



**New Jersey
Department of Environmental Protection**



**Site Remediation and
Waste Management Program**

Capping of Volatile Contaminants for the Impact to Ground Water Pathway

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1.0 Introduction

Previously, capping as a remedial option to prevent contaminants from impacting the ground water was not permitted by the New Jersey Department of Environmental Protection (Department or NJDEP), although capping has been allowed at sites for other reasons if the remedy for the Impact to Ground Water Pathway did not depend on the presence of the cap. In 2014, the Department released *Capping of Inorganic and Semi-volatile Contaminants for the Impact to Ground Water Pathway* guidance that allows for capping of inorganic and semi-volatile organic contaminants as a method to specifically address the impact to ground water pathway under certain conditions

(www.nj.gov/dep/srp/guidance/rs/). Volatile contaminants were not included in the 2014 guidance because these contaminants may still migrate downwards, even in the absence of infiltrating rainwater when a site is capped, via vapor phase diffusion. This complicating factor regarding the capping of volatiles has now been addressed and capping as a remedy for addressing exceedances of default Impact to Ground Water Soil Screening Levels (IGWSSLs) and/or site-specific Impact to Ground Water Soil Remediation Standards (IGWSRSs) is now permitted under certain conditions for volatile contaminants.

Volatile contaminants are defined as those with Henry's law constants greater than $10^{-5} \text{ atm}^{-3} \text{ mol}^{-1}$ and vapor pressures greater than 1 mm Hg at 25°C. These contaminants are listed in Table 1. The conditions under which volatile organic contaminant exceedances of IGWSSLs and/or site-specific impact IGWSRSs are allowed under a capped site are presented in this guidance document. By definition, this is a restricted use remedial action and therefore a deed notice is required pursuant to N.J.A.C. 7:26 C. All remediation involving deed notices require a Remedial Action Permit (RAP) for soil for the long-term maintenance of this engineering control.

In all cases, the maintenance of a low permeability cap will be required until default IGWSSLs or site-specific IGWSRSs are achieved. Additionally, free and residual product must be removed to the extent practicable, as discussed later in this document.

Under the purview of this guidance, sites are handled differently based on whether or not ground water is contaminated with volatile organic chemicals.

Sites with contamination in the vadose zone, but not the ground water, require measurement of soil vapor concentrations at appropriate locations and comparison of these concentrations to Impact to Ground Water Soil Vapor Screening Levels (IGW-SVSLs) to demonstrate that existing volatile contamination in the vadose zone does not pose a risk for impact to ground water. A substantial portion of this guidance document explains development and application of IGW-SVSLs. Refer to Section 6 of this document.

Sites with existing ground water contamination that is at least partly due to a previous discharge into the vadose zone may be handled, with additional restrictions, according to currently established procedures described in the *Ground Water Technical Guidance: Site Investigation, Remedial Investigation, and Remedial Action Performance Monitoring* (www.nj.gov/dep/srp/guidance/). The procedures include the establishment of a Classification Exception Area (CEA) for the ground water (see *Final Guidance on Designation of Classification Exception Areas* available at: www.nj.gov/dep/srp/guidance/cea/cea_guide.htm)

and demonstration of Monitored Natural Attenuation (MNA) (see *Monitored Natural Attenuation Technical Guidance* available at www.nj.gov/dep/srp/guidance/). Refer to Section 5 of this document.

Volatile petroleum hydrocarbons pose less of a risk for ground water contamination than other volatile organic compounds (VOCs), due to their tendency to degrade during transport, even through short distances. As such, the use of vertical separation distances (which may also be used in vapor intrusion assessments) or the evaluation of these contaminants using the SESOIL model may be appropriate prior to using the capping approach. For further information, see the SESOIL guidance documents (www.nj.gov/dep/srp/guidance/rs/) and Section 7 of this document.

In 2012, the Department established a committee to review and update existing guidance for the Impact to Ground Water pathway. The committee includes stakeholders and Department staff. This guidance document represents the work of this committee, which was comprised of the following individuals:

Swati Toppin, Ph.D., Chair, NJDEP

Barry Frasco, Ph.D., NJDEP

MaryAnne Kuserk, NJDEP

Paul Sanders, Ph.D., NJDEP

Matthew Turner, NJDEP

Stephen Posten, LSRP, Wood Environment and Infrastructure Solutions, Inc.

Michael Gonshor, LSRP, Roux Associates, Inc.

2.0 Background

Contaminant concentrations in soil that exceed default IGWSSLs or site-specific IGWSRSs represent a potential contamination threat to ground water. While inorganic and semi-volatile contaminants are primarily mobilized and impact the ground water via ground water recharge from infiltrating rain water or runoff, volatile contaminants may also migrate downward to ground water via vapor phase diffusion and advection, even in the absence of infiltrating water (USEPA, 2015a; Oostrom et al. 2010; Pasteris et al., 2002; Hartman, 1998). For this reason, simply capping contaminated sites to prevent downward migration of volatile contaminants to the ground water via water infiltration may not be sufficient.

While quantitatively modeling downward vapor phase diffusion through soil is relatively straightforward, intermittent upward or downward soil gas advection is harder to model. Additionally, the rate of transfer of a contaminant across the interface from the vadose zone vapor phase into the ground water appears to be an area needing further research (Truex et al., 2009). The two primary difficulties are 1) complications involving the effect of variable moisture in the capillary zone (USEPA 2004) and 2) uncertainties in adapting models that are normally used to predict transfer of volatiles from water to the vapor phase when both phases are well-mixed. The vadose zone and ground water phases are not well-mixed and contain a solid (soil) phase. Generally accepted procedures for quantitatively predicting the transfer rate across the soil vapor-ground water interface and the subsequent dispersion and dilution of contaminants entering the ground water immediately under an area of concern when no ground water recharge is occurring (i.e., for a capped site) have not been established.

