NEBRASKA

DEPT. OF WATER, ENERGY, AND ENVIRONMENT

03-151 (Revision 9) August 2025

AIR EMISSIONS GUIDANCE

FOR

PETROLEUM REMEDIATION SITES

Produced by: Nebraska Department of Water, Energy, and Environmenty, P.O. Box 98922, Lincoln, NE 68509-8922; phone (402) 471-2186. To view this, and other information related to our agency, visit our web site at ***https://dwee.nebraska.gov***

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IMPORTANT NOTICE

Implementation of remedial systems that emit pollutants (e.g., soil vapor extraction, air stripper, vacuum enhanced recovery) without an air emissions assessment or with an assessment not first approved by the Department's Petroleum Remediation Section may result in reimbursement reduction of up to 100 percent. Furthermore, construction and operation of remedial systems exceeding the permitting threshold levels established in Title 129 – Nebraska Air Quality Regulations are subject to enforcement and possible penalties by the Department's Air Quality Division.

SECTION 1 LIST OF ACRONYMS AND CONTACTS

1.1 Applicable Acronyms

AS	Air Stripper
AST	Above Ground Storage Tank
BTEX	Benzene, Toluene, Ethylbenzene and Xylenes
CAS	Chemical Abstract Service
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
COC	Chemical of Concern
DMR	Discharge Monitoring Report (required under NPDES permit)
EPA	United States Environmental Protection Agency
HAPs	Hazardous Air Pollutants
ISCST Model	Industrial Source, Complex, Short Term Model
LAST	Leaking Aboveground Storage Tank
LUST	Leaking Underground Storage Tank
M&I	Municipal and Industrial
MTBE	Methyl Tertiary-Butyl Ether
DWEE	Nebraska Department of Water, Energy, and Environment
NPDES	National Pollutant Discharge Elimination System
PRS	Petroleum Remediation Section
PM	Project Manager
PTE	Potential To Emit
QA/QC	Quality Assurance/Quality Control
RAP	Remedial Action Plan
RCRA	Resource Conservation and Recovery Act
RP	Responsible Party
SVE	Soil Vapor Extraction
SSTL	Site Specific Target Level
tpy	Tons per year
TV	Total Volatiles
UST	Underground Storage Tank
VC	Volatile Compounds
VE	Vacuum Extraction
VOCs	Volatile Organic Compounds
VRA	Voluntary Remedial Action process

1.2 DWEE Contacts

Air Quality Permitting Section	(402) 471-2189
Air Quality Compliance Section	(402) 471-2189
Petroleum Remediation Section	(402) 471-2186
NPDES Permit Unit, Wastewater Section	(402) 471-4220
DWEE Website: Pertinent regulations and guidance documents	https://dwee.nebraska.gov

SECTION 2 INTRODUCTION

2.1 Purposes and Use; Pre-approved Workplan

This document is guidance only and should not be construed as being regulation. The Nebraska Department of Water, Energy, and Environment (hereafter referred to as Department or DWEE) developed this guidance in response to concerns regarding potential Air Quality Construction and/or Operating Permit requirements. It also addresses risks of exposure to air emissions generated by the remediation of soil and ground water contaminated with petroleum hydrocarbons (hereafter referred to as petroleum) through the use of air strippers (AS), soil vapor extraction (SVE) systems, or other vacuum extraction (VE) systems that discharge pollutants to the air. For the purposes of this guidance, the term vacuum extraction includes any remedial technologies (e.g., bioventing, dual phase pump and treat) other than SVE that extract petroleum vapors from the subsurface and emit them to the atmosphere.

When followed, this guidance serves as a pre-approved workplan for compliance with air emissions requirements. Following this guidance means a separate workplan is not necessary. It also assures actions taken as explained in this document will be considered for reimbursement under Title 200 for eligible remediation projects. Alternative actions and methods may also be acceptable but will need Department approval prior to implementation.

2.2 General Information

This guidance is applicable to any petroleum remediation site, including those contaminated by leaking underground storage tanks (LUSTs), leaking aboveground storage tanks (LASTs), pipelines, or other petroleum storage and/or conveyance vessels. It is also intended to assist in the design of remediation systems to ensure that air emissions meet the requirements pertaining to the emissions of air pollutants at petroleum remediation sites. Unless approved by the Department, this guidance is not to be used to assess exposure risks for hazardous substance or hazardous waste remediation sites (e.g., CERCLA, RCRA, landfills, etc.), nor is it be used to evaluate risks for routine air emissions associated with stationary sources (e.g., factories, industries, etc.). This guidance is not applicable to situations determined by the Department to be emergencies until emergency conditions have been mitigated.

Applicable statutes and regulations include, but are not limited to:

- Petroleum Products and Hazardous Substances Storage and Handling Act §81-15,124(2);
- Title 118 - Ground Water Quality Standards and Use Classification;
- Title 119 - Rules and Regulations Pertaining to the Issuance of Permits under the National Pollutant Discharge Elimination System;
- Title 126 - Rules and Regulations Pertaining to the Management of Wastes;
- Title 129 - Nebraska Air Quality Regulations;
- Title 200 - Rules and Regulations for Petroleum Release Remedial Action Reimbursement Fund.

