APPENDIX C
ESTIMATION OF REPRESENTATIVE SOIL AND GROUNDWATER CONCENTRATIONS

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C.1 BACKGROUND

When performing a risk assessment, it is assumed that a receptor would typically be exposed to chemicals of concern (COCs) over a defined geographical area, for a specified exposure duration, and through one or more routes of exposure. The geographical area and the exposure duration for a receptor may vary for different routes of exposure. The geographical area over which a receptor is exposed to COCs is called the exposure domain. Because COC concentrations typically vary over the exposure domain and exposure duration, it is necessary to estimate a representative COC concentration consistent with the receptor's exposure domain and exposure duration. For purposes of calculating the representative COC concentration for risk assessment purposes, the area of impact(s) within the exposure domain should be used if the exposure domain is larger than the area of impact(s). This avoids the potential for inappropriate "dilution" of the representative concentration that can result from inclusion of non-detect values outside the area of impact and helps to address any concerns associated with use of "average" concentrations in MRBCA in lieu of the more traditional 95% Upper Confidence Limit (UCL) concentration approach articulated in EPA guidance.

A representative COC concentration is the average concentration to which the receptor is exposed over the specified exposure duration, within a specified geographical area, and for a specific route of exposure. In most risk assessments, the exposure point concentration is assumed constant over the exposure duration.

Representative concentrations are necessary for both the "backward" and "forward" mode of risk assessments. The backward mode of risk assessment results in target levels for each complete route of exposure identified in the exposure model and each COC. Representative concentrations are used in the risk management step in which the target concentrations are compared with the representative concentrations. The forward mode of risk assessment results in the calculation of risk for each complete route of exposure identified in the exposure model, and representative concentrations are used to estimate risk.

The calculation of representative concentrations is complicated by several factors. These include:

- Spatial variability in the concentrations,
- Temporal variability in the concentrations, and
- Lack of sufficient site-specific concentration data.

Further complication arises because environmental data is typically obtained through biased sampling in that the sampling is focused on identifying the source areas and extent of contamination and does not consist of samples collected systematically over the exposure domain (area of impact). Additional complications arise because the concept of representative concentration is often associated with a site as opposed to an exposure pathway and receptor. Because several complete pathways may exist at a site, several representative concentrations, one for each complete pathway, must be estimated for each

receptor. This appendix discusses the methodology used to estimate the representative concentrations for each complete route of exposure.

The calculation of the representative concentration requires the following steps for each receptor:

1. Identification of all of the media of concern. Typically these include surficial soil, subsurface soil, soil up to the depth of construction, and groundwater,
2. Identification of all the complete routes of exposure under current and future conditions,
3. Identification of the exposure domain (area of impact) for each media identified in Step1, and each complete route of exposure identified in Step 2,
4. Identification of the COC concentration data available within the exposure domain (area of impact) for each media, and
5. Calculation of the representative concentration, which would be the average of the data from Step 4 above.

When using the average concentration as the representative concentration, the value should not be artificially lowered or "diluted." To avoid this, the following should be kept in mind (also refer to Section 9.5, Recommend the Next Course of Action):

1. Do not use data beyond the exposure domain (area of impact) unless there is not enough data within the domain and data is available just outside the domain. If data is available just outside the exposure domain, judgement should be used whether to interpolate and use this data or to collect additional data within the exposure domain.
2. Within the area of impact, replace the non-detect values with half the detection limit. Concentrations with a J laboratory qualifier, which is a judgement made at the laboratory, should use the laboratory-estimated value.
3. As a simple or red flag check, determine if the maximum concentration of any COC exceeds ten times the representative concentration of that COC for any exposure pathway. Note the maximum concentration here refers to the maximum concentration within an area of impact, not the site-wide maximum concentration. Possible reasons for an exceedance could be:
   - The maximum concentration is an outlier,
   - The average concentration was inaccurately calculated,
   - The area of impact is not adequately characterized, or
   - A hot spot may not have been adequately characterized.
4. If the representative concentration is based on extrapolation using a model, the model must be supported by site-specific data.
5. When calculating the representative groundwater concentration, first estimate the average concentration in each well based on recent data, assuming data from multiple events is available, and then use the average of each well to estimate the representative concentration.
6. If free product is present at a monitoring point, use the effective solubility or effective vapor pressure to estimate the concentration at that point.
7. For wells with multiple years of groundwater data, use the most recent two years of data to estimate the representative concentration. In certain cases, data that is more than two years old may be used, but it must be justified (also refer to C.2.4.1).

