representative scenario (e.g., soil type and characteristics, weather data, depth to aquifer); (2) identify pesticide fate parameters not considered in the Tier 1 Simulations (subsurface degradation and subsurface sorption); (3) change application reoccurrence; (4) considerations of well setbacks; (5) explore different exposure durations.	Degradation and linear sorption	No	No
SCI-GROW (*S*creening *C*oncentration *I*n *GRO*und *W*ater)[c]	EPA OPP's very simple, conservative screening model used to develop an estimate of likely ground-water concentrations if a pesticide is used at the maximum allowable rate in areas with ground water exceptionally vulnerable to contamination.	A simple user interface with 6 inputs. Intended for estimating conservative or high-end exposure values because the model is based on ground-water monitoring studies which were conducted by applying pesticides at maximum allowed rates and frequency to vulnerable sites. Does not have the capability to consider variability in leaching potential of different soils, weather (including rainfall), cumulative yearly applications or depth to aquifer.	Degradation and linear adsorption coefficient.	No	No

Model	Description	Usability	Processes	Probabilistic Modeling Framework	Nonlinear Sorption Isotherms
SESOIL/AT123D (SEasonal SOIL compartment model) / (Analytical Transient 1-, 2-, and 3-Dimensional Simulation of Waste Transport in the Aquifer System)[d]	SESOIL is a one-dimensional soil compartment model. Downward transport through soil column. Has been linked to the ground water transport model (AT123D). Has become fairly well established and accepted by several state agencies and the U.S. EPA for calculating remediation standards.	Both SESOIL and AT123D source codes are available free of charge from the U.S. EPA but they lack a user interface. Commercially available interfaces are available.	Adsorption, volatilization, degradation/decay, convective transport, and metal nonlinear isotherms for sorption (Freundlich).	No	Yes
VLEACH (Vadose zone LEACHing model), Version 2.2a[e]	Numerical solution and screening model with a one-dimensional, finite difference model for making preliminary assessments of the effects on ground water from the leaching of volatile, sorbed contaminants through the vadose zone. Not intended for modeling metal constituents.	Model execution is initiated from a DOS command line and inputs are read from manually created, structured text input files.	Advection, sorption, vapor-phase diffusion, and three-phase equilibration. Linear isotherms describe the partitioning of the pollutant between the liquid, vapor and soil phases	No	No

A5.0 Recommendations

Based on the results of the model review and detailed analysis of the IWEM/EPACMTP results for the SFS home garden scenario, the following recommendations are made (and instituted in the Final SFS risk assessment) to support SFS home gardener groundwater pathway screening:

- **Continue to use IWEM.** IWEM meets or exceeds all of the criteria specified for this review, and contains features (like the probabilistic modeling framework and nonlinear sorption isotherms for metals) that are not available in most of the other identified models.
- **Change the modeled operating life.** Set operating life to the default (40-year) and maximum (200-year) values to allow sufficient time for the plume to develop and for the peak concentrations to be achieved at the receptor well. The 1-year "operating life" as implemented in the Peer Review Draft SFS modeling effort removes the SFS-amended soil after 1 year, which does not reflect how most people manage their gardens (i.e., garden soils are likely always left in place). Because removing the amended soil effectively stops the leaching process after 1 year, this significantly underestimates the well concentrations because it does not allow sufficient time for the contaminant plume to develop before the simulation is stopped.
- **Continue to use a 1 m receptor well distance.** This well distance is acceptable and reasonable considering the SFS home garden exposure scenario, and gives the highest concentrations when compared to other well distances as long as a sufficient and reasonable modeling time (i.e., "operating life") is used.
- **Use 10,000 flow and transport simulations.** 5,000 simulations is not sufficient to ensure stability in the tails of the resulting distribution of receptor well concentrations.

Appendix A: References

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