Reasonable costs of remedial actions employed for the cleanup of petroleum releases from LASTs and LUSTs are eligible for reimbursement consideration under the Title 200 reimbursement program. Title 200 requires that the Department approves remedial actions taken at LUST and LAST sites in order for the work to be eligible for reimbursement consideration unless the work is performed under the Voluntary Remedial Action (VRA) process. Under the VRA process, all work performed is to follow all applicable rules and regulations to allow reimbursement consideration. Reimbursement consideration will be given according to the procedures as set out in Department guidance. If there is a desire to vary from this guidance while conducting remediation, then it is recommended that approval is first sought from the Department in order for the actions performed under VRA to remain eligible for Title 200 reimbursement. Emission assessments for both permitting and risk exposure are to be completed. The manner in which they are completed is generally left to the discretion of the responsible party (RP) or their representative, but the use of this guidance is strongly recommended as it can assist in the design of a remedial system.

Utilizing this standard guidance and Emissions Calculation Workbook provided on the Department's web page reduces review time for DWEE personnel. Should the responsible party (RP) or their consultant wish to propose evaluating air emissions using alternative methodologies, it is to be done by submitting the proposal, in detail and in writing, for review to the Petroleum Remediation (PR) Section prior to development of the Remedial Action Plan (RAP) for the site. At a minimum, it is to be justified that any emission alternative methodology will provide equal or better data than the methodologies provided and, at the same time, be of cost benefit. The Department will review alternative proposals on a case-by-case basis.

The AS portion of this document was developed in accordance with EPA document "AIR/SUPERFUND TECHNICAL GUIDANCE STUDY SERIES: Estimation of Air Impacts for Air Stripping of Contaminated Water" (EPA-450/1-91-02). In addition, much of this guidance is a collaborative effort of the Department's Air Quality Division and Petroleum Remediation Section (PRS) and its contractor. DWEE would like to also recognize the Health and Human Services Environmental Health Section for its assistance in developing the guidance for assessing risks posed by carcinogenic contaminants.

2.3 Air Construction and Operating Permit Assessments

AS and SVE/VE systems are considered air pollutant sources. If more than one AS and/or SVE/VE system is installed, the contaminant emissions are to be calculated for each system and summed in order to provide the total quantity of pollutants emitted at the site. That is, the quantity or emission rate of applicable pollutants determined from the sampling of each system's emission point is to be calculated and then summed for each sampling event. The resulting totals are then averaged over a "rolling" twelve-month period (Section 5.3). Applicable air pollutants to be evaluated are Volatile Organic Compounds (VOCs) and Hazardous Air Pollutants (HAPs), as designated by Title 129 Appendices II and III. The HAPs list is provided in Appendix B. If a petroleum remedial system is designed, operated, and/or, modified and sampled/monitored as described immediately below and summarized in Appendix A, it is approved and will not need Construction and Operating permits from the Department's Air Quality Division.

- The system is designed and operated in such a manner as not to exceed the potential annual emissions that would necessitate the need for construction and operating permits (Section 3.3).

- Samples are collected in the time periods established in Section 4.4 utilizing the analysis methods identified in Section 4.2 and 4.3.

- All air emissions sampling data are submitted in accordance with Section 7.0 - Reporting Procedures.

2.4 Risk Assessment

For those carcinogenic compounds identified at a petroleum remediation site, exposure risk to the public due to air emissions is to be calculated based upon an excess cumulative cancer risk of **1×10^{-5}** (see SECTION 6). If air emissions pose a cumulative cancer risk less than or equal to 1×10^{-5}, then the system design is approved for purposes of risk exposure. This process is summarized in Appendix A. Benzene, ethylbenzene, 1,2-dibromoethane, 1,2-dichloroethane, and naphthalene are typically the carcinogenic chemicals of concern (COCs) for petroleum, but others might be present and are to be considered. Carcinogens are indicated in the HAPs List provided in Appendix B. For sites utilizing both AS and SVE/VE systems, and/or more than one AS or SVE/VE system, the cancer risk calculated for each system is to be summed in order to provide the total cancer risk for the site. That is, the cancer risk for each system is to be determined individually, then summed, and averaged for all sampling events. If a petroleum remedial system (i.e., AS, SVE/VE, combined systems) is designed, operated, modified, and sampled/monitored as described immediately below, it is approved.

- The system is designed and operated in such a manner that the total emissions do not exceed a cumulative cancer risk of 1×10^{-5} (see SECTION 6).

- Samples are collected in the time periods established in Section 4.4 utilizing the analysis methods identified in Section 4.2 and 4.3.

- All air emissions sampling data are submitted in accordance with SECTION 7, Reporting Procedures.

If an operating system generates emission concentrations greater than those allowed by the applicable permitting thresholds indicated in Section 3.3, and/or a cumulative cancer risk exceeding 1×10^{-5}, then it is to be reported to the PRS project manager (PM), and the remedial system is to be redesigned (e.g., raise the stack or reduce the stack diameter in accordance with Title 129, Chapter 16). If the system continues to emit pollutants at quantities greater than the applicable thresholds, then best engineering practices (i.e., emissions control/treatment or system design modifications) are to be used to ensure that the permitting thresholds and/or cancer risk are not exceeded.

2.5 Remediation System Construction

Remediation systems are to be designed using best engineering practices. For systems using SVE/VE technologies, it is worthy to note that using smaller diameter stacks (e.g., 2 to 4 inches) and increasing stack height will disperse emissions higher in the air column, thus being more protective of receptors.

