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**Draft MDH Cmths -Soil ScrnngTec Doc.doc**

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History: This message has been replied to and forwarded.

MDH Comments: Draft Alternatives Screening Technical Memorandum – Soils St. Regis Paper Company Site, Cass Lake, Minnesota (February 25, 2009)

General Comments:

The site soils were extensively stained with PAHs because site operations utilized petroleum based materials in the pole treatment process. Despite this, the vast majority of site soils were not adequately analyzed for PAHs. The lack of PAH data is a potential under estimation of both cancer and non-cancer health risks. Furthermore, over 95% of the site soil data were collected at the surface and therefore little is known about the potential health risks from deeper soil contaminant levels. Adding to this uncertainty is the extensive alteration to the site soil column during prior remedial efforts. The utility of 5 sub-samples to characterize average soil concentrations in parcels approximately 114 ft x 144 ft, and larger, is questionable under these conditions. Even after several 5-year reviews and 8 years into the site assessment process, numerous parcels within OU1, have not been sampled at all and large areas of OU1 remain uncovered with levels of dioxins approaching 1000 ppt at the surface and potentially greater below 6 inches. Additionally, areas outside the current delineated site boundaries are contaminated or are potentially contaminated and need further characterization.

Requirements for institutional controls are more restrictive than is suggested in the document. Additionally, if contamination is left on site, 5yr reviews are required.

Introduction

OU1- Former Operating Area, pg 5.

MDH has commented numerous times that PAHs likely contribute the unacceptable human cancer and non-cancer health risk at the site. This significant omission in the risk assessment has not been addressed even though MDH has requested at each sampling event that all soil samples be analyzed for extended list of PAHs (<http://www.health.state.mn.us/divs/eh/risk/guidance/PAHmemo.html>).

The exposure to soil vapor gas needs to be considered as part of the potential accumulative risk. The MPCA Superfund RCRA and Voluntary Cleanup Section has a Risk-Based Guidance for the Vapor Intrusion Pathway posted on the web (<http://www.pca.state.mn.us/publications/c-s4-06.pdf>). A bigger groundwater plume area will

pose a potential risk as defined by the guidance. Note that groundwater plume is very shallow in some areas of the site

OU2-Southwest Area, pg 5.

Soil data collected on the Leech Lake Band of Ojibwe Division of Natural Resources property contain elevated levels of dioxins and furans outside OU2 boundaries.

OU7-Residential Area, pg 5.

The lack of PAH data and the lack of soil data collected at depth is a significant data gap leading to an inaccurate estimate of risk. It does not appear that all OU7 properties were individually sampled.

2.0 Remedial Action Objectives

2.2 Site-Specific Remedial Action Objectives, pg 8

- OU1-Soils:

Potential soil vapor migration issues must be considered in the remedial action objectives. The risk contribution of PAH exposures must be included before the designation of soils needing remediation. Additionally, the potential migration of site contamination into residential areas to the south (OU7) is equally probable in the residential area north of the site. Aerial photos show that the main operations and the Teepee burner were closer to residential areas on the north than OU7. Residential yards need to be individually sampled north of the tracts along Railroad St in order to provide accurate public health advice regarding dioxin levels in each yard.

- OU1-Groundwater:

A shallow water table and high levels of groundwater contaminants may contribute to potential future soil vapor exposures. Use of the State Risk-Based Guidance for the Vapor Intrusion Pathway would delineate a larger groundwater plume as an unacceptable risk (see Figure 3-3).

- OU2-Soils:

Soil impacts to other surrounding areas around OU2 need to be characterized. The dioxin soil levels on Division of Resource Management property illustrate the wider distribution of contaminated soils from past site activities, remedial actions and natural processes. Greater soil sampling density is warranted in OU2.

- OU7-Soils:

PAH exposures are equally probable in OU7 residential properties. Exposure to deeper soils is a concern without any soil data collected deeper than 6 inches.

2.4 Preliminary Remediation Goals (PRGs), pg 13.

MDH requests that PRGs be calculated using MN State cancer and non-cancer risk methodologies and criterion. Results should be presented in the same manner as International Paper's preferred PRGs (charts, figures, tables and graphs). Please provide electronic spread

sheets with all the cancer and non-cancer PRG calculations so the reader can review the derivations.

3.2 Media and Locations, pg 15

- OU1- Soil:

The 8 soil samples collected north of the track along Railroad Ave prove that properties have dioxin impacts. Although the dioxin concentrations were below 51 ppt, these samples were composites of multiple of yards and are not useful for communicating risk to individual property owners. Some individual properties could have dioxin levels far above 51 ppt. Furthermore, it is not reasonable to assume that the samples collected are average exposures when residents/children will be exposed primarily within their own property boundaries. This is another example of how the Saint Regis Human Health Risk Assessment does not adequately characterize potential risk to local residents. Note that potential sources for contamination such as the teepee burner and the wood treatment production facility were located next to the railroad tracks on the north edge of OU1 and closer to Railroad Street.

Large swaths of the site have not been sampled on the surface and most of the site has not been sampled at depth greater than a foot. Barr's own map shows that nearly all of OU1 was graded (see MDH Soil Health Consultation, August 20, 2004). The soil heterogeneity leads to greater uncertainty about the dioxins, PAHs and other site contaminant levels and extent. A greater number of samples are needed to characterize site contaminant levels.

No soil vapor samples have been collected on-site. Groundwater naphthalene concentrations are sufficiently high to pose a soil vapor concern based on MPCA guidance. The potential future soil vapor pathway was not considered in the HHRA.

- OU2- Soil: pg 16.

The dioxin soil impacts at the DRM property need be addressed.

- OU7- Soil: pg 16.

It is not reasonable to assume the clean soil cover is uniformly mixed with deeper soils when one digs into the soil as suggested in Table A-4. This assumption is also flawed because the site residential data consist of only surface soil data (≤ 1 ft deep). The deeper soils are a data gap.

The site is still under investigation, and two abandoned properties on the corner Norway (2nd Ave) and 3rd St South were graded by heavy equipment. These two properties were previously shown to have elevated levels of dioxin. The altered soil profile creates a data gap for these properties.

Appendix A

Derivation of Risk-Based Remediation Goals

A.1 Future Child Resident Scenario, pg A-1

It is unreasonable to assume uniform mixing of the contaminated EPC soil with temporary soil cap. MDH requested in its June 23, 2005 Interim Action letter to EPA, "that soil levels (contaminant concentrations) used to evaluate remedial actions not include the dilution caused by the interim action". There are no assurances that mixing is occurring or that it is mixed homogeneously. And, when does the exposure occur – before, during or after the mixing? Additionally, we have no soil data deeper than 6 inches in most areas.