8. If the area of impact is smaller than the exposure domain, the exposure factors may be modified (in Tier 3 evaluation) to account for this circumstance. .
9. For the subsurface-soil-to-indoor-inhalation pathway, do not use soil data collected below the water table. Similarly, for the groundwater-to-indoor-inhalation pathway, groundwater data from the first encountered saturated zone must be used.

C.2 CALCULATION OF REPRESENTATIVE CONCENTRATIONS

C.2.1 Surficial Soil (0-3 feet below ground surface)

The Missouri Risk-Based Corrective Action (MRBCA) process requires the evaluation of four routes of exposure associated with surficial soil:

1. The ingestion of COCs in groundwater due to leaching of residual COCs present in the surficial soil,
2. Accidental ingestion of soil,
3. Outdoor inhalation of vapors and particulates from surficial soil emissions, and
4. Dermal contact with surficial soil.

The latter three pathways are combined and referred to as the "direct contact with soil" pathway. Thus at least two different surficial soil representative concentrations are required, one for leaching to groundwater and one for direct contact with soil. In certain cases, depending on use and characteristics of the site, a single representative concentration may suffice for both pathways.

C.2.1.1 Representative Surficial Soil Concentration for Leaching to Groundwater

The exposure domain for this pathway is the area of impact through which leachate generation may occur and COCs can migrate to the water table. The representative surficial soil concentration should be calculated using the surficial soil data collected within the are of impact. Thus, prior to calculating the representative concentration, it is necessary to clearly define the horizontal extent of the impacted area and to identify the surficial soil data available within this area.

C.2.1.2 Representative Concentrations for Direct Contact Pathway

The representative surficial soil concentration (0 to 3 feet)is based on the area of impact - that is, the area of the site over which the receptor might be exposed to contaminated surficial soil. The exact exposure domain of the receptor is difficult to estimate because the assumption is that the receptor is exposed over a period of time equal to the exposure duration. In the absence of specific information about the receptor's activities, the area(s) of impact should be considered the receptor's exposure domain. For potential future exposures and in the absence of any engineering controls, it may be necessary to assume that exposures that might otherwise be prevented/minimized (e.g., due to paving) will need to be evaluated as if exposure to contaminated surficial soil will occur.

To calculate the representative concentration for the direct contact pathway, one must
1. determine the extent of impact,
2. estimate the receptor's exposure domain(s), and
3. determine the number of soil samples available within the area of impact or the number of samples necessary to adequately represent the area of impact .

For a non-resident worker, the average concentration over the area of impact may be used. For a child receptor, the maximum concentration must be used and, therefore, a representative concentration need not be calculated if a child is an actual or potential receptor. For direct soil contact pathway for a construction worker, refer to Section C.2.3.

C.2.2 Subsurface Soil (greater than 3 feet below ground surface)

The MRBCA process includes the following two routes of exposure associated with subsurface soil: (i) leaching of residual COC concentrations in the subsurface soil to groundwater, and (ii) indoor inhalation of vapor emissions. Thus, a representative concentration must be calculated for each complete pathway. Calculation of additional representative concentrations may be required if the assumptions for current and future site conditions are different.

C.2.2.1 Representative Subsurface Soil Concentration for Protection of Groundwater

The representative concentration for this pathway should be the average concentration in subsurface soil measured within the area of impact.

C.2.2.2 Representative Subsurface Soil Concentration for Protection of Indoor Inhalation

Subsurface soil concentrations protective of indoor inhalation are estimated using an emission model such as the Johnson and Ettinger (2001) model. This model assumes that chemicals volatilize from the subsurface soil source, travel vertically upwards without any lateral or transverse spreading, and enter the building through cracks in the foundation and floor. To ensure consistency with the model, the representative concentration for this pathway should be based on soil concentrations measured directly below or immediately adjacent to the footprint of the enclosed space.