NOTE: Hinged rain caps should be used on stacks in order to prevent precipitation from entering. “T” shaped or tent rain caps are not to be used as they greatly reduce vertical emissions dispersion.

NOTE: Implementation of AS and/or SVE/VE remedial systems without a permit evaluation and risk assessment or with an assessment not first approved by the Department’s PRS may result in reimbursement reduction of up to 100 percent. Permitting and risk assessments are also to be performed regardless of whether or not the remediation project (e.g., gasoline release from a pipeline, transportation incident) is associated with an UST or AST. Furthermore, operation of a remedial system exceeding the permitting threshold levels established in Title 129 may lead to enforcement and possible penalties by the Department’s Air Quality Division.

SECTION 3 AIR QUALITY REGULATIONS

3.1 Introduction

This section provides an overview of Title 129 as it applies to AS and SVE/VE petroleum remediation systems. For additional information or questions, Title 129 should be reviewed, or the Department's Air Quality Permit Section should be contacted. If an AS and/or SVE/VE system is designed, operated, and modified as described in Section 2.2 of this guidance, it is approved and will not need Air Quality Construction and Operating Permits.

NOTE: Several laboratory methods for analyzing pollutants in air and water are referenced in this guidance. The most current version of each of the analysis methods is to be used.

3.2 Air Pollutants

Air pollutants emitted by AS and SVE/VE petroleum remediation systems are typically limited to VOCs and HAPs. Identification and quantification (estimate only) of contaminants are performed prior to submitting a remedial action plan (RAP).

3.3 Air Quality Construction Permit Requirements

If an air emissions source (e.g., petroleum remediation system) has the "potential-to-emit" (PTE) pollutants in quantities that exceed regulatory thresholds, an Air Quality Construction Permit is typically required prior to initiating construction activities. The DWEE Environmental Guidance Document 01-104 entitled "Acceptable Pre-construction Dirt Work" provides more information on what work may be conducted prior to receipt of a construction permit, and the DWEE Environmental Guidance Document 05-165 entitled "Air Quality Construction Permits" provides more information on the Air Quality Construction Permits.

The PTE is a theoretical quantity of emissions that would result if the remediation system operated 24-hours a day, 365 days a year (i.e., 8,760 hours per year) at the maximum flow rate of the equipment (e.g., blower, pump, compressor) without emission control devices (e.g., oxidizer, activated carbon). The regulatory thresholds applicable to an air emissions source in Nebraska are:

- PTE of 40 or more tons per year (tpy) of VOCs; or
- PTE of 2.5 or more tpy of any HAP; or
- PTE of 10 or more tpy of total HAPs.

For the purpose of this guidance, a "year" is defined as twelve consecutive calendar months and is represented by a rolling twelve month average (see Section 5.3).

Unfortunately, application of the PTE concept to AS and SVE/VE petroleum remediation systems is difficult because the flow-rates and concentrations of VOCs and HAPs vary throughout the system's operation and are difficult to predict or estimate.

The design and operation for petroleum remediation systems contained within this guidance document are intended to limit the PTE of the systems, whether they need PRS approval or not, to less than the regulatory thresholds contained in Title 129. Conformance with this guidance is intended to eliminate the need to obtain an Air Quality Construction Permit. **Failure to follow the procedures described herein, or other mitigating circumstances, may trigger the regulatory requirement under Title 129 to obtain an Air Quality Construction Permit.** The procedure for determining the need for Air Quality Construction Permits is summarized in Appendix A on the flowchart titled "DWEE Air Emissions Guidance for Petroleum Remediation Sites Permit Evaluation Flow Chart."

It is important to note that additional regulatory requirements may apply to petroleum remediation systems operating at facilities that have other air emission sources (e.g., industrial facilities). The additional emissions from the petroleum remediation system may alter a facility's air emission status, and the emissions may need to be tracked for the facility's air emission inventory. Additional information on air quality regulations is available on the DWEE website.

SECTION 4 PERMIT-RELATED DATA COLLECTION

4.1 What to Sample

4.1.1 Pre-Pump Test and/or Pre-SVE/VE Pilot Test

Up until now, the investigation has focused on petroleum chemicals of concern (COCs). It is not uncommon, however, to discover that hazardous substances (e.g., chlorinated compounds or other non-petroleum VOCs) have commingled with a petroleum plume either in the ground water, soils, or both. In order to determine prior to construction of the proposed remediation system what pollutants will be discharged to surface waters and/or emitted to the air, a ground water sample is to be collected from each of the following prior to performing a ground water pump test and/or SVE/VE pilot test:

- Monitor well up-gradient of source area(s); and
- Monitor well identified to contain the greatest dissolved phase contaminant concentrations during the assessment phase

The ground water samples are to be analyzed for an extended list (commonly referred to as Method 8260 full list) of VOCs by the methods described later in Section 4.2.1. If it is suspected that pollutants are present other than those included in the Method 8260 full list that need different analysis methods in order to quantify, then the proposed methods are to be submitted in writing to the PRS PM for approval. For all petroleum contaminated sites, whether they are eligible for Title 200 reimbursement or not, the ground water laboratory results are to be included in the pump test/pilot test work plan that is to be submitted to the PRS PM prior to RAP development. Lastly, the pollutants that are identified in the ground water are to be considered when applying for an NPDES permit to discharge treated water.