MDH does not agree with IP's handling of the fish exposure pathway in the PRG derivations.



Introduction

Vapor intrusion is the migration of volatile compounds from the subsurface into overlying buildings or structures. This document provides an overview of the process to be used to assess the potential risk posed by vapor intrusion at sites undergoing investigation and cleanup within the Minnesota Pollution Control Agency (MPCA) Superfund Program, Resource Conservation and Recovery Act (RCRA) Corrective Action Program, and the Voluntary Investigation and Cleanup Program.

The intrusion of vapors from contaminated soil or ground water into buildings is a concern because inhalation of these vapors can pose a risk to human health. A vapor source, a migration route and a receptor must be present for the vapor intrusion pathway to be complete and pose a potential health risk. Relatively low concentrations of some volatile compounds in indoor air may pose long term chronic health risks if sufficiently long exposures occur. High concentrations of certain volatile compounds in indoor air have the potential to cause acute health risks. Most compounds of concern are volatile organic compounds (VOCs), although mercury in certain forms is sufficiently volatile and toxic to pose a vapor risk. Mercury vapor investigations are highly site-specific and are not discussed further in this guidance document. Any mercury spill or release to the environment must be closely coordinated with the MPCA.

Vapor sources can include soil, ground water contamination and light non-aqueous phase liquids (NAPL). Residential, commercial and industrial buildings may have other sources of indoor air contaminants that do not result from vapor intrusion. Examples include common household cleaning products, petroleum fuels, and industrial chemicals used in the workplace. These other sources of volatile compounds may be difficult to differentiate from vapor intrusion when investigating contamination of indoor air.

This vapor intrusion guidance document is supplemented by a Vapor Intrusion Technical Support Document (Technical Support Document) which provides more detailed technical guidance for evaluating the vapor intrusion pathway. This guidance document will be updated as necessary as the MPCA incorporates information from active Minnesota vapor intrusion sites. A vapor intrusion guidance document is also available from the MPCA Petroleum Remediation Program.

Overview of Vapor Intrusion Guidance

This document outlines the procedures for conducting initial vapor risk screening, receptor surveys, subsurface soil gas investigations, and building-specific investigations to evaluate risks to potential receptors and to make corrective action decisions. Potential receptors are defined for the purpose of this guidance as all occupied buildings, either existing buildings or those proposed as part of a planned development. This guidance emphasizes the use of empirical field data rather than the use of fate and transport modeling. However, information gathered during a vapor intrusion investigation should be incorporated into a descriptive site conceptual model to better understand and interpret the field data and to evaluate the source, fate and transport of subsurface vapors and their relationship to identified receptors.

Tiered Decision-Making Framework for Vapor Intrusion Investigations

The guidance utilizes a three-tiered risk-based approach for evaluating the vapor intrusion pathway. Each tier requires increasingly more site-specific information to determine if investigation at the next tier is needed or whether response actions are necessary. The need for taking more rapid action than the step-wise investigation approach described below should be considered if there is evidence of an imminent health risk.

- Tier 1: Evaluate existing historical site information and initial site investigation results to determine whether vapor intrusion represents a potential concern for nearby receptors.
- Tier 2: Collect subsurface soil gas samples overlying known vapor sources and near occupied or proposed buildings and evaluate the results within the context of the site conceptual model in order to identify the potential risk for vapor intrusion.

- Tier 3: Collect building-specific sub-slab and indoor air samples as necessary and complete an interior building inspection and indoor air quality inventory. If an unacceptable risk associated with vapor intrusion is indicated based on all lines of evidence, conduct appropriate response actions to eliminate vapor intrusion risks.

Important factors to consider when evaluating the vapor intrusion pathway include the type of vapor sources (e.g. soil contamination, ground water, NAPL), the characteristics of the compounds of concern, the extent and magnitude of soil vapor impacts, the nature of vapor migration pathways, site-specific geology, the location of buildings relative to the vapor sources and the soil vapor plume, and the use of these buildings. Detailed and site specific geologic cross-sections and plan-view maps are necessary to understand the three-dimensional model of vapor migration and to support the rationale for risk-based decisions.

Remedial actions, if necessary, may include source area remediation of soil or ground water, an active or passive building vapor mitigation system, building ventilation and pressurization, exposure pathway interruption (e.g., sealing of building openings) or a combination of remedial strategies. In many cases, buildings at risk can be mitigated through the use of the same technologies as used in the radon mitigation industry. A feature of this guidance is that if vapor intrusion risks are identified or suspected, remedial actions may be conducted at any stage of the investigation to proactively reduce identified or potential risks to receptors. This can result in bypassing some of the investigation steps in order to concentrate resources on corrective actions such as mitigation of buildings.

Vapor Intrusion Screening Values (ISVs)

The MPCA in cooperation with the Minnesota Department of Health have developed compound-specific inhalation risk screening values, referred to as Intrusion Screening Values (ISVs), for volatile compounds commonly evaluated during vapor investigations. The ISVs, provided in Table 1, were developed using information from the Minnesota Department of Health, the U.S. Environmental Protection Agency's (EPA) IRIS database, and other current toxicity data sources. The majority of the compounds listed in Table 1 have chronic ISVs that are based on lifetime chronic exposure. Some compounds also have acute ISVs that indicate the potential for adverse health effects from short term exposure to higher concentrations. Additivity of cancer and non-cancer risks may need to be considered at sites that have multiple compounds of concern, especially for evaluating risks posed by indoor air sampling results.

The ISVs are to be used as screening values for evaluating risks posed by volatile compounds identified in indoor air when those compounds are present due to vapor intrusion. Media-specific soil vapor, sub-slab and ground water screening values, based on conservative attenuation factors, are also provided in this guidance. An attenuation factor is a proportionality constant relating an indoor air concentration to a soil gas, sub-slab vapor or dissolved ground water concentration. Screening values are then calculated using the compound-specific ISV and the media-specific attenuation factor. Screening values for soil gas and sub-slab soil vapor samples are thus described as a factor of the ISVs (i.e., 10 or 100 times the ISVs) and are provided in Table 1 for reference. Ground water screening values are provided in Table 2 and are based on the compound's potential to volatilize from ground water to the overlying soil vapor phase and the compound-specific ISV. At industrial facilities that manufacture or use the potential chemicals of concern for the vapor intrusion pathway, the ISVs will not replace the applicable OSHA occupational exposure concentrations. At other receptor locations, however, the ISVs and the other media-specific screening values will be used to evaluate risks posed by vapor intrusion.