For the reasons stated above, a simple procedure has been developed for determining whether a potential threat to ground water exists when a volatile contaminant above the default IGWSSL or site-specific

IGWSRS is present under a capped site. This procedure is used when ground water is currently uncontaminated. For cases where ground water is already contaminated, an MNA approach may be used (with additional requirements) to manage the site. Both types of cases require the installation of a low permeability cap, upgrading an existing cap to one that exhibits low permeability, ongoing maintenance and monitoring of the low permeability cap, and removal of free and residual product, as practicable.

3.0 Cap Selection

Low permeability caps, which minimize infiltration of precipitation, are required when addressing the Impact to Ground Water pathway. As described in the *Technical Guidance on the Capping of Sites Undergoing Remediation* (www.nj.gov/dep/srp/guidance/), typical materials used in the construction of low permeability caps for the purpose of reducing water infiltration include, but are not limited to, concrete building foundations, geomembranes, clay barriers, geosynthetic clay liners, Portland concrete, and bituminous concrete (asphalt). Permeable caps such as gravel caps, soil caps, and soil with vegetative cover are not an appropriate remedy for this pathway because mobilization of contaminants may occur via infiltrating precipitation. During cap design and selection, it is advisable to account for the concentrations of remaining contaminants with respect to all exposure pathways and current and future land use.

Leaving contaminant concentrations in soil that are in excess of default IGWSSLs and/or site-specific IGWSRSs pose a risk to the underlying ground water if the cap is breached or if site conditions do not allow for the maintenance of a long-term cap. Therefore, the suitability of capping as a remedy for the impact to ground water pathway should be evaluated on a site-by-site basis.

New or existing caps must be low permeability caps and prevent infiltration of precipitation and runoff. Existing caps such as parking lots may have numerous cracks or other preferential pathways for rainfall and runoff infiltration, and their suitability as low permeability caps should be assessed. In contrast to caps used solely to address the direct contact pathway, cracks or other damage or deterioration must be repaired or sealed to prevent infiltration of water to the vadose zone.

The cap should extend far enough beyond the boundaries of the contaminated area to prevent infiltrating water near the edges of the cap from laterally moving underneath the cap and reaching the contaminated zone. This potential concern is magnified if there is no storm water collection system, as uncontrolled sheet flow can significantly increase the amount of infiltrating water around the edges of the cap. Therefore, at a minimum, all federal, state and local regulations for storm water management should be implemented.

4.0 Free and Residual Product Removal

Free or residual product must be addressed in accordance with the Technical Requirements for Site Remediation at N.J.A.C. 7:26E-5.1(e), which states, “The person responsible for conducting the remediation shall treat or remove free product and residual product to the extent practicable, or contain free product and residual product when treatment or removal is not practicable.”

5.0 Vadose Zone and Ground Water Contaminated with Volatile Organic Compounds

[Figure 1 Ground Water Contaminated](#)

When the ground water is already contaminated with VOCs, and the contamination is at least partly due to a previous discharge in the vadose zone, MNA can be used to demonstrate that, while contamination to the ground water from the vadose zone may still be occurring, the contribution from the vadose zone is decreasing and is predicted to cease by the end of the CEA timeframe that is established for the contaminated ground water, as indicated in the *Monitored Natural Attenuation Technical Guidance* (www.nj.gov/dep/srp/guidance/). The decreasing concentration trends required to demonstrate natural attenuation are assumed to include the decreasing impact of vadose zone vapor transport to ground water. The vertical vapor concentration profile in the vadose zone, and its resultant vapor impact on the ground water, is assumed to reach steady-state within several months, due to the rate of vapor-phase diffusion. This assumption is also made for the vapor intrusion pathway when assessing vapor impacts on buildings due to contaminated ground water (USEPA 2015a). While transport of a contaminant across the vadose zone-ground water interface into the ground water is a slower process (which may take somewhat longer to reach steady-state conditions), the two-year (eight quarter) monitoring period to establish natural attenuation is considered an adequate timeframe for this process to occur.

The flowchart provided in Figure 1 outlines the procedure to be followed when assessing the potential impact to ground water of VOCs in the vadose zone. Flow chart components are numbered for reference in the following discussion. First, a CEA for the site must be established, with a discrete (not indeterminate) time frame (1.0, 1.1). If the site is not already capped (2.0, “No”), demonstration of natural attenuation will need to be performed after the site is capped (2.1), since the capping process will eliminate infiltrating water, increase the soil gas airspace (dry out the soil), and result in an increased potential for vapor phase transport to the ground water. If a site does have a low permeability cap over the area of concern, but MNA was not demonstrated prior to cap installation (3.0, “No”), MNA will need to be demonstrated again (3.1), for the same reason discussed above. If MNA has been demonstrated while an existing low permeability cap has been in place over the area of concern (3.0, “Yes”), then the impact to ground water pathway has been adequately addressed, but it should be ensured that vapor intrusion is not of concern. If ground water concentrations of VOCs exceed vapor intrusion Ground Water Screening Levels (GWSSLs) within trigger distances from existing buildings, (4.0, “Yes”), a vapor intrusion investigation should be performed in accordance with the *Vapor Intrusion Technical Guidance* (www.nj.gov/dep/srp/guidance/vaporintrusion/)(4.1). Applications both for soil and ground water RAPs should then be submitted (*Remedial Action Permits for Soils Guidance*, www.nj.gov/dep/srp/guidance/; *Ground Water Remedial Action Permit Guidance*, www.nj.gov/dep/srp/guidance/) (5.0) and subsequently approved by the Department (6.0). The soil RAP will need to include the requirement that the capping conditions used to demonstrate MNA are maintained until default IGWSSLs and/or site-specific IGWSRSs are achieved (7.0).

If MNA cannot be demonstrated following capping, the impact to ground water pathway for this scenario has not been addressed, and the MNA guidance document should be consulted (3.1). Further investigation, source removal, and/or source treatment may be required.