4.1.2 Pump Test and Pilot Test Sampling

According to Title 129, the PTE is to be determined. If a pump test or pilot test is performed, the analysis results are to be submitted in the RAP. If these tests are not conducted, the PTE and risk values for the remediation project will have to be determined using another method as determined by the RP/consultant and approved by the Department.

4.1.2.1 Pump Test Calculations for an AS

If an AS is proposed as part of the remediation system, pump tests are not to be conducted in areas where the ground water has been impacted. However, if no uncontaminated area is present, then the pump test is to be performed in an area of least contamination. This presents a problem for calculating/modeling the PTE. For calculating and modeling prior to the installation of the remediation system, see Section 5 for calculating and modeling the PTE values and Section 6.3 for risk calculations and modeling.

4.1.2.2 Pilot Test Calculations for SVE/VE

The PTE is to be determined for SVE/VE systems prior to system design. This information is collected when performing a pilot test in the area where SVE/VE wells will be installed. Two methods to collect this information are presented below. Other approaches to collecting this data exist for the purpose of obtaining a good representation of the pollutant concentrations that could be potentially emitted. In any case, the method used is to be presented in the pilot test work plan.

- If it is feasible, the SVE blower is to be connected simultaneously to several of the wells used for the pilot test in the area where the ground water and/or soil concentrations fail the Site Specific Target Levels (SSTLs). If free product is present, at least one well in the pilot test as well as at least one with the greatest dissolved contaminant concentrations are to be included. The rest of the wells connected to the SVE blower should provide a good representation of moderate to significant contaminant concentrations. Air emissions are then collected from the SVE blower for laboratory analysis. The resulting contaminant concentrations are used in the PTE and risk calculations/modeling.

- If it is infeasible to connect the SVE blower to wells simultaneously, then vapor samples are to be collected from individual wells in the areas mentioned above. The concentrations for each pollutant from each sampling point is then totaled and averaged. The average concentration for each contaminant is then used to calculate/model the PTE and risk.

4.1.3 Operating System

4.1.3.1 Air Stripper

For operating AS systems, the water flow rates are measured and the ground water influent and effluent concentrations are determined using analysis methods for VOCs and TEH as gasoline, diesel, and oil (See Section 4.1.3.2 for exceptions). Measuring the water flow rate and the influent/effluent concentrations serves to provide an estimation of AS system emissions utilizing mass balance equations. The difference between the "influent concentrations times flow rate" and "effluent concentrations times flow rate" represents the contaminant mass stripped from the ground water by the AS system and emitted to the atmosphere.

To adequately quantify VOC and HAPs emissions, the operating remediation systems' air exhaust streams are to be measured and sampled for the following parameter:

- Exit air flow rate

The following information is also to be recorded:

- Water influent flow rate during operation (not the average flow rate, and not accounting for cycling);
- Cycling frequency and duration of AS operation;
- Exhaust stack height above ground level;
- Exhaust stack nominal inside diameter;
- Operational period covering influent and effluent samples; and
- System initial startup date.

Due to the fluctuations in concentration and flow, the humidity in the air stream does not need to be sampled, and the corresponding flow rate does not need to be corrected (i.e., the humidity correction factor should be insignificant compared to the error induced by other potential system fluctuations).

4.1.3.2 Vapor Extraction

To adequately quantify VOC and HAP emissions, the operating remediation systems' air exhaust streams are to be measured and sampled for the following parameters:

- Exit air flow rate; and
- Concentration of VOCs and HAPs.

The following information is to be recorded also:

- Exhaust stack height above ground level;
- Exhaust stack nominal inside diameter;
- Operational period for each effluent sampling result; and
- System initial startup date.

Due to the fluctuations in concentration and flow, the humidity in the air stream does not need to be sampled, and the corresponding flow rate does not need to be corrected (i.e., the humidity correction factor should be insignificant compared to the error induced by other potential system fluctuations).

Exceptions

VOCs and HAPs air emissions analyses are not necessary at sites where it has been confirmed prior to performing pump and/or pilot tests (see Section 4.1.1) that only long-chained petroleum hydrocarbons are present (e.g., kerosene, fuel oils, JP-8, bunker oil, and other such heavy petroleum distillates). The ground water sampling and analysis methods described below are used to determine if heavy fuels/oils are the only pollutants present at a site.

4.2 VOCs Analysis Methods

VOCs are defined as compounds of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate, which participate in atmospheric photochemical reactions (Title 129, Chapter 1, Section 160). However, some chemicals identified in the soil and ground water at petroleum remediation sites may be exempt from the definition of a VOC. For example, methane, acetone, and ethane are exempt because they have been demonstrated to have negligible photochemical reactivity. A complete list of exempted organic compounds can be found within 40 CFR 51.100(s)(1). Generally speaking, the pollutants emitted from the remediation of lighter petroleum distillates (e.g., gasoline, diesel fuel) are VOCs.

4.2.1 Ground Water Analysis Methods

The total VOC concentration (i.e., the sum of concentrations for all VOCs present) identified in the ground water can usually be approximated by combining the results of:

- EPA Method 8260 total scan (Volatile Organic Compounds by Gas Chromatography/Mass Spectrometry (GC/MS);
- OA-2 (Extractable Petroleum Products and Related Low Volatility Organic Compounds) or SW-846 Method 8015B; and
- Method 8270 Semivolatile Organic Compounds by GC/MS.