Tier 1: Initial Vapor Intrusion Pathway Screening

The potential for vapor intrusion to pose a risk to human health must be evaluated at sites in the Superfund RCRA and Voluntary Cleanup Section. It is recommended that Tier 1 screening be conducted concurrently with Phase I and initial Phase II environmental site assessments using the following steps:

1. Collect and review historical information about the site to determine if a release of VOCs has or may have occurred;
2. Conduct a receptor survey and determine whether there are receptors are located sufficiently near vapor sources for the vapor intrusion pathway to pose be a potential risk;
3. Characterize through sampling and analysis the extent and magnitude of VOC-impacted soil, ground water or NAPL (the potential vapor sources) and develop a subsurface soil gas sampling plan for Tier 2 evaluation if potential risks are identified.

Historical Records and Investigation Data Review

Sites with no historical use of volatile compounds and where site investigations identify no evidence of volatile compounds in soil or ground water require no further evaluation of the vapor intrusion pathway.

If the review of historical information indicates that the vapor intrusion pathway may be a concern, the subsequent screening steps (2 and 3) should be conducted concurrently to evaluate whether a) the soil or ground water contaminant concentrations are sufficiently high to pose a vapor intrusion risk and b) potential receptors are sufficiently close to any vapor source to indicate they may be at risk. When Tier 1 screening is conducted using only limited site sampling data, it is critical that the extent and magnitude of the volatile releases be at least sufficiently determined such that the screening can be based on the worst case areas associated with the release. If the distribution of soil or ground water contamination is uncertain or is due to an unknown source, a passive soil gas investigation may be appropriate to assist in determining the extent of soil and ground water contamination.

Receptor Survey and Area of Potential Concern

The purpose of the receptor survey is to document the type and use of buildings and their location relative to nearby vapor sources. A subsurface soil gas investigation (Tier 2) should be conducted if receptors are located within a 100-foot lateral distance of vapor sources (soil, ground water and NAPL). Soil contamination as a potential vapor source should be evaluated by collecting subsurface soil gas samples from the worst case soil contamination. If receptors are not located closer than 100 lateral feet to soil gas concentrations that are 10X-ISVs or higher, then the risk to those receptors are considered low and no further action at those buildings will likely be necessary. If receptors are located within 100 lateral feet to soil vapors with concentrations equal or greater than 10X-ISVs additional information will be necessary. If it is not possible to make this determination based on the available data then a subsurface soil gas investigation (Tier 2) is necessary. The use of the 100 foot lateral screening distance for ground water vapor sources is determined through the use of ground water screening values described below.

Ground Water Screening Values

Ground water screening values for volatile compounds (Table 2) have been developed for evaluating the relative potential risk posed by ground water contamination via the vapor intrusion pathway. Sampling results collected from dissolved ground water contamination at or near the water table (or perched water) should be compared with the compound-specific ground water screening levels. The ground water screening values, if exceeded, indicate the possibility that there may be a risk posed to indoor air via the vapor intrusion pathway.

If receptors are locations within 100 lateral feet to ground water contamination with concentrations that equal or exceed the ground water screening levels, then a subsurface soil gas investigation (Tier 2) should be conducted. If receptors are not located closer than 100 lateral feet to ground water contamination as determined by comparison with these screening levels, then the risk to those receptors are considered low and no further action at those buildings will likely be necessary unless the receptors are located within 100 feet of soil gas sample concentrations that are equal to or greater than 10X-ISVs.

Consider the Need for Rapid Action

If vapor intrusion is suspected to pose an existing or imminent threat to human health, then the three-tiered approach may be bypassed in favor of rapid action to assess and manage such risks. Examples of situations that may call for more rapid action are sites where elevated or even acute indoor air contamination is suspected based on NAPL identified beneath an occupied building, reports of vapor odors within the lower level of a building, or buildings with obvious vapor entry points (earthen floor areas, sumps, etc.) directly over highly contaminated shallow ground water. Appropriate rapid actions will be situation dependent and could involve immediately initiating a phased subsurface soil gas investigation; conducting sub-slab or indoor air sampling; installing a building mitigation system; or even the relocation of building occupants. When an acute or emergency hazard from vapor intrusion is suspected, the initial priority should be the immediate safety of the building occupants. The need to have such situations coordinated with the MPCA Emergency Response and Preparedness Section will be determined on a site-by-site basis.

Tier 2: Subsurface Soil Gas Investigation

A Tier 2 evaluation involves conducting a subsurface soil gas investigation overlying the vapor sources in the direction of nearby receptors within the area of potential concern as determined by the Tier 1 evaluation. The goal of the subsurface soil gas investigation is to better determine which receptors may be potentially at risk, based on a comparison of soil gas concentrations with the soil gas screening levels (Table 1). In some cases, soil gas data may have been collected as part of the initial site investigation. In other cases, additional investigation phases may be necessary to collect sufficient data to adequately define the extent and magnitude of soil gas contamination.

Soil Gas Sampling Methodologies and Strategies

EPA Method TO-15 is typically used for analysis of VOCs in soil vapor samples. When lower detection limits are required than are available with Method TO-15, the use of EPA Method TO-15-SIM may be appropriate. EPA Method TO-14 is sometimes recommended by laboratories and used in cases where contaminant concentrations in vapor samples are suspected to be relatively high. Soil vapor analyses conducted by mobile laboratories using EPA Method 8260 or 8021 may be appropriate in some situations for determining the extent and magnitude of subsurface soil gas, although at least 10 percent duplicate analyses by fixed-based laboratories (e.g. using Method TO-15) should be conducted for quality assurance and control purposes.

Subsurface soil gas sampling locations should be as close as possible to potential receptors. In situations where access to a site is restricted or in order to assess a larger area of concern, soil gas samples can be collected from public right-of-ways. For larger buildings, soil gas samples on multiple sides of the building may be needed to ensure adequate sampling density. The presence of subsurface utility corridors or geologic features that may act as preferential migration routes for soil gas should be considered when sampling plans are developed.

Subsurface soil gas sampling depths should be at least 2 feet above the water table or perched water, and at least 3 feet below the surface grade. Samples taken adjacent to or near a building with a basement should be collected from depths at or just below the basement floor slab (generally 8 to 10 feet below ground surface). For a slab-on-grade building, soil vapor samples should be collected from 3 to 5 feet below grade. When soil gas data has been collected in multiple locations near a particular receptor, the highest soil gas sample concentrations should be used for screening purposes.