6.0 Vadose Zone Contaminated with Volatile Organic Compounds and Ground Water Uncontaminated

[Figure 2 Ground Water Uncontaminated](#)

In cases where capped volatile contamination exists in the vadose zone, but the ground water is currently uncontaminated, soil vapor samples must generally be taken in the vadose zone and compared with IGW-SVSLs to ascertain the potential impact of the vadose zone contamination on the ground water. The sections below describe the development of IGW-SVSLs and their use at sites where this situation exists.

6.1 Development of Impact to Ground Water Soil Vapor Screening Levels – Background

To develop IGW-SVSLs, it is assumed that equilibrium partitioning of a volatile contaminant occurs between measured vapor phase concentrations in the contaminated soil at the site and the ground water. IGW-SVSLs (not to be confused with sub-slab soil gas screening levels associated with vapor intrusion (VI) investigations), have been developed for application in this technical guidance document. The IGW-SVSLs are calculated from the health-based New Jersey Ground Water Quality Criterion (NJ GWQC), the Henry's law constant for the chemical, and the default dilution-attenuation factor (DAF) of 20 (Table 1). The DAF predicts dilution into the ground water when ground water recharge is occurring. In the absence of this recharge, the actual dilution of a contaminant into ground water would be greater, since transfer into ground water is much slower when it only occurs via diffusion. As discussed earlier, quantifying the actual DAF under these conditions is difficult due to theoretical uncertainties in its calculation. For this reason, the default DAF of 20 is used for these screening levels and is considered to be adequately protective.

It may be argued that the IGW-SVSLs are equally conservative as the default impact to ground water soil screening levels, since they simply assume equilibrium partitioning. However, the IGW-SVSLs are compared to direct measurements of the vapor concentrations of contaminants that have been released from the soil sorbed phase. This procedure bypasses the uncertainty of predicting contaminant desorption from soil and quantifies the actual contaminant concentration in the vapor phase that may diffuse directly downward to the ground water. As a result, the IGW-SVSLs are less conservative than the IGW soil screening levels since the uncertainty in one step of the contaminant transport process has been removed from their calculation.

6.2 Calculation of Impact to Ground Water Soil Vapor Screening Levels

IGW-SVSLs are calculated using the equation for the Henry's law constant, rearranged to predict acceptable soil vapor phase concentrations from the NJ GWQC, combined with the additional dilution provided by the DAF, as follows:

$$\text{IGW-SVSL} = \text{GWQC} * 1000\text{L/m}^3 * H * \text{DAF}$$

Where:

- GWQC is the health-based New Jersey Ground Water Quality Criterion ($\mu\text{g/L}$),
- H is the Henry's law constant at 13°C (dimensionless),
- DAF is the New Jersey default dilution-attenuation factor of 20 (dimensionless), and
- IGW-SVSL is the Impact to Ground Water Soil Vapor Screening Level ($\mu\text{g/m}^3$).

Henry's law constants at 13°C are used because this is the average temperature of shallow ground water in New Jersey. This temperature is also used for Department Vapor Intrusion Ground Water Screening Levels and associated Johnson & Ettinger (J&E) spreadsheets (www.nj.gov/dep/srp/guidance/vaporintrusion/). The 2013 J&E spreadsheets, adapted from the USEPA Johnson and Ettinger spreadsheets (USEPA 2004), contain an equation (the Clausius-Clapeyron relationship) which is used to adjust Henry's law constants as a function of temperature. This relationship was used to adjust Henry's law constants to a temperature of 13°C . To make this adjustment, the Henry's law constant at a reference temperature (25°C) is needed, along with the contaminant's boiling point, critical temperature, and enthalpy of vaporization at the boiling point. Henry's law constants were obtained from the USEPA Regional Screening Level Tables (Regional Screening Levels (RSLs) – Generic Tables: www.epa.gov/risk/regional-screening-levels-rsls-generic-tables). Boiling points (experimental values) were obtained from USEPA's EPI Suite Program (EPI Suite™-Estimation Program Interface: www.epa.gov/tsca-screening-tools/epi-suitetm-estimation-program-interface), which is the same software used by the USEPA for determination of many of their chemical properties for the Regional Screening Level Tables. Critical temperatures were taken from the Hazardous Substances Databank (HSDB) (toxnet.nlm.nih.gov), or the USEPA J&E spreadsheets when not available on the HSDB. Enthalpies of vaporization were used as listed in the USEPA Johnson & Ettinger spreadsheets (USEPA 2004).

IGW-SVSLs are shown in Table 1. Other supporting contaminant parameters are shown in Table 2.

6.3 Soil Vapor Sampling and Sample Analytical Methods

Soil vapor sample analysis must be conducted using New Jersey-certified laboratories pursuant to the Technical Requirements for Site Remediation, N.J.A.C. 7:26E-2.1(a)1. For information on soil vapor sampling, Section 9.0 of the *NJDEP Field Sampling Procedures Manual* (FSPM) may be consulted (www.nj.gov/dep/srp/guidance/). In the FSPM, soil vapor sampling is referred to as soil gas sampling. Additional information regarding soil vapor sampling and analysis may be found in the Department's *Vapor Intrusion Technical Guidance* (www.nj.gov/dep/srp/guidance/vaporintrusion/). Generally, USEPA Method TO-15 is used. Since many of the IGW-SVSLs are substantially higher than existing reporting limits, 1-liter canisters may be adequate in most situations to obtain soil vapor samples. The investigator should ensure that the reporting limits meet the IGW-SVSLs for the volatile organic constituents of concern at each area of concern being investigated. For the analysis of constituents or categories of constituents for which certification is not available pursuant to the Regulations Governing the Certification of Laboratories and Environmental Measures, N.J.A.C. 7:18, the person responsible for conducting the remediation shall ensure that the selected laboratory is capable of performing the analysis and meeting the data quality objectives specified in the site specific Quality Assurance Project Plan prepared pursuant to the Technical Requirements for Site Remediation at N.J.A.C. 7:26E-2.2. When certification of such

constituents or categories of constituents is codified in N.J.A.C. 7:18, the procedures in N.J.A.C. 7:18 shall be followed (see the Technical Requirements for Site Remediation at N.J.A.C. 7:26E-2.1(a)2).