To evaluate the potential future indoor inhalation pathway, (i.e., an enclosed structure is constructed over contaminated soil), the size (footprint) and location of the planned structure must be estimated. In the absence of site-specific information regarding planned structures, the future location and size of the structure must be approximated based on the evaluator's professional judgement. A conservative option is to locate the hypothetical structure over the area of impact (that is, the area of maximum COC concentrations). However, this is only one conservative option and its applicability will vary from site to site. For sites where the footprint of a current on-site structure is or

might be different from that of a structure erected in the future, a representative subsurface soil concentration must be calculated for both the current and potential future structure.

To estimate the representative concentration, the evaluator must:
1. Identify the footprint of the structure within which the receptor is located,
2. Identify the footprint of the potential future enclosed structure,
3. Identify the soil concentration data available within each of these two footprints, and
4. Calculate the average of these concentrations.

If sufficient data are not available within the building footprint, data collected within 20 feet of the building footprint may be used to calculate average COC concentrations in soil. Data from locations beyond the 20 foot building footprint buffer may be considered/needed in cases where preferential pathways such as soil macropores, utility conduits, or soil fractures may cause vapor migration towards the building. Generally, vapor concentrations are expected to decrease with increasing distances from the source. When calculating the representative concentration, a horizontal attenuation factor may be applied to concentrations that are more than 20 feet from the building footprint, if adequate technical support is provided for derivation of the attenuation factor.

If several samples within and adjacent to the building footprint are available, more weight should be given to the samples collected within the footprint. Two scenarios are possible: (i) the building footprint is located entirely within the contaminated area, and (ii) the building footprint is partially located within the contaminated area. For both scenarios, the representative soil concentration would typically be based on data collected within and directly adjacent to the footprint of the building. In the second scenario, the representative concentration may differ from that calculated in scenario one because a portion of the structure lies over uncontaminated soil.

C.2.3 Representative Concentration for Construction Worker

The MRBCA process requires the evaluation of the following three routes of exposure for the construction worker:
1. Accidental ingestion, dermal contact and outdoor inhalation of vapors and particulates from soil,
2. Outdoor inhalation of vapors from groundwater, and
3. Dermal contact with groundwater.

Thus three representative concentrations are required. Each of these is discussed below.

C.2.3.1 Representative Soil Concentration

For the construction worker, no distinction is made between surficial and subsurface soil because, during construction, the construction worker might be exposed to both. To estimate the representative concentration for the construction worker, it is necessary to identify the (i) depth of construction, (ii) areal extent of construction, and (iii) the

horizontal and vertical extent of soil impacts within the area of construction including the number of samples available to calculate the representative concentration within the zone of construction . The potential future depth of construction should be estimated based on the likely type of structure that might be built and by identifying the typical depth of utilities on and adjacent to the site. If the areal extent of the construction area is not known, a conservative option (not the only option), would be to assume that the construction zone will be entirely within/across the area of impact. The representative concentration would be the averaged concentration within this zone of construction.

C.2.3.2 Representative Groundwater Concentration

As with estimating representative soil concentrations, it is necessary to estimate the areal extent of the construction zone and identify the groundwater data available for this zone. The representative concentration would then be calculated as the average concentration within this zone. Temporal variations in groundwater concentrations should be evaluated as discussed in Section B.2.4.1. If contaminated groundwater is known to be present just below the depth of planned construction (as opposed to within the depth of planned construction), best professional judgement should be used in deciding if outdoor inhalation of vapors from groundwater should be evaluated

C.2.4 Groundwater

The MRBCA process requires the evaluation of the following three routes of exposure associated with groundwater:

1. Ingestion of groundwater,
2. Dermal contact with groundwater, and
3. Indoor inhalation of vapor emissions from groundwater (only from shallow groundwater).

Where multiple aquifers are present, the shallowest aquifer would be considered for the volatilization pathway. The specific aquifers that are or might be used for domestic use or in another manner in which dermal contact could occur must be considered for the ingestion and dermal contact pathways. Representative concentrations must be calculated for each aquifer and associated exposure pathway(s).. Thus, depending on the number of complete pathways, up to three different groundwater representative concentrations, one for each complete pathway, must be calculated.