The type of sampling strategy may vary depending upon the size of the site, the ability to obtain access to properties and uncertainties regarding the origin of the vapor sources. The vapor assessment may need to include confirmation sampling or seasonal monitoring. For additional information on sampling methods, sample collection techniques and investigation strategies refer to the Technical Support Document.

Evaluation of Tier 2 Subsurface Soil Gas Results

The decision points outlined below assume that the nature and extent of vapor sources and soil vapor impacts are known and that soil vapor data is consistent with site-wide spatial data trends. An understanding of the source, fate, and transport of subsurface vapors is necessary in order to evaluate potential risk to receptors and to make appropriate decisions about the need for vapor mitigation.

Subsurface Soil Gas Results Less than 10X-ISVs

A site with representative soil gas sampling results less than 10 times the ISVs is not considered to pose a risk to receptors. No additional action is necessary relative to the vapor intrusion pathway if supported by the site conceptual model.

Subsurface Soil Gas Results Between 10X-100X ISVs

A site with soil gas sampling results greater than 10 times the ISVs requires additional information to better quantify potential risks to nearby receptors. In many cases proceeding directly to a Tier 3 evaluation may be the most appropriate next step. Soil gas levels within this range may or may not represent a potential risk to nearby receptors. Factors to consider when evaluating the soil gas results includes whether preferential pathways for vapor migration may be present, the soil type, the property use of the buildings being evaluated, the type of building construction, the integrity of the foundation and whether other vapor entry points into the building are observed, and the spatial and temporal patterns of the soil gas plume relative to potential receptors.

The following building conditions would indicate lower potential risks that if supported by other lines of evidence could be used to support a no further action decision (all four conditions should apply):

1. The building type is commercial or industrial, and a lower sub-grade level, if present, is not occupied;
2. Positive pressurization of all occupied portions of the building through the use of a heating, ventilation, and air-conditioning (HVAC) system can be documented, and appropriate operation and maintenance procedures are in place;
3. A interior building inspection has been conducted and has not identified the presence of vapor entry points into the building, and
4. Spatial trends of soil gas data and evidence of ground water plume stability provide support that the soil gas concentrations are not likely to increase. This is also supported by temporal trends of soil gas data, if collected.

Note that an interior building inspection is a required component of a Tier 3 investigation and is also needed to provide support for a no action decision at a commercial or industrial building if a vapor mitigation system is not utilized. At buildings (i.e. residential, commercial or industrial) where vapor mitigation controls (e.g. the use of a vapor barrier and a sub-slab depressurization system) have been implemented or are proposed to be implemented, and whose remedial effectiveness can be verified, no additional action at the building will likely be necessary other than the appropriate specified operation and maintenance of the vapor mitigation system.

Subsurface Soil Gas Results >100X ISVs

If subsurface soil gas results exceed 100 times the ISVs, a Tier 3 investigation should be conducted to determine if a complete exposure pathway exists. If clear preferential pathways for vapor migration are observed in the building, corrective actions may need to be considered. Such actions, if implemented, should be closely coordinated with the MPCA.

Tier 3: Building Specific Vapor Investigations

The goal of a Tier 3 risk evaluation is to collect building-specific vapor sampling data and information regarding the building's construction and condition to determine whether there is a complete exposure pathway and unacceptable risks that require response actions. Building specific vapor sampling can include sub-slab, indoor air and outdoor ambient air sampling.

Interior Building Inspection and Indoor Air Quality Survey

An interior building inspection should be conducted during or prior to the collection of sub-slab samples. This inspection involves a physical examination of the interior of a building, particularly the building's lower level, to document any potential vapor entry locations, the type of building construction, the condition of the building floor and foundation, the type of ventilation, and information on the building use and occupants. Preferential pathways into the building that should be documented include sumps and floor drains, foundation drainage systems, elevator shafts, piping or other utility penetrations, wiring and ducts through the foundation. If earthen floors or crawl-spaces are present indoor air sampling should be conducted in addition to collecting sub-slab samples.

An indoor air quality survey is conducted to document the type and location of potential background sources of indoor air contamination. Many buildings typically have their own interior sources of indoor air contamination resulting from the presence of household cleaning or other chemical products, volatile compounds off-gassing from building materials, or commercial or industrial chemical use. Air quality impacts from these sources are referred to as interior background contamination. Additional guidance regarding how to conduct the interior building inspection and the indoor air quality survey, including an example reporting form, is provided in the Technical Support Document.

Sub-slab Soil Gas Sampling

Sub-slab soil gas samples are collected to characterize the magnitude and extent of soil gas contamination directly beneath the foundation slab of a building. To evaluate the spatial variation in sub-slab soil gas distribution, a minimum of one sub-slab sample should be collected for every 1000 square feet of building footprint or for every section of building separated by footings or foundations at different levels. For larger buildings (i.e. >5,000 square feet) a minimum of five sub-slab samples should be collected, spaced throughout the building footprint. If the results from these initial samples are greater than 10X-ISVs, another phase of sub-slab sampling should be conducted to provide better coverage throughout the building footprint. At some buildings, one sub-slab sampling event may be sufficient to assess potential risks and determine the appropriate next steps. At other buildings, two or more sub-slab sampling events may be necessary, particularly in cases where the extent and magnitude of the vapor source is not known, or where the sub-slab results are deemed inconclusive or anomalous.

Sub-slab samples are typically collected as grab samples using a vacuum gas canister (e.g. Summa®) and analyzed using Method TO-15. Detailed procedures for conducting sub-slab sampling are provided in the Technical Support Document.

Sub-slab Results Less than 10X-ISVs

The presence of volatile compounds in sub-slab soil gas at concentrations less than 10 times the ISVs indicates a low potential for indoor air risk and no further action at this building will be necessary.

Sub-slab Results Between 10X-ISVs and 100X-ISVs

Sub-slab soil gas concentrations within this range indicate a higher potential for risk associated with vapor intrusion. Residential homes typically represent a higher risk than many commercial or industrial buildings due to the longer average exposure duration of the occupants and the likelihood that a home's stack effect will produce a negative pressure within the building relative to sub-slab conditions. Necessary follow-up actions include the collection of representative indoor air samples to document existing conditions within the home or the preemptive installation of a vapor mitigation system.

A commercial or industrial building typically represents a lower risk if no vapor entry points are identified. A no further action decision for commercial or industrial buildings can be recommended if any identified vapor entry points have been thoroughly sealed; and

1. Indoor air sampling results indicate levels are below the ISVs; or
2. Positive pressurization of the interior of the entire building through the use of an HVAC system can be documented, or
3. A vapor mitigation system has been installed and the remedial effectiveness has been verified.