4.2.1.1 Other Water Analysis Methods

The National Pollutant Discharge Elimination System (NPDES) program (Title 119) requires that treated water effluent samples be analyzed using methods approved in 40 CFR Part 136. The Department's NPDES program, however, does allow discharges from petroleum remediation systems under a general permit if certain conditions are met. The analysis methods to be used for determining the presence of pollutants and their concentrations are set forth in the general permit. Additional information may be obtained from the NPDES Permits and Compliance Section at 402-471-4220.

Questions regarding ground water analysis methods used for the purpose of monitoring the progress of petroleum remediation should be directed to the PRS.

4.2.2 Air Emission Analysis Methods

The total VOC concentration in air can be determined using:

- The analytical portion of EPA Method 25 Determination of Total Gaseous Nonmethane Organic Emissions as Carbon (Method 25);

- EPA Method 25A Determination of Total Gaseous Organic Concentration Using a Flame Ionization Analyzer (Method 25A); or

- EPA Method TO-3 (Method for the Determination of Volatile Organic Compounds in Ambient Air Using Cryogenic Pre-Concentration Techniques and Gas Chromatography with Flame Ionization and Electron Capture Detection). TO-3 is for more volatile constituents and might not adequately characterize emissions from diesel fuel and used oil (i.e., TO-3 might underestimate the VOC concentrations), so TO-3 is best used when it is known that the pollutants are comprised mostly or entirely of VOCs.

4.3 HAPs Analysis Methods

EPA has established certain chemicals and chemical groups as hazardous air pollutants (HAPs), generally due to their toxicity. The list of HAPs is included in Title 129, Appendix II, and is also included in Appendix B of this guidance along with an indication of which petroleum products might include HAPs as constituents. HAPs typically found in petroleum products at significant concentrations include, but are not limited to:

- Benzene;
- Ethylbenzene;
- n-Hexane;
- Methyl tertiary-Butyl Ether (MTBE);
- Naphthalene;
- Toluene; and
- Xylenes.

Method 8260 (i.e., a total scan) is the principal method of choice for determining the concentration of each HAP in ground water at a petroleum remediation site. It is important to note that no single method is capable of identifying all of the HAPs. If other contaminants are suspected, but cannot be detected using Method 8260, the following additional analysis methods may be used following consultation and approval by the PRS PM:

- EPA Method 8270: Semi-Volatile Organic Compounds by GC/MS;
- EPA Method 8315: Determination of Carbonyl Compounds by High Performance Liquid Chromatography (HPLC);
- EPA Method 602: Purgeable Aromatics;
- EPA Method 624: Purgeables; and
- EPA METHOD 1624 Revision B: Volatile Organic Compounds by Isotope Dilution GC/MS.

Once the contaminants present in the ground water have been identified, the resulting concentration of each species of HAPs present in the air emissions can be determined using EPA Compendium Method TO-15 (Determination of VOCs in Air Collected in Specially-Prepared Canisters and Analyzed by GC/MS) or EPA Method 18 (Measurement of Gaseous Organic Compound Emissions by Gas Chromatography). Appendix B lists petroleum chemical compounds and corresponding analytical test methods as well as those for many of the HAPs.

4.4 When to Sample

4.4.1 AS Systems

4.4.1.1 Pre-System Startup

In order to determine the pollutant mass emitted to the air from an AS system, both the influent and effluent concentrations have to be considered in order to calculate the PTE. Since empirical data cannot be collected during a pump test, please see Sections 4.1.2.1 and 5.1 for guidance.

4.4.1.2 Post-System Startup

When an AS is used to treat contaminated ground water, Title 119 requires an NPDES permit to discharge the treated water to waters of the State. Treated water discharged to a sanitary sewer does not need an NPDES permit, but local officials should be contacted for approval and requirements. NPDES permits require sampling of the effluent every three months, and the information is to be submitted in quarterly Discharge Monitoring Reports (DMRs).

In order to quantify the emissions released and/or confirm the manufacturer's treatment efficiency of the AS system, influent samples are to be collected at the same time as effluent samples as specified in the NPDES permit.

Table 1. Sampling Frequencies for AS Systems

MONTH	COMMENTS
1. Between 7 and 30 days following system startup	Collect both influent and effluent samples for air emissions calculations. Effluent sample results are also to be submitted in the DMR and every subsequent quarter as specified in the NPDES permit
2.	Use sampling results from Month 1 for air emissions calculations
3. About 90 days following system startup	Collect both influent and effluent samples for air emissions calculations
4.	Use sampling results from Month 3 for air emissions calculations
5.	Use sampling results from Month 3 for air emissions calculations.
6. About 180 days following system startup	Collect both influent and effluent samples for air emissions calculations.
7.	Use sampling results from Month 6 for air emissions calculations.
8.	Use sampling results from Month 6 for air emissions calculations
9. About 270 days following system startup	Collect both influent and effluent samples for air emissions calculations
10.	Use sampling results from Month 9 for air emissions calculations.
11.	Use sampling results from Month 9 for air emissions calculations
12. About 360 days following system startup	Collect both influent and effluent samples for air emissions calculations
Semi-annually sampling hereafter unless the conditions stated in 5.3 have been achieved.	