6.4 Soil Vapor Sampling Procedures at Sites where Ground Water is Uncontaminated

If the ground water is currently uncontaminated, or if it has not been investigated, then demonstration that the vadose zone contamination does not have the potential to impact the ground water above the health-based GWQC is necessary.

Volatile petroleum hydrocarbon contaminants, such as benzene, toluene ethylbenzene and xylene, often degrade readily in soil and may potentially be addressed using expedited procedures, such as the use of vertical separation distances, as discussed in Section 7 below. Additionally, petroleum hydrocarbons in the vadose zone are often easily shown to not impact the ground water using the SESOIL model, when at least one to two feet of uncontaminated soil exists between the source contamination and the water table. Refer to SESOIL modeling guidance available on the Department's web page at www.nj.gov/dep/srp/guidance/rs/.

The flow chart provided in Figure 2 outlines the procedure to be followed in the case of uncontaminated ground water. Flow chart components are numbered for reference in the following discussion.

When expedited procedures for volatile petroleum hydrocarbon contaminants do not apply (P.1, "No"), the collection of appropriate soil vapor samples for comparison to the IGW-SVSLs will be necessary. Soil vapor samples may be taken either in the worst-case location of contamination (1.0, "Option 1") or directly above the capillary zone (2.0, "Option 2") to demonstrate compliance with the IGW-SVSLs. One advantage when sampling in the worst-case location (Option 1) is that a cap does not necessarily need to be in place before sampling because establishment of a stable soil vapor vertical profile is not required when sampling in the highest concentration zone. However, for both options, samples should not be taken at a depth of less than 5 feet below the ground surface due to the potential for artifacts in the soil vapor sampling. Problems when sampling soil vapor close to the surface include: (1) atmospheric air being drawn into the sample via preferential pathways along the sampling tubing or direct push tube that extends up to the soil surface, (2) atmospheric air being drawn into the sample via preferential pathways resulting from cracks in the soil that may form when the sampling device is driven into the soil, (3) the radius of the sphere of vapor sampled with the device extending to the soil surface, and (4) atmospheric pressure fluctuations due to weather events resulting in increasing variation in soil vapor concentration at depths closer to the surface. This limitation on soil vapor sampling locations and depths is analogous to restrictions contained in the Department's *Vapor Intrusion Technical Guidance*, (www.nj.gov/dep/srp/guidance/vaporintrusion), and is also discussed in the *NJDEP Field Sampling Procedures Manual*, (<http://www.nj.gov/dep/srp/guidance/>), and the Interstate Technology & Regulatory Council's guidance document on the vapor intrusion pathway (ITRC 2007).

6.4.1 Soil vapor sampling in the most contaminated zone (Option 1)

[Figure 2 Ground Water Uncontaminated](#)

If the most contaminated zone in the soil is at least five feet below the ground surface (1.1, “Yes”), a vapor probe may be installed in this zone (1.2), and a soil vapor sample obtained (1.3). A low permeability cap does not need to be in place. However, if a cap is not in place, a soil vapor sample taken immediately after a rainfall may not reflect soil vapor concentrations that will develop as the soil dries out and the soil air space increases. In this case, the soil vapor should be sampled at least three days after measurable rainfall. If the soil vapor sample results indicate that soil vapor concentrations do not exceed the IGW-SVSLs (1.4, “No”), then the impact to ground water pathway has been addressed. If the area of concern is not capped, a low permeability cap needs to be installed prior to application for a RAP (4.0). An application for a soil RAP is submitted (5.0) and subsequently approved by the Department (6.0, “Yes”). The permit must require that the cap be maintained until default IGWSSLs and/or site-specific IGWSRSs have been attained (7.0).

If the most contaminated zone in the soil is less than five feet below the ground surface (1.1, “No”), or if the soil vapor sample taken indicates that IGW-SVSLs are exceeded (1.4, “Yes”), then soil vapor sampling should be conducted directly above the capillary zone (Option 2.0), as discussed below.

6.4.2 Soil vapor sampling above the capillary zone (Option 2)

[Figure 2 Ground Water Uncontaminated](#)

When sampling directly above the capillary zone, the following table (from the Department’s *Vapor Intrusion Technical Guidance*, www.nj.gov/dep/srp/guidance/vaporintrusion), indicates the height of the capillary zone above the saturated zone (as a function of USDA soil texture), at which the vapor sampling probe should be installed (2.1). This table should be used to determine the minimum distance above the saturated zone for vapor sampling. It is recommended that soil vapor be sampled just above the top of the capillary zone, because this location will reflect the full extent of source vapor attenuation that has occurred within the vadose zone.

Capillary Zone Heights for Select Soil Textures

<i>USDA Soil Texture</i>	<i>Capillary Zone Height (cm)</i>	<i>Capillary Zone Height (feet)</i>
Sand	17	0.6
Loamy Sand	19	0.6
Sandy Loam	25	0.8
Sandy Clay Loam	26	0.9
Sandy clay	30	1.0
Loam	38	1.2
Clay Loam	47	1.5
Silty Loam	68	2.2
Clay	82	2.7
Silty Clay Loam	134	4.4
Silt	163	5.3
Silty clay	192	6.3

Note that for many common soil types, sampling at approximately 1.5 feet above the saturated zone is acceptable. For soils finer-textured than USDA loam, using an analytical method which separates and quantitatively determines silt and clay fractions, may be warranted to determine the height of the capillary zone. Consult the Department’s *Vapor Intrusion Technical Guidance* for further details (www.nj.gov/dep/srp/guidance/vaporintrusion).

As discussed earlier, soil vapor samples above the capillary zone must be at least five feet below the ground surface. If the top of the capillary zone is less than five feet below the ground surface, soil vapor sampling is not reliable for reasons discussed above. Direct sampling of the shallow ground water may be conducted in place of the required soil vapor sampling.