C.2.4.1 Representative Demonstration Well Concentration for Protection of Groundwater Ingestion (Drinking Water Pathway)

For the ingestion of groundwater pathway, maximum contaminant levels (MCLs) or, where MCLs are lacking, calculated risk-based concentrations, must be met at the point of exposure (POE) well. Often the point of exposure well is hypothetical and, therefore, data for the POE might not be available. During the course of groundwater remediation, one or more point of demonstration (POD) wells must be identified, target concentrations

calculated and the POD well(s) monitored to ensure that unacceptable exposures do not occur at the POE..

The representative concentration at the POD and POE should be calculated based on measured COC concentrations in groundwater, as discussed below.

- If COC concentrations in groundwater are stable, the representative concentration is the arithmetic average of the most recent data collected over a period of no more than two years on at least a quarterly basis.

- If COC concentrations are decreasing, the representative concentration is the arithmetic average of the most recent data collected over a period of no more than one and one-half years on at least a quarterly basis.

- If COC concentrations are increasing, the arithmetic average of the most recent data collected over a period of no more than one year on at least a quarterly basis.

C.2.4.2Representative Groundwater Concentration for Protection of Indoor Inhalation

Groundwater concentrations protective of indoor inhalation are typically estimated using a model such as the Johnson and Ettinger (2001) model. This model assumes no lateral or transverse spreading of the vapors as they migrate upward from the water table through the capillary fringe and the vadose zone and into the enclosed space. Thus, representative concentrations for this pathway should be based on groundwater concentrations measured within the footprint of the building or up to 20 feet from the building. As mentioned above for soil, data beyond 20 feet may be considered/necessary based on the presence of features in vadose zone soils (e.g., macropores, fractures, utility conduits, etc.) that could influence vapor migration. Refer to Section C.2.2.2 for a discussion of the evaluation of future structures and their relationship to the area of impact.

For the groundwater to indoor air pathway, multiple representative concentrations might be needed if the plume has migrated below several current or potential future buildings. For example, if a plume has migrated or is likely to migrate below two different buildings, one on-site and one off-site, a representative concentration would have to be calculated for each building.

After identifying the location of the building footprints (whether real or hypothetical) and the available groundwater monitoring data within or adjacent (within 20 feet and in some cases up to or more than 100 feet) to each footprint, the average concentration within each footprint must be estimated, as discussed in Section C.2.2.2. However, groundwater data may not be available for each footprint; therefore, several options are available. These include:

1. Installation of additional monitoring wells within or adjacent to the footprint lacking data,
2. Interpolation or extrapolation of existing data (in the case where the plume originates

under a building, extrapolated data gathered from areas adjacent to the footprint may not be adequate) or,

3. As a conservative approach, use of data from wells located upgradient of the building that are between the building and the source of contamination.

C.2.4.3 Representative Groundwater Concentration for Dermal Contact

The average concentration of COCs in the groundwater that a receptor might come in contact with is used as the representative concentration. Note that temporal variations in COC concentrations will be considered as discussed in Section C.3. More than one representative concentration might be needed where a receptor might contact groundwater from more than one aquifer or saturated zone.

C.3 GENERAL CONSIDERATIONS FOR CALCULATING REPRESENTATIVE CONCENTRATIONS

As discussed in this document, calculation of representative concentrations requires considerable professional judgement. Prior to performing the computations identified in Section C.2, the following should be considered:

- Evaluate whether the spatial resolution of the data is sufficient. While an exact number of samples cannot be specified herein due to the variability in conditions from site to site, data should be available from known or likely impacted areas within the various receptors' exposure domains.

- If the data are old (greater than four years old) and the COC concentrations exceed Tier 1 Risk Based Target Levels, new data may be collected (especially groundwater data). If a new release has been documented, new data must be collected in order to characterize adequately the nature and extent of the current impact. If old data are to be eliminated from the risk evaluation, the reason for elimination must be clearly documented in the Tiered Risk Assessment Report (see section 7.2 of the MRBCA guidance).
- Non-detect soil and groundwater samples located at the periphery of the area of impact should not be used.
- Non-detect results associated with certain COCs within the exposure domain (area of impact) should be replaced by half the detection limit. In this context, certain COCs refers to those constituents that are below analytical detection limits in a particular sample but are within a known area of impact based on other COCs associated with that sample that are present above analytical detection limits. For example, if vinyl chloride was not present in a sample above its analytical detection limit but TCE was present above its limit, then for that sample one-half the detection limit for vinyl chloride would be used in figuring the average concentration of vinyl chloride since, based on the TCE detection, the sample is considered to be within an area of impact. This differs from the approach of using one-half the detection limit for samples where all COCs were non-detect. In that case, none of the sample results should be used to figure the average since that sample is not considered to be within an area of impact.