In the case of condition 2 and 3 above an appropriate operation and maintenance plan should be completed as appropriate based on site specific conditions.

Sub-slab Results Greater than 100X-ISVs

The presence of volatile compounds in sub-slab vapor samples at concentrations greater than 100X-ISVs should be followed by the collection of indoor air samples and/or remedial measures designed to eliminate the potential for vapors to enter the building. Building mitigation controls such as sealing vapor entry points and installing a depressurization system below the slab can eliminate or significantly reduce the potential for vapor intrusion. Even if indoor air samples show that a complete exposure pathway may not be present, the MPCA recommends that building mitigation controls be evaluated and possibly implemented as a best management practice, due to the uncertainties associated with foundation integrity and the possibility of minor building leaks allowing vapor intrusion.

Indoor Air Sampling

The goal of indoor air sampling is to determine if there is a complete exposure pathway due to vapor intrusion and whether mitigation is required to address unacceptable risks. Indoor air sampling may also be a required element of post-mitigation monitoring.

To allow a meaningful evaluation of indoor air data, the indoor air sampling event should include the collection of concurrent sub-slab vapor samples and outdoor ambient air background samples. Indoor air samples should be collected from the basement or lower level near suspected pathways for vapor entry and from commonly occupied spaces to assess the worst case exposure. Indoor air sampling from main or upper level floors may be appropriate in addition to sampling from lower levels especially if concentrations are detected above the ISVs in the lower level. Earthen floors, unsealed crawlspaces and sumps provide a direct preferential pathway for subsurface vapors to enter the building, and, if present, samples should be collected from these areas. One indoor air sample from the basement and from each floor will likely be sufficient for a typical single family residential home, whereas multiple indoor air sample locations are necessary for multi-family residential units and commercial or retail buildings.

Ambient air background sampling involves the collection of representative samples of the outdoor ambient air to determine if outside air sources of contamination may be contributing to indoor air contamination. An appropriate number of ambient air samples should be collected based on the size of the investigation area and the number and location of potential background sources. A minimum of one ambient air background sample for each building under investigation is recommended.

Indoor Air Sampling Methods

Indoor air samples should be collected as a 24-hour time-weighted sample using a vacuum gas canister and analyzed using Method TO-15 for the same list of compounds used for the analyses of subsurface soil gas and sub-slab samples. The vacuum gas canister sample port should be placed in the breathing zone, approximately 3 to 5 feet from the floor and preferably near the center of the room and away from windows. Samples should be collected under conditions representative of building use (i.e., doors open or closed and use of HVAC as is typical for the time of year). In summer months, however, windows should be closed at least 24 hours prior to sampling in order to minimize the contribution of outside air. It is recommended that an indoor air quality survey be completed at least two weeks prior to collecting indoor air samples, if possible, so that cooperation from the building occupants can be obtained and potential background sources of contamination can be removed or minimized prior to the sampling event.



Evaluating Indoor Air Results

Indoor air results are best interpreted through the use of multiple lines of evidence and a well understood site conceptual model. Factors that need to be considered when evaluating indoor air data include:

- background sources that may exist within or outside the building
- contaminants of concern and constituent ratios
- spatial patterns of vapor sources
- spatial and temporal trends of subsurface, sub-slab, and indoor air vapor results

Contaminants of concern for the vapor intrusion study should be clearly identified and should be determined based on the collective results of the ground water, soil gas and sub-slab investigations. Other compounds detected in indoor air are likely due to indoor or outdoor air background sources and should be clearly identified as such. Contaminants of concern that are identified in indoor air may be due to vapor intrusion or may in part be due to background sources. The results of the interior building inspection and indoor air quality inventory should be carefully evaluated to determine the potential for background sources of indoor air contamination.

When there are multiple contaminants of concern at a site, it may be helpful to compare their respective ratios in sub-slab samples to their ratios in indoor air samples. Ideally, the ratios of the contaminants of concern in the sub-slab samples would be comparable to the ratios of the same compounds in the indoor air, if the indoor air contaminants resulted from vapor intrusion. However, due to the spatial variability that can occur both beneath and within a building, this evaluation should be considered as only one line of evidence when evaluating indoor air results.

If it is determined that indoor air contamination is due to vapor intrusion, the data should be compared to the ISVs to determine if any contaminant exceeds its indoor air screening value. If exceedances of the indoor air screening levels are identified in occupied buildings, remedial actions will be necessary to eliminate the exposure pathway and any chronic or acute vapor intrusion risks. If the interpretation of the results is borderline or uncertainties exist with respect to spatial or temporal trends, then additional indoor air samples collected at different times of the year should be considered.

Response Actions for the Vapor Intrusion Pathway

Response actions for vapor intrusion are necessary for an existing building when there is evidence of a completed exposure pathway and the risks posed to human health are deemed unacceptable. The goal of response actions is to eliminate the pathway between the source of the vapors and receptors in a building. Response action is used here in a broad sense and refers to both source area remediation and building mitigation controls. Response actions are necessary for a new building when construction is planned in an area with documented soil gas impacts exceeding 10X the ISVs. Response actions can be conducted at any stage in the investigation and often may be the most efficient and cost-effective means of addressing potential vapor intrusion concerns. Additional guidance regarding the selection of appropriate remedial alternatives, post-remedial verification and monitoring, and closure criteria are provided in the Technical Support Document.

Response Action Alternatives

Source area remediation is the remediation of the contaminated soil, ground water or NAPL vapor sources. Source remediation can be effective to eliminate long term risks, although building mitigation or pathway interruption (e.g. sealing vapor entry points) may be necessary in the short term in order to eliminate risks to human health. Building mitigation technologies include: a) sealing potential points of vapor entry; b) sub-slab depressurization or sub-membrane depressurization (i.e. for crawl spaces); c) installation of a passive venting system and vapor barrier for new construction, and; d) the use of building pressurization or HVAC modification at commercial and industrial buildings. The selection of the appropriate response actions will be site specific and the proposed response action plan should be provided to MPCA staff for review and approval.

While sealing building vapor entry points should be conducted if they can be identified, these activities alone cannot be relied upon as a long term remedy to address vapor intrusion risks. Sub-slab depressurization is considered one of the most effective building technologies to eliminate vapor intrusion concerns and is similar to the technology typically used for radon mitigation. The design and construction of building mitigation systems may require civil, mechanical, electrical or plumbing design plans, permits and inspections. These activities should be overseen by appropriate experienced professionals. At commercial and industrial sites institutional controls may be appropriate if long term response actions are required involving the operation and maintenance of remedial systems or to document the presence of contamination.