When sampling directly above the capillary zone, at least two years should have passed since (1) the area of concern was capped with a low permeability cap (2.2, “Yes”) and (2) the discharge occurred (2.4, “Yes”), to allow for the establishment of a stable vertical soil vapor concentration profile. If these conditions are met, a soil vapor sample is obtained (2.4A). If the soil vapor sample results indicate that the IGW-SVSL is not exceeded (2.5, “No”), then the impact to ground water pathway has been addressed. An application for a soil RAP may be submitted (5.0) and subsequently approved by the Department (6.0, “Yes”). The permit must include the requirement that the cap be maintained until IGWSSLs and/or site-specific IGWSRSs have been attained (7.0).

If sampling directly above the capillary zone, and a low permeability cap has not been in place for at least 2 years (2.2, “No”), and/or the discharge occurred less than 2 years prior (2.4, “No”), semi-annual sampling of the soil vapor (after capping) may be conducted for two years to

demonstrate that soil vapor concentrations have stabilized due to the establishment of a stable vertical soil vapor profile (2.3, 2.3A). The first vapor sample should be obtained at least six months after the installation of the cap and/or the discharge. If concentrations at the end of the monitoring period do not exceed the IGW-SVSLs (2.5, “No”), then an application for a soil RAP may be submitted (5.0) and subsequently approved by the Department (6.0, “Yes”). The permit must require that the cap be maintained until default IGWSSLs and/or site-specific IGWSRSs have been attained (7.0).

If soil vapor concentrations at the end of the monitoring period exceed the IGW-SVSLs (2.5, “Yes”), the impact to ground water pathway has not been addressed (3.0). In this case, application of other impact to ground water compliance options may be pursued (www.nj.gov/dep/srp/guidance/rs), or further investigation, source removal, and/or source treatment may be required.

7.0 Volatile Petroleum Hydrocarbons/Vertical Separation Distance

[Figure 2 Ground Water Uncontaminated](#)

Volatile petroleum hydrocarbons, such as benzene, toluene, ethylbenzene, and xylenes, are known to degrade rapidly in the soil as long as some moisture is available, and oxygen is present (Ririe et al. 2002; Hers et al. 2000). For this reason, the Department has adapted USEPA and Interstate Technology & Regulatory Council (ITRC) guidelines that have specified vertical separation distances between a contaminant source and a receptor (a building foundation) to conclude that vapor migration of volatile petroleum hydrocarbons does not pose a threat to indoor air (USEPA 2015b; ITRC 2014). The Department’s *Vapor Intrusion Technical Guidance* (www.nj.gov/dep/srp/guidance/vaporintrusion/), states that a vertical separation distance of greater than five feet is adequate for dissolved-phase sources when ground water concentrations are between the applicable ground water screening level and the water solubility of the contaminant. For light non-aqueous phase liquid (LNAPL) sources, a vertical separation distance of greater than 15 to 18 feet is required between the source and the receptor.

For purposes of this document, when assessing potential soil vapor impacts to ground water, the source is the contaminated soil zone, where concentrations of contaminants exceed the default IGWSSL or site-specific IGWSRS, and the receptor is the ground water. In the absence of LNAPL, a vertical separation distance of greater than five feet between the water table and the depth of the IGWSSL/IGWSRS exceedance is adequate to address the impact to ground water pathway. The soil saturation limit (C_{sat}) is the concentration above which non-aqueous phase (NAPL) appears. Contaminant-specific values for C_{sat} may be found in the chemical properties table for the remediation standards (<http://www.nj.gov/dep/srp/guidance/rs/>). For contaminant concentrations above the soil saturation limit, it must first be determined that only residual saturation is present, because free product (concentrations above a contaminant’s residual saturation limit) may continue to drain downward to the ground water under the influence of gravity. For residual saturation contamination, which include contaminant concentrations between the soil saturation limit and the residual saturation limit, a vertical separation distance of greater than 15 to 18 feet between the source and the ground water is required.

Before applying vertical separation distances for LNAPL contamination in the vadose zone, the investigator is reminded that free and residual product must be addressed in accordance with the Technical Requirements for Site Remediation at N.J.A.C. 7:26E-5.1(e).

The application of vertical separation distances for petroleum hydrocarbon contamination is shown in Figure 2. Flow chart components are numbered for reference in the following discussion. If the appropriate vertical separation distances as discussed above apply to the site (P.1, “Yes”), then the site should be capped, if not already capped (4.0). An application for the soil-RAP is submitted (5.0) and approved by the Department (6.0). The permit must require that the cap be maintained until default IGWSSLs and/or site-specific IGWSRSs have been attained and the cap is no longer required to address the impact to ground water pathway (7.0).

When the separation distance between the contaminant source and the ground water is less than five feet, use of the SESOIL model may prove useful if contaminant concentrations are moderate. Even though simulation of rainfall infiltration and ground water recharge is required when using the SESOIL model, the contaminant degradation rate for volatile petroleum hydrocarbons may be sufficient to indicate that potential impacts to ground water are not of concern. Refer to the SESOIL guidance document for additional information (www.nj.gov/dep/srp/guidance/rs/).

8.0 Submission Requirements

Capping as a means to address an exceedance of the default IGWSSL and/or site-specific IGWSRS represents a remedial action; it does not represent an alternative remediation standard or screening level for the IGW pathway. As such, a specific form or documentation submittal to support development of an alternative remediation standard or screening level is not warranted.

The investigator should sufficiently document soil conditions, including soil vapor sampling methods, results, findings, and details regarding the low permeability cap design and installation in the applicable remedial phase documents submitted to the Department (i.e., the Remedial Investigation Report, Remedial Action Workplan and Remedial Action Report). Additionally, details regarding the soil conditions, cap, and maintenance and monitoring required for the cap should be included in the Deed Notice for soil and the supporting documentation provided with the soil RAP application. Similarly, applicable remedial phase documents and soil RAP supporting documentation should include the results of all previously completed vapor sampling and monitoring. Compilation of these data is necessary prior to the submittal of the soil RAP application.