4.4.2 SVE/VE Systems

The following sampling frequencies are needed following system installation and startup, unless otherwise directed by the PRS PM. Following the sampling performed prior to and during the pilot test, monthly samples are to be collected about 30 days apart or in multiples of 30 days unless otherwise indicated. DWEE recognizes that remediation systems typically emit higher concentrations of contaminants at the startup than will be sustained during their operational period. Therefore, the concentrations collected during system startup do not need to be considered in either the permit or risk calculations. Summa canisters are to be used to collect air samples for the first month, sixth month, and twelfth month sampling events (see Section 5.3).

Table 2. Sampling Type and Frequencies for SVE/VE Systems

MONTH	SAMPLING TECHNIQUE	COMMENTS
1. Between 7 and 30 days of following system startup)	One hour Summa Canister	
2. About 30 days following 1st month sampling event	Other recommended sampling technique	
3. About 30 days following 2nd month sampling event	Other recommended sampling technique	
4. About 30 days following 3rd month sampling event	Other recommended sampling technique	
5. About 30 days following 4th month sampling event	Other recommended sampling technique	
6. About 30 days following 5th month sampling event	One hour Summa Canister	
7.	No sampling needed	Use sampling results from Month 6 for calculations
8.	No sampling needed	Use sampling results from Month 6 for calculations
9. About 90 days following 6th month sampling event	Other recommended sampling technique	
10.	No sampling needed	Use sampling results from Month 9 for calculations
11.	No sampling needed	Use sampling results from Month 9 for calculations
12. About 90 days following 9th month sampling event	One hour Summa Canister	
Semi-annually hereafter unless the conditions stated in 5.3 have been achieved.	Other recommended sampling technique	Use results from the last sampling event for the 6-month calculations

4.5 Where to Sample

The appropriate sampling locations are necessary to obtain samples that are representative of the petroleum remediation system conditions. It is recommended that the following approaches to sampling be followed.

Cyclonic Flow

Although cyclonic flow measurements are not needed at petroleum remediation systems, it is important to understand what affects cyclonic flow has upon the systems' sampling points. Therefore, sampling points (e.g., ports) in locations where cyclonic flow potentially exist are to be avoided.

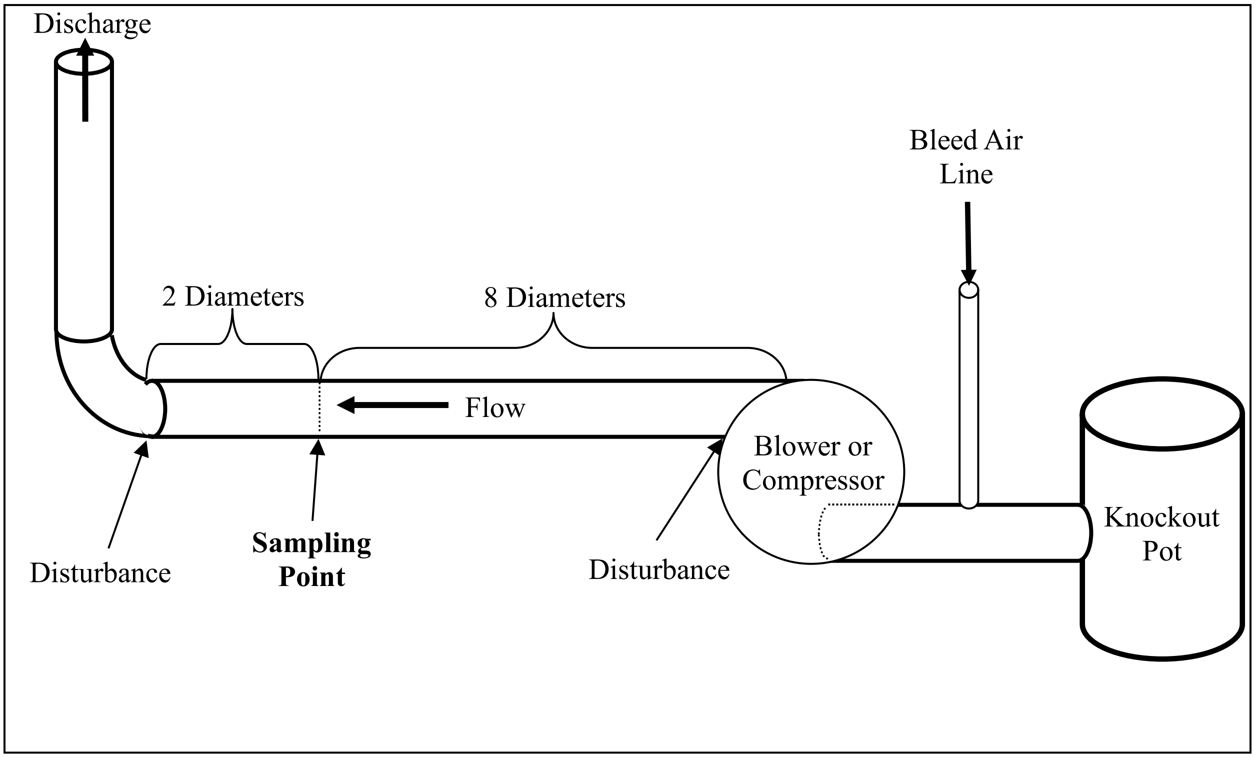
Cyclonic flow is a swirling flow that occurs in pipes, ducts, and stacks usually because something about their construction is causing a disturbance; thus, measurements in such locations might provide inaccurate results. Where possible, sampling should not be performed at locations where cyclonic flow typically occurs in pipe, duct, or stack locations. For petroleum remediation sites, however, cyclonic flow inspections are not needed, but sampling locations where cyclonic flow is expected are to be avoided.