Remedial Action Maintenance, Monitoring and Closure

Remediation systems, including building mitigation systems, should include appropriate maintenance and post-remedial verification monitoring. The specific monitoring and maintenance requirements for remedial systems will be site specific and depend on the type of remedial system used. Mitigation systems installed in buildings should be inspected after they are installed and during the first several months of operation to document that they are working effectively. Long term monitoring may be required for sites where risks to receptors would be potentially greater in the event of system failure or in cases where passive technologies rather than active remediation are employed. An Operations and Maintenance Plan should be prepared which outlines the responsibilities of various parties (i.e. developer, homeowner, landlord, etc.), action steps, and closure criteria.

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Table 1: Intrusion Screening Values (ISVs) for Vapor Intrusion Risk Evaluation - September 2008 Version

Refer to the Risk Based Guidance for the Vapor Intrusion Pathway for guidance in applying the ISVs

and the 10X and 100X-ISV factors that are used for both soil gas and sub-slab screening purposes.

Refer to the ISVs Excel Workbook worksheet tab labeled *Chemical Info* for chemical toxicity documentation.

Chemical	CAS #	Intrusion Screening Values (ISVs)	Basic	Source	10X ISVs	100X ISVs	Acute Intrusion Screening Values	Source
		($\mu\text{g}/\text{m}^3$)			($\mu\text{g}/\text{m}^3$)	($\mu\text{g}/\text{m}^3$)	($\mu\text{g}/\text{m}^3$)	
Acetone	67-64-1	400	NC	V	4,000	40,000	63,000	A
Benzene	71-43-2	4.5	C	M	45	450	1,000	M
Benzyl chloride	100-44-7	0.2	C	C	2	20	240	C
Bromodichloromethane	75-27-4	0.6	C	V	6	60	NA	
Bromoform	75-25-2	9	C	I	90	900	NA	
Bromomethane (Methyl Bromide)	74-83-9	5	NC	M	50	500	2,000	M
1,3-Butadiene	106-99-0	0.3	C	M	3	30	NA	
2-Butanone (Methyl ethyl ketone, MEK)	78-93-3	5,000	NC	I	50,000	500,000	10,000	M
Carbon disulfide	75-15-0	700	NC	M	7,000	70,000	6,000	M
Carbon tetrachloride	56-23-5	0.7	C	I	7	70	1,900	C
Chlorobenzene	108-90-7	50	NC	E	500	5,000	NA	
Chloroethane (Ethyl chloride)	75-00-3	10,000	NC	I	100,000	1,000,000	100,000	M
Chloroform	67-66-3	100	NC	A	1,000	10,000	150	M
Chloromethane (Methyl chloride)	74-87-3	6	C	H	60	600	1,000	A
Cyclohexane	110-82-7	6,000	NC	I	60,000	600,000	NA	
Dibromochloromethane	124-48-1	0.4	C	V	4	40	NA	
1,2-Dibromoethane (Ethylene dibromide)	106-93-4	0.02	C	I	0.2	2	NA	
1,2-Dichlorobenzene	95-50-1	200	NC	H	2,000	20,000	NA	
1,3-Dichlorobenzene	541-73-1	100	NC	V	1,000	10,000	NA	
1,4-Dichlorobenzene	106-46-7	60	NC	A	600	6,000	12,000	A
1,1-Dichloroethane	75-34-3	500	NC	H	5,000	50,000	NA	
1,2-Dichloroethane	107-06-2	0.4	C	I	4	40	NA	
1,1-Dichloroethene (DCE)	75-35-4	200	NC	I	2,000	20,000	NA	
cis-1,2-Dichloroethene	156-59-2	40	NC	V	400	4,000	NA	
trans-1,2-Dichloroethene	156-60-5	60	NC	E	600	6,000	825	A
Dichlorodifluoromethane (Freon 12)	75-71-8	200	NC	H	2,000	20,000	NA	
1,2-Dichloropropane	78-87-5	4	NC	I	40	400	235	A
cis-1,3-Dichloropropene*	10061-01-5	3	C	I	30	300	NA	
trans-1,3-Dichloropropene*	10061-02-6	3	C	I	30	300	NA	
Dichlorotetrafluoroethane	76-14-2	NA			NA	NA	NA	

Table 1: Intrusion Screening Values (ISVs) for Vapor Intrusion Risk Evaluation - September 2008 Version

		Intrusion Screening Values (ISVs)	Basis	Source	10X ISVs	100X ISVs	Acute Intrusion Screening Values	Source
Chemical	CAS #	($\mu\text{g}/\text{m}^3$)			($\mu\text{g}/\text{m}^3$)	($\mu\text{g}/\text{m}^3$)	($\mu\text{g}/\text{m}^3$)	
Ethanol	64-17-5	15,000	NC	M	150,000	1,500,000	180,000	M
Ethyl acetate	141-78-6	3,000	NC	M	30,000	300,000	40,000	M
Ethylbenzene	100-41-4	1000	NC	I	10,000	100,000	10,000	M
4-Ethyltoluene	622-96-8	NA			NA	NA	NA	
n-Heptane	142-82-5	NA			NA	NA	NA	
Hexachloro-1,3-butadiene	87-68-3	0.5	C	I	5	50	NA	
n-Hexane	110-54-3	2,000	NC	M	20,000	200,000	NA	
2-Hexanone	591-78-6	NA			NA	NA	NA	
Mercury (Inorganic)	7439-97-6	0.3	NC	I	3	30	1.8	C
4-Methyl-2-pentanone (Methyl isobutyl ketone, MIBK)	108-10-1	3,000	NC	I	30,000	300,000	NA	
Methylene Chloride (Dichloromethane)	75-09-2	20	C	M	200	2,000	10,000	M
2-Methylnaphthalene	91-57-6	70	NC	V	700	7,000	NA	
Methyl-tert-butyl ether (MTBE)	1634-04-4	3,000	NC	I	30,000	300,000	7,300	
Naphthalene	91-20-3	9	NC	M	90	900	NA	
Polychlorinated biphenyls (PCBs)	1336-36-3	0.1	C	I	1	10	NA	
2-Propanol (Isopropyl alcohol)	67-63-0	7,000	NC	C	70,000	700,000	3,200	C
Propylene (Methylethylene)	115-07-1	3,000	NC	C	30,000	300,000	NA	
Styrene	100-42-5	1,000	NC	M	10,000	100,000	21,000	M
1,1,2,2-Tetrachloroethane	79-34-5	0.2	C	I	2	20	NA	
Tetrachloroethylene (PCE)	127-18-4	20	C	M	200	2,000	20,000	M
Tetrahydrofuran	109-99-9	NA			NA	NA	NA	
Toluene (Methylbenzene)	108-88-3	5,000	NC	I	50,000	500,000	37,000	M
1,2,4-Trichlorobenzene	120-82-1	4	NC	E	40	400	NA	
1,1,1-Trichloroethane (Methyl chloroform)	71-55-6	1,000	NC	E	10,000	100,000	140,000	M
1,1,2-Trichloroethane	79-00-5	0.6	C	I	6	60	NA	
Trichloroethylene (TCE)	79-01-6	3	C	M	30	300	2,000	M
Trichlorofluoromethane (Freon 11)	75-69-4	700	NC	H	7,000	70,000	NA	
1,1,2-Trichlorotrifluoroethane (CFC-113)	76-13-1	30,000	NC	H	300,000	3,000,000	NA	
1,2,4-Trimethylbenzene	95-63-6	7	NC	E	70	700	NA	
1,3,5-Trimethylbenzene	108-67-8	6	NC	E	60	600	NA	
Vinyl acetate	108-05-4	200	NC	M	2,000	20,000	NA	
Vinyl chloride	75-01-4	1	C	M	10	100	180,000	C
m&p-Xylene**	108-38-3	100	NC	I	1,000	10,000	43,000	M
o-Xylene**	95-47-6	100	NC	I	1,000	10,000	43,000	M