9.0 Frequently Asked Questions

Can I use the IGW-SVSLs even though I have a site where the ground water is contaminated?

While the procedures discussed above regarding the use of CEAs and MNA would normally be used to address vapor transport to ground water when ground water is already contaminated, the IGW-SVSLs may be used if desired. There may be situations where this would expedite the resolution of the impact to ground water pathway, especially if sampling the soil vapor in the most contaminated or “worst-case” locations.

If I am monitoring soil vapor concentrations directly above the capillary zone, and measured vapor concentrations are decreasing over time but are still above the soil vapor concentration after two years of monitoring, can I continue the monitoring for a longer time period?

If the soil vapor data collected to date (a minimum of four samples collected over two years) indicates indicate that the soil vapor screening level is exceeded, but soil vapor concentrations are consistently decreasing over time, and nearing the screening level, then vapor monitoring may be extended for an additional period, based on site-specific conditions and Department input, to attempt to achieve the soil vapor screening level. If soil vapor concentrations remain substantially greater than screening levels, or do not show consistent decreasing trends with time, then additional remediation of the contamination should be considered.

If I am monitoring soil vapor concentrations over time directly above the capillary zone, and only the last soil vapor sample (at two years) gives concentrations below the soil vapor screening level, is this acceptable?

Generally yes, since the Department considers two years long enough to establish potential impacts to ground water from soil vapor transport. However, if the collected data over time does not show consistent decreasing trends, or if prior results yielded concentrations substantially above the screening level, consideration should be given as to whether an additional confirmatory sample should be taken, or whether monitoring should be extended for a longer time period.

What if I do not know if the ground water is contaminated?

If a ground water investigation has not been triggered, then proceed as if the ground water is uncontaminated.

What if I am unable to sample at least five feet below the ground surface due to a shallow water table?

If the worst-case contaminant location is less than five feet below the ground surface (Figure 2, 1.1, “No”), sampling directly above the capillary zone should be conducted (Figure 2, 2.1). If this location is also less than five feet below the ground surface, then the shallow ground water should be sampled directly, and results should be compared to the Ground Water Quality Standards to determine compliance with the impact to ground water pathway. See the *Ground Water Technical Guidance: Site Investigation, Remedial Investigation, and Remedial Action Performance Monitoring* for sampling requirements (www.nj.gov/dep/srp/guidance/).

What constitutes a “low permeability” cap?

Relevant information regarding low permeability caps is contained in Section 3.1 of the *Technical Guidance on the Capping of Sites Undergoing Remediation*, available at www.nj.gov/dep/srp/guidance/.

If historic fill is present, and a historic fill CEA is in place, do I need an additional CEA for VOCs impacts on historic fill?

Yes. VOCs are not considered to be part of the suite of contaminants found in historic fill. The VOC contamination should be considered a separate discharge into the historic fill, distinct from the historic fill itself. If ground water is also contaminated, a separate and time-limited CEA for the volatile

contamination will be needed. If the ground water is not contaminated with VOCs, refer to Section 6 of this document for procedures to be followed.

In cases where ground water is uncontaminated, and monitoring wells have previously been installed, can I sample the ground water instead of the soil vapor?

If the monitoring wells are directly under the source and screened across the water table, it may be acceptable to monitor the ground water as long as two years of monitoring data are collected after the discharge and the capping of the site.

Can I use other approaches or models to demonstrate no vapor impacts to the ground water?

The procedures for a person to vary from the technical requirements in regulation are outlined in the Technical Requirements for Site Remediation at N.J.A.C. 7:26E-1.7. Variances from a technical requirement or departure from guidance must be documented and adequately supported with data or other information, and will be subject to Department review. In such cases, a technical consultation with the Department is recommended prior to the initiation of alternative approaches (www.nj.gov/dep/srp/srra/technical_consultation/).

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TABLE 1**Impact to Ground Water Soil Vapor Screening Levels
for Volatile Contaminants**

Contaminant	CAS Number	Health-based Ground Water Quality Criterion (µg/L)	Henry's Law Constant at 13°C (dimensionless)	Impact to Ground Water Soil Vapor Screening Level (µg/m³)
Acetone (2-propanone)	67-64-1	6,000	0.000876	110,000
Acrolein	107-02-8	4	0.00311	250
Acrylonitrile	107-13-1	0.06	0.00315	4
Benzene	71-43-2	0.2	0.133	530
Bis(2-chloroethyl)ether	111-44-4	0.03	0.000277	0.2
Bromodichloromethane (Dichlorobromomethane)	75-27-4	0.6	0.049	590
Bromoform	75-25-2	4	0.0106	850
Bromomethane (Methyl bromide)	74-83-9	10	0.21	42,000
2-Butanone (Methyl ethyl ketone) (MEK)	78-93-3	300	0.00134	8,000
Carbon disulfide	75-15-0	700	0.383	5,400,000
Carbon tetrachloride	56-23-5	0.4	0.675	5,400
Chlorobenzene	108-90-7	50	0.0663	66,000
Chloroethane (Ethyl chloride)	75-00-3	NA	0.312	NA
Chloroform	67-66-3	70	0.0918	130,000
Chloromethane (Methyl chloride)	74-87-3	NA	0.269	NA
2-Chlorophenol (o-Chlorophenol)	95-57-8	40	0.000208	170
Dibromochloromethane (Chlorodibromomethane)	124-48-1	0.4	0.021	170
1,2 Dibromoethane (ethylene dibromide)	106-93-4	0.0004	0.0135	0.1
1,2 Dichlorobenzene (o-dichlorobenzene)	95-50-1	600	0.0354	420,000
1,3 Dichlorobenzene (m-Dichlorobenzene)	541-73-1	600	0.0511	610,000
1,4 Dichlorobenzene (p-Dichlorobenzene)	106-46-7	75	0.0463	69,000
Dichlorodifluoromethane	75-71-8	1000	8.12	160,000,000
1,1 Dichloroethane	75-34-3	50	0.142	140,000
1,2 Dichloroethane	107-06-2	0.3	0.0276	170
1,1-Dichloroethene (1,1-Dichloroethylene)	75-35-4	1	0.704	14,000
1,2-Dichloroethene (cis) (c-1,2-Dichloroethylene)	156-59-2	70	0.101	140,000
1,2-Dichloroethene (trans) (t-1,2-Dichloroethylene)	156-60-5	100	0.24	480,000
1,2-Dichloropropane	78-87-5	0.5	0.0654	650
1,3-Dichloropropene (cis and trans) (summed)	542-75-6	0.4	0.0791	630
Ethyl benzene	100-41-4	700	0.164	2,300,000
Methyl acetate	79-20-9	7,000	0.00264	370,000