To avoid cyclonic flow locations, sampling and/or velocity measurements are to be conducted at a point located at least eight stack, pipe, or duct diameters downstream and at least two diameters upstream from any flow disturbance such as a bend, expansion, or contraction in the stack or from a process vessel (Figure 1). These distances are for ideal conditions, but if necessary, alternative locations can be selected with less pipe diameters up and downstream of the sample point. It is recommended that the ratio between the downstream distance and the stack, pipe, or duct diameter remain approximately 4 to 1. For example, if the stack diameter is four inches, the downstream distance should be 16 inches (i.e., four inches multiplied by four).

Stratification

Stratification occurs where different concentrations or velocities are present in certain areas of a pipe, duct, or stack. However, stratification across pilot test and remediation system exhaust stacks, pipes, or ducts is not expected to be significant because their diameters are typically less than twelve inches in diameter. It should also be noted that EPA Method 1 (i.e., Sample and Velocity Traverses for Stationary Sources) is not applicable to stacks, pipes, or ducts less than twelve inches in diameter.

Figure 1. Sampling point location to minimize the effects of disturbances



Air Bleeding

According to Title 129, Chapter 36, Section 001 - Control Regulations; Circumvention, When Excepted:

"*No person shall cause or permit the installation or use of any machine, equipment, device or other article, or alter any process in any manner which conceals or dilutes the emissions of contaminants without resulting in a reduction of the total amounts of contaminants emitted.*"

However, allowing outside air to enter the vacuum side of the SVE/VE remediation system (often referred to as "air bleeding") is the method typically used to balance gas pressure within the system. When "air bleeding" is used, the VOC and HAP concentrations will be diluted by the "bleed air." This is allowed, however, only when it is conducted as part of the operation and optimization of the remediation system, but not with the intent of diluting the concentration of the contaminants emitted. If outside air is used to balance the system, the air flow rate is to be measured and recorded at the point where the air samples are collected during each sampling event.

Vacuum Trucks

If a vacuum truck is used to perform an SVE/VE pilot test, the sampling point is best located upstream of the vacuum truck to avoid sampling of contaminants that might be present in the vacuum truck, but not in the subsurface. A sampling device capable of overcoming the vacuum pressure will be needed as well as control valves to allow testing at different vacuum pressures.

4.6 How to Sample

Flow Rate

Flow rate monitoring may be conducted using an anemometer, Pitot tube, venturi, orifice plate, variable area flowmeter, or other methods approved by the DWEE Air Quality Compliance Section. Some measurement devices may be considered a disturbance if evaluating cyclonic flow. A continuous flow measurement device can be installed on the remediation system, but it is to be maintained as well as calibrated for each sampling event. The manufacturer's recommendations are to be followed when installing flow measurement devices such as properly aligning a hot-wire anemometer probe. During the sample collection, the emission flow rate through the stack is to be monitored and recorded. All manufacturers' directions are to be followed.

VOC and HAPs Concentrations

VOC/HAPs samples are to be collected in accordance with the appropriate EPA method requirements. DWEE is not specifying that the sampling procedure set forth in EPA Method 25 be followed. For each method, air samples will be collected directly from the effluent air stream into an appropriate container for quantification through laboratory analyses. At a minimum, air samples collected for the one-month, six-month, and twelve-month sampling events are to be collected using batch-certified Summa canisters set to pull vacuum for a period of one hour. Tedlar bags may be used to collect air samples during sampling events when Summa canisters are not used, unless otherwise directed by the PRS PM. The first-year sampling results from Tedlar bags and Summa canisters are to be compared to determine if use of the Tedlar bags alone is acceptable, and the consultant is to make a recommendation to DWEE on future sampling methods. A decision will be made as to whether or not Tedlar bags alone are appropriate for future sampling.

Tedlar bag air samples can be collected either as grab or time-integrated samples. Tedlar bags need a mechanized filling device to collect a sample unless the sample point is under positive pressure. If the sample point is on the vacuum side of a piece of equipment (e.g., blower), the sampling equipment needs to have sufficient suction to overcome the vacuum induced by the system.

A Summa canister can be filled without the use of a pump if the sampling point is at ambient or positive pressure. In addition, Summa canisters can be equipped with a flow controller to allow time-integrated sampling such as the one-hour Summa canister sampling needed for the one-month, six-month, and twelve-month sampling events. When collecting a time-weighted sample, the consultant is to document the flow controller setting (one-hour, two-hour, etc.) and the starting and sample completion canister vacuum pressure.

NOTE: Samples collected in Tedlar bags that are not immediately analyzed in a mobile laboratory are to be analyzed by a laboratory within 72 hours of collection. DWEE requests that samples collected with Summa canisters are analyzed within a maximum of 30 days of collection. A shorter holding time might be necessary to ensure that Air Emission Monitoring Reports are submitted by the established compliance date (Section 7.1).