Table 1: Intrusion Screening Values (ISVs) for Vapor Intrusion Risk Evaluation - September 2008 Version

NOTES:

* based on 1,3-Dichloropropene cas # 542-75-6

** based on total xylenes cas # 1330-20-7

NA - No toxicity data available

Basis: C = based on carcinogenicity; NC = based on noncancer health effects

Source: I = EPA IRIS; E = EPA NCEA; M = MDH; H = HEAST; A = ATSDR; C = CalEPA; V = EPA VI Guidance

Screening value calculations:

non-cancer: = (RfC)(Hazard Quotient)

HQ = 1

RfC in $\mu\text{g}/\text{m}^3$

cancer: = (additional lifetime risk) / (Unit Risk Factor)

additional lifetime risk = 10E^{-5}

URF in $\mu\text{g}/\text{m}^3$

Table 2: Ground Water Screening Values for Vapor Intrusion Pathway (GW_{ISV})

MPCA Superfund Section - September 2008 Version

Refer to the Risk Based Guidance for the Vapor Intrusion Pathway for guidance in applying the ground water screening values

CHEMICAL	CAS #	Henry's Law Constant* (Hcc)	Henry's Law Constant* (Hcc)	Source*	Intrusion Screening Value	GW _{ISV}
		25° C	10° C		(ug/m3)	Based on α of 0.001*
		dimensionless	dimensionless		(ug/m3)	(ug/L)
Acetone	67-64-1	1.58E-03	8.43E-04	e	400	500000
Benzene	71-43-2	2.26E-01	1.14E-01	e	4.5	40
Benzyl chloride	100-44-7	1.69E-02	6.21E-03	c	0.2	30
Bromodichloromethane	75-27-4	6.52E-02	3.12E-02	e	0.6	20
Bromoform	75-25-2	2.40E-02	8.43E-03	e	9	1000
Bromomethane (Methyl Bromide)	74-83-9	2.54E-01	1.64E-01	c	5	30
1,3-Butadiene	106-99-0	3.00E+00	2.00E+00	c	0.3	0.2
2-Butanone (Methylethylketone, MEK)	78-93-3	2.28E-03	1.12E-03	c	5000	4000000
Carbon disulfide	75-15-0	1.24E+00	7.15E-01	c	700	1000
Carbon tetrachloride	56-23-5	1.24E+00	6.42E-01	e	0.7	1
Chlorobenzene	108-90-7	1.51E-01	6.52E-02	w	50	800
Chloroethane (Ethyl chloride)	75-00-3	3.60E-01	2.75E-01	w	10000	40000
Chloroform	67-66-3	1.50E-01	7.94E-02	e	100	1000
Chloromethane (Methyl chloride)	74-87-3	3.60E-01	2.49E-01	c	6	20
Cyclohexane	110-82-7	6.13E+00	3.15E+00	c	6000	2000
Dibromochloromethane	124-48-1	3.19E-02	1.81E-02	e	0.4	20
1,2-Dibromoethane (Ethylene dibromide)	106-93-4	3.03E-02	1.27E-02	c	0.02	2
1,2-Dichlorobenzene	95-50-1	7.75E-02	2.80E-02	e	200	7000
1,3-Dichlorobenzene	541-73-1	1.26E-01	5.21E-02	w	100	2000
1,4-Dichlorobenzene	106-46-7	9.79E-02	3.74E-02	e	60	2000
1,1-Dichloroethane	75-34-3	2.29E-01	1.23E-01	e	500	4000
1,2-Dichloroethane	107-06-2	3.99E-02	1.94E-02	e	0.4	20
1,1-Dichloroethene (DCE)	75-35-4	1.06E+00	6.35E-01	e	200	300
cis-1,2-Dichloroethene	156-59-2	1.66E-01	8.68E-02	e	40	500
trans-1,2-Dichloroethane	156-60-5	3.82E-01	2.12E-01	e	60	300
Dichlorofluoromethane (Freon 12)	75-71-8	1.40E+01	2.85E+00	c	200	70

Table 2: Ground Water Screening Values for Vapor Intrusion Pathway (GW_{ISV})