Contaminant	CAS Number	Health-based Ground Water Quality Criterion (µg/L)	Henry's Law Constant at 13°C (dimensionless)	Impact to Ground Water Soil Vapor Screening Level (µg/m³)
Methylene chloride (Dichloromethane)	75-09-2	3	0.0843	5,100
Methyl tert butyl ether (MTBE)	1634-04-4	70	0.015	21,000
Styrene	100-42-5	100	0.0561	110,000
1,1,2,2-Tetrachloroethane	79-34-5	1	0.00743	150
Tetrachloroethene (PCE) (Tetrachloroethylene)	127-18-4	0.4	0.384	3,100
Toluene	108-88-3	600	0.148	1,800,000
1,1,1-Trichloroethane	71-55-6	30	0.425	260,000
1,1,2- Trichloroethane	79-00-5	3	0.0178	1,100
Trichloroethene (TCE) Trichloroethylene	79-01-6	1	0.23	4,600
Trichlorofluoromethane	75-69-4	2,000	2.68	110,000,000
Vinyl chloride	75-01-4	0.08	0.834	1,300
Xylenes	1330-20-7	1,000	0.137	2,700,000

TABLE 2

Chemical Properties of Volatile Contaminants

Contaminant	CAS Number	Henry's Law Constant at 25°C (dimensionless) ^a	Henry's Law Constant at 25°C (atm·m ³ /mole) ^a	Boiling Point (°K) ^b	Critical Temperature (°K) ^c	Enthalpy of Vaporization at Normal Boiling Point (cal/mole) ^d
Acetone (2-propanone)	67-64-1	0.0014309	3.50E-05	328.65	508.1	6955
Acrolein	107-02-8	0.0049877	1.22E-04	325.75	506.15	6731
Acrylonitrile	107-13-1	0.0056419	1.38E-04	350.45	519.15	7786
Benzene	71-43-2	0.2269011	5.55E-03	353.15	562	7342
Bis(2-chloroethyl)ether	111-44-4	0.000695	1.70E-05	451.65	659.79 ^d	10803
Bromodichloromethane (Dichlorobromomethane)	75-27-4	0.0866721	2.12E-03	363.15	585.85 ^d	7800
Bromoform	75-25-2	0.0218724	5.35E-04	422.25	696 ^d	9479
Bromomethane (Methyl bromide)	74-83-9	0.3000818	7.34E-03	276.65	467.15	5714
2-Butanone (Methyl ethyl ketone) (MEK)	78-93-3	0.0023262	5.69E-05	352.65	536.7	7481
Carbon disulfide	75-15-0	0.5887163	1.44E-02	319.15	553.15	6391
Carbon tetrachloride	56-23-5	1.1283729	2.76E-02	349.95	556.35	7127
Chlorobenzene	108-90-7	0.1271464	3.11E-03	404.85	632	8410
Chloroethane (Ethyl chloride)	75-00-3	0.4538021	1.11E-02	285.45	460.15	5879
Chloroform	67-66-3	0.1500409	3.67E-03	334.25	536.4	6988
Chloromethane (Methyl chloride)	74-87-3	0.3605887	8.82E-03	249.15	416.25	5115
2-Chlorophenol (o-Chlorophenol)	95-57-8	0.0004579	1.12E-05	448.05	675 ^d	9572
Dibromochloromethane (Chlorodibromomethane)	124-48-1	0.0320114	7.83E-04	393.15	678.2 ^d	5900
1,2 Dibromoethane (ethylene dibromide)	106-93-4	0.026574	6.50E-04	404.75	582.95	8310
1,2 Dichlorobenzene (o-dichlorobenzene)	95-50-1	0.0784955	1.92E-03	453.15	690.35	9700
1,3 Dichlorobenzene (m-Dichlorobenzene)	541-73-1	0.10751 ^b	2.63E-03	446.15	688.45	9230.18
1,4 Dichlorobenzene (p-Dichlorobenzene)	106-46-7	0.0985282	2.41E-03	447.15	680.65	9271