- If multiple surficial soil samples and/or multiple subsurface soil samples are available from the same borehole within the area of impact/exposure domain, the average concentration of these samples may be used.
- The maximum concentration of any COC within the area of impact should not exceed ten times the representative average concentration. If this situation occurs, further evaluation of the analytical data to assess its usability may be necessary.
- In certain cases, an area-weighted average may be a better estimate of the representative concentration. An area-weighted average differs from an arithmetic average in that it considers the area over which an individual measurement applies as opposed to assuming equal weighting of all individual results. For example, if sampling has been focused on establishing the maximum concentration present (hot spot) and the limits of impact (horizontal and vertical extent), there may be limited concentration data available for the area of impact in between these two extremes. In these cases, the results may need to be "area weighted" so that the resulting average is not skewed in a particular direction for risk assessment purposes. For example, if a single hot spot sample concentration is averaged with multiple edge of impact concentrations, the resulting average could be biased on the low side if a simple arithmetic average is used. If a gridded sampling pattern has been used to sample soil, the arithmetic average is a good approximation of the area-weighted average. However, if a biased sampling pattern has been used, then it may be necessary to use an area-weighted average to accurately determine the representative concentration. There are different ways to calculate weighted averages across an area of impact. For relatively simple situations with few samples, a calculation methodology such as the Thiessen Polygon Method could be used. However, in the majority of cases, it will likely be more efficient to use available computer software to contour areas of impact and automatically perform area weighted average concentration calculations. Prior to performing any area-weighted average calculations, the remediating party should discuss the specifics with the project manager.

The following considerations are necessary to evaluate representative groundwater concentrations.

- To account for temporal variations in groundwater concentrations, the representative concentration in a well may be estimated as follows:
  1. If COC concentrations in groundwater are stable, the arithmetic average of the most recent data collected over a period of no more than two years on at least a quarterly basis.
  2. If COC concentrations are decreasing, the arithmetic average of the most recent data collected over a period of no more than one and one-half years on at least a quarterly basis.
  3. If COC concentrations are increasing, the arithmetic average of the most recent data collected over a period of no more than one year on at least a quarterly basis.

  Data from wells on the periphery of the area(s) of impact having COC concentrations consistently below detection limits cannot be used in the calculation of representative groundwater concentrations.

- For wells that contain or have contained free product within the most recent two years, the concentration representative of those chemicals comprising the free product in the well should be the effective solubility of the various chemicals comprising the free product.

Table C-1
Calculation of Representative Concentrations

Route of Exposure	Calculation of Representative Concentration
Surficial Soil (0 to 3 feet bgs)	
Soil concentration protective of leaching to groundwater or surface water body	Average of surface soil concentrations collected within the area of impact.
Direct contact with soil including ingestion of soil, dermal contact with soil, and the outdoor inhalation of vapors and particulates emitted by surficial soils	Average of the surface soil concentrations within area of impact for non-residential receptor. Maximum concentration for child receptor.
Subsurface Soil (greater than 3 feet bgs)	
Indoor inhalation of vapor emissions	Average of the subsurface soil concentrations collected below or within 20** ft of the real or hypothetical footprint of the building (Excluding concentrations below water table and capillary fringe).
Soil concentration protective of leaching to groundwater	Average of the subsurface soil concentrations within the area of impact (Excluding concentrations below water table and capillary fringe).
Groundwater	
Indoor inhalation of vapor emissions	Average of the groundwater concentrations within 20** feet of the footprint of the real or hypothetical building
Dermal contact with groundwater	Average of the groundwater concentrations that a receptor may come in contact with
Groundwater domestic use pathway • Concentration at POE • Concentration at POD	 Average of the groundwater concentrations* Average of the groundwater concentrations*

*: Refer to Section C.2.4.1.
**: Refer to discussion in Section C.2.2.2.