CHEMICAL	CAS #	Henry's Law Constant* (Hcc)	Henry's Law Constant* (Hcc)	Source*	Intrusion Screening Value	GW _{ISV}
		25° C	10° C			Based on α of 0.001*
		dimensionless	dimensionless		(ug/m3)	(ug/L)
1,2-Dichloropropane	78-87-5	1.14E-01	5.50E-02	e	4	70
cis-1,3-Dichloropropene	10061-01-5	1.11E-01	4.75E-02	c	3	60
trans-1,3-Dichloropropene	10061-02-6	3.56E-02	1.73E-02	c	3	200
Dichlorotetrafluoroethane (Freon 114)	76-14-2	1.14E+02	6.37E+01	c	NA	NA
Ethanol	64-17-5	2.04E-04	8.43E-05	c	15000	200000000
Ethyl acetate	141-78-6	5.63E-03	2.71E-03	c	3000	1000000
Ethylbenzene	100-41-4	3.21E-01	1.35E-01	e	1000	7000
4-Ethyltoluene	622-96-8	2.04E-01	7.75E-02	c	NA	NA
n-Heptane	142-82-5	8.17E+01	3.89E+01	c	NA	NA
Hexachloro-1,3-butadiene	87-68-3	3.32E-01	1.11E-01	c	0.5	5
n-Hexane	110-54-3	6.80E+01	3.59E+01	c	2000	60
2-Hexanone	591-78-6	3.81E-03	1.59E-03	c	NA	NA
Mercury (Inorganic)	7439-97-6	4.38E-01	1.25E-01	e	0.3	2
4-Methyl-2-pentanone (Methyl isobutyl ketone)	108-10-1	5.63E-03	2.46E-03	c	3000	1000000
Methylene Chloride (Dichloromethane)	75-09-2	8.93E-02	4.99E-02	e	20	400
2-Methylnaphthalene	91-57-6	2.11E-02	6.49E-03	c	70	10000
Methyl-tert-butyl ether (MTBE)	1634-04-4	2.55E-02	1.30E-02	w	3000	200000
Napthalene	91-20-3	1.97E-02	6.35E-03	e	9	1000
Polychlorinated biphenyls (PCBs)	1336-36-3	1.20E-01	2.69E-02	c	0.1	4
2-Propanol (Isopropyl alcohol)	67-63-0	3.23E-04	1.29E-04	c	7000	50000000
Propylene (Methylethylene)	115-07-1	8.01E+00	6.14E+00	c	3000	500
Styrene	100-42-5	1.12E-01	4.58E-02	e	1000	20000
1,1,2,2-Tetrachloroethane	79-34-5	1.41E-02	5.63E-03	e	0.2	40
Tetrachloroethylene (PCE)	127-18-4	7.50E-01	3.31E-01	w	20	60
Tetrahydrofuran	109-99-9	2.88E-03	1.48E-03	c	NA	NA
Toluene (Methylbenzene)	108-88-3	2.71E-01	1.24E-01	e	5000	40000
1,2,4-Trichlorobenzene	120-82-1	5.79E-02	1.83E-02	e	4	200
1,1,1-Trichloroethane (Methyl chloroform)	71-55-6	7.01E-01	3.62E-01	e	1000	3000
1,1,2-Trichloroethane	79-00-5	3.72E-02	1.64E-02	e	0.6	40

Table 2: Ground Water Screening Values for Vapor Intrusion Pathway (GW_{ISV})

CHEMICAL	CAS #	Henry's Law Constant* (H _{cc})	Henry's Law Constant* (H _{cc})	Source*	Intrusion Screening Value	GW _{ISV}
		25° C	10° C			Based on α of 0.001*
		dimensionless	dimensionless		(ug/m3)	(ug/L)
Trichloroethylene (TCE)	79-01-6	4.21E-01	2.04E-01	w	3	20
Trichlorofluoromethane (Freon 11)	75-69-4	3.95E+00	2.17E+00	c	700	300
1,1,2-Trichlorotrifluoroethane (CFC-113)	76-13-1	1.96E+01	1.18E+01	c	30000	3000
1,2,4-Trimethylbenzene	95-63-6	2.51E-01	9.48E-02	c	7	70
1,3,5-Trimethylbenzene	108-67-8	2.40E-01	9.08E-02	c	6	70
Vinyl acetate	108-05-4	2.08E-02	1.03E-02	c	200	20000
Vinyl chloride	75-01-4	1.10E+00	7.50E-01	e	1	1
m&p-Xylene	108-38-3	2.99E-01	1.25E-01	e	100	800
o-Xylene	95-47-6	2.12E-01	8.69E-02	e	100	1000

NOTES:

* $GW_{ISV} = ISV / (\alpha * 1000 L/m^3 * H_{cc})$, where

- a) GW_{ISV} is the ground water screening value in ug/L
- b) The screening values are based on an dimensionless attenuation factor (α) of 0.001
- c) H_{cc} is the dimensionless Henry's Law Constant dimensionless form based on concentrations (volumetric basic)
- d) ISV is the compound-specific Intrusion Screening Value in units of ug/m^3 , based on chronic risk, if available;
- e) NA indicates that an ISV has not been developed.

*Ground water-to-indoor-air attenuation factors are generically calculated by dividing a measured indoor air concentration by the vapor concentration calculated from the estimated ground water concentration.

The attenuation factor, (α) of 0.001 is based on data compiled and documented in U.S. EPA's Vapor Intrusion Database: "Preliminary Evaluation of Attenuation Factors, March 4, 2008," which identifies this value as corresponding with the 95th Percentile attenuation factor based on 1229 ground water and indoor air attenuation from 36 different sites.

* Henry's Law Constants are a function of temperature and for the GWSLs are based on an average ground water temperature in Minnesota of 10°C.

The source of the temperature corrected Henry's Law Constants are the following:

- e = from the USEPA online calculator available at: <http://www.epa.gov/athens/learn2model/part-two/onsite/esthenry.htm> with calculations based on the Clausius-Clapeyron relationship as discussed in the USEPA Fact Sheet

Table 2: Ground Water Screening Values for Vapor Intrusion Pathway (GW_{ISV})

NOTES (cont):

(June 2001), "Correcting the Henry's Law Constant for Soil Temperature."

w = from the USEPA on-line calculator with calculations based on methods developed by Washington (1996)

Washington, J., 1996, "Gas partitioning of dissolved volatile organic compounds in the vadose zone: Principles, temperature effects and literature review," *Ground Water*, 34(4), 709-718.

c = calculated using the Clausius-Clapeyron relationship using the guidance provided in the USEPA 2001 Fact Sheet and physical constants obtained principally from the National Library of Medicine Hazardous Substances Data Bank (HSDB) available on-line at: <http://toxnet.nlm.gov/index.html>.

* The majority of the Henry Law Constants used to calculate the temperature adjusted values were obtained from the chemical table of the U.S. EPA Vapor Intrusion Database available at: <http://iavi.rti.org/>

Henry's Law Constants for ethanol and 2-propanol was obtained from the California Air Resources Board chemical database; and the values for the dichloropropenes were obtained from the Draft ASTDR toxicological profile for Dichloropropenes, ATSDR, 2006; the value for PCBs (based on Aroclor 1254) and propylene were obtained from the HSDB.

* The 10° C temperature value used for the temperature-adjusted Henry's Law Constants was chosen to represent an estimated average temperature for shallow Minnesota ground water. This value was estimated using a combination of the ground water temperature map in Collins, W.D., 1925, "Temperature of Water Available for Industrial Use in the United States, United States Geological Survey, Water Supply Paper 520-F," referenced on the USEPA on-line calculator Web page.

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