Contaminant	CAS Number	Henry's Law Constant at 25°C (dimensionless) ^a	Henry's Law Constant at 25°C (atm-m ³ /mole) ^a	Boiling Point (°K) ^b	Critical Temperature (°K) ^c	Enthalpy of Vaporization at Normal Boiling Point (cal/mole) ^d
Dichlorodifluoromethane	75-71-8	14.022895	3.43E-01	243.35	384.9	9421
1,1 Dichloroethane	75-34-3	0.2297629	5.62E-03	330.55	523.4	6895
1,2 Dichloroethane	107-06-2	0.048242	1.18E-03	356.65	563.15	7643
1,1-Dichloroethene (1,1-Dichloroethylene)	75-35-4	1.0670482	2.61E-02	304.75	493.95	6247
1,2-Dichloroethene (cis) (c-1,2-Dichloroethylene)	156-59-2	0.1668029	4.08E-03	328.15	544.2	7192
1,2-Dichloroethene (trans) (t-1,2-Dichloroethylene)	156-60-5	0.3834832	9.38E-03	328.15	516.7	6717
1,2-Dichloropropane	78-87-5	0.1152903	2.82E-03	368.65	572 ^d	7590
1,3-Dichloropropene (cis and trans) (summed)	542-75-6	0.1451349	3.55E-03	385.15	587.38 ^d	7900
Ethyl benzene	100-41-4	0.3221586	7.88E-03	409.25	617.1	8501
Methyl acetate	79-20-9	0.0047016	1.15E-04	365.15	506.85	7260
Methylene chloride (Dichloromethane)	75-09-2	0.13287	3.25E-03	313.15	508.2	6706
Methyl tert butyl ether (MTBE)	1634-04-4	0.0239984	5.87E-04	328.35	497.1 ^d	6677.66
Styrene	100-42-5	0.1124285	2.75E-03	418.15	636.85	8737
1,1,2,2-Tetrachloroethane	79-34-5	0.0150041	3.67E-04	419.65	661.15	8996
Tetrachloroethene (PCE) (Tetrachloroethylene)	127-18-4	0.7236304	1.77E-02	394.45	620.25	8288
Toluene	108-88-3	0.2714636	6.64E-03	383.75	591.75	7930
1,1,1-Trichloroethane	71-55-6	0.7031889	1.72E-02	347.15	585	7136
1,1,2- Trichloroethane	79-00-5	0.0336877	8.24E-04	386.95	602 ^d	8322
Trichloroethene (TCE) Trichloroethylene	79-01-6	0.4026983	9.85E-03	360.35	544.2	7505
Trichlorofluoromethane	75-69-4	3.9656582	9.70E-02	296.85	471.15	5999
Vinyl chloride	75-01-4	1.1365495	2.78E-02	259.85	424.61	5250
Xylenes	1330-20-7	0.2710548	6.63E-03	411.65	622.11 ^e	8570 ^e

^a From USEPA Regional Screening Tables (November 2017) unless otherwise noted

^b From EPI Suite software (experimental value)

^c From Hazardous Substances Databank (March 2017) unless otherwise noted

^d From the USEPA Johnson and Ettinger spreadsheet database

^e Average of the three isomers

Figure 1: Ground Water Contaminated

Start

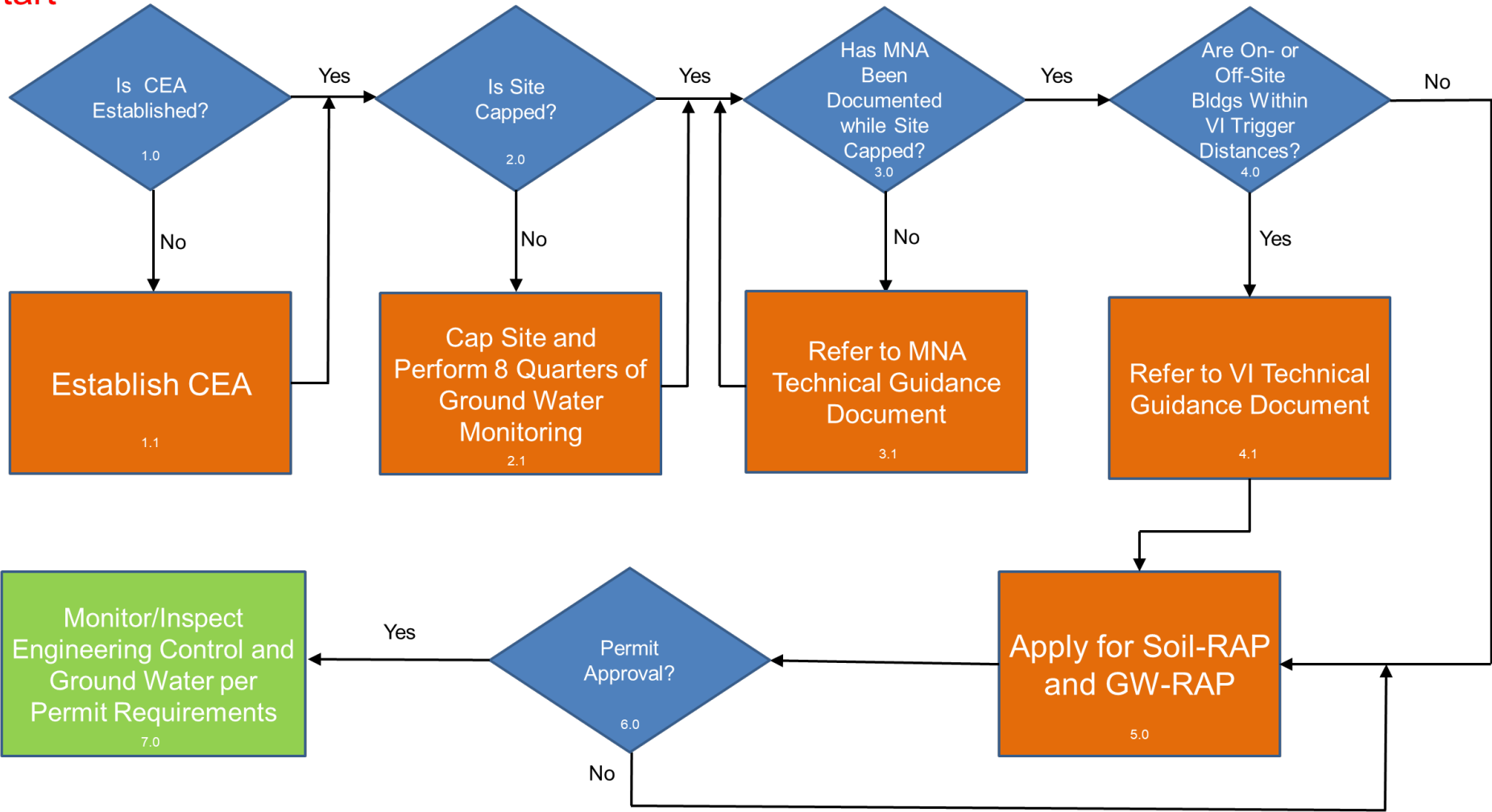


Figure 2: Ground Water Uncontaminated