4.7 Pollutants to be Sampled

The chemicals to be monitored are those identified by laboratory analyses of the ground water collected in preparation for developing a RAP (see Section 4.1.1). In other words, those VOCs or HAPs identified in the ground water collected during the pilot test and/or pump test are to be included in the laboratory analytes for subsequent air emissions samples.

4.8 Quality Assurance and Quality Control

Because of the potential variability in the VOC and HAP concentrations over time due to rapid variations caused by changes in operating conditions, soil moisture, etc., there is no need for quality assurance and quality control samples such as duplicate samples (i.e., the sampling error is expected to be significantly less than the error associated with the temporal variability).

SECTION 5 PERMIT-RELATED CALCULATION METHODS

5.1 Permit Emission Calculations

Several methods can be used to calculate the air emission quantities for remediation systems. The RP/consultant, in accordance with Title 129, Chapter 17, is responsible for choosing a method, which will provide an accurate estimate of potential emission quantities. An example method is provided below. The chosen method and associated calculations are to be provided as part of the RAP submitted to the PRS; however, the DWEE PRS's Air Emissions Calculation Workbook will perform all these calculations.

If the proposed remediation system uses more than one remediation technology (e.g., AS coupled with SVE/VE) that will emit pollutants to the atmosphere, then the permitting emission calculations for each system are to be derived individually and the sum of the results calculated to determine the total tonnage of pollutant(s) emitted. In addition, the calculation is to be completed for each pollutant and combination of pollutants.

The following permitting calculation procedures are provided as one method to determine the amount of emissions generated by the AS and/or SVE/VE systems. These procedures are based on data collected from a pump test and/or SVE/VE pilot test. If these tests were not conducted, the potential emissions from this remediation project will have to be determined using another method as determined by the RP/consultant and approved by the Air Quality Permitting Section.

AS System

The equations use only three variables: (1) the designed system influent flow (pumping) rate (Q); (2) the maximum estimated influent pollutant concentration (C_i) based the on ground water analysis; and (3) the minimum estimated effluent pollutant concentration (C_e) based on system design efficiency. Prior to construction of the remediation system, C_e is based on NPDES discharge permit levels, or the system design efficiency where NPDES discharge permit levels are not available. Once the remediation system starts operation, the actual minimum effluent pollutant concentrations are used for C_e. All other parameters used are either constants or derived from these variables. It is very important to represent the data in the units outlined in this document. For convenience and consistency, it is recommended that the DWEE Petroleum Remediation Section Air Emissions Calculation Workbook, available on the DWEE website, be used as that will facilitate more effective Departmental review of this information. Specifically, the AS section of the ***Emission Rate*** worksheet can be used to calculate the emission rate, with this result being used in the tonnage equation below. There is a range of cells in the ***Emission Totals*** worksheet where the RP/consultant can enter a pollutant that is not on the default list of parameters. The worksheet will calculate the pounds per day emission rate, which can be converted by the user to tons per year.

Parameters used:

ER = Pollutant emission rate (ug/sec)
Q = Influent flow (pumping) rate (L/sec)
C_i = Estimated maximum influent pollutant concentration(s) (ug/L)
C_e = Minimum effluent pollutant concentration(s) (ug/L)
Prior to system construction: NPDES discharge permit levels and/or system design efficiency
After system implementation: minimum effluent pollutant concentration(s)
X = Number of days of operation per year (twelve consecutive months)
86,400 = Seconds per day
2.205×10^{-9} = Conversion factor (micrograms to pounds)
2,000 = Pounds per ton
T = Tons of pollutant per year

ER Calculation: $$\mathrm{ER} = \mathrm{Q} * (\mathrm{C_i} - \mathrm{C_e})$$

Tonnage Calculation:

$$\mathrm{T} = \frac{\mathrm{ER} * \mathrm{X} * \left(86{,}400 \frac{\text{seconds}}{\text{day}}\right) * \left(2.205 * 10^{-9} \frac{\text{micrograms}}{\text{pound}}\right)}{\left(2{,}000 \frac{\text{pounds}}{\text{ton}}\right)}$$

SVE/VE System

The equations use only two variables: the designed system exhaust airflow rate (Q) and the maximum pollutant concentration in the exhaust air stream (C_b). (NOTE: This needs a pilot test.) All other parameters used are either constants or derived from these variables. It is very important to represent the data in the units outlined in this document, and for convenience and consistency, it is strongly recommended that the DWEE Petroleum Remediation Section Air Emissions Calculation Workbook be used. Specifically, the venting section of the ***Emission Rate*** worksheet can be used to calculate the emission rate, with this result being used in the tonnage equation below.

Parameters used:

ER = Pollutant emission rate (ug/sec)
Q = Exhaust air flow rate (L/sec)
C_b = Maximum pollutant concentration(s) in the exhaust air (ug/m^3)
X = Number of days of operation per year (twelve consecutive months)
86,400 = Seconds per day
$2.205\text{x}10^{-9}$ = Conversion factor (micrograms to pounds)
2,000 = Pounds per ton
T = Tons of pollutant per year

ER Calculation: $$\mathrm{ER} = \frac{\mathrm{Q} * \mathrm{C_b}}{1000\,\text{liter/m}^3}$$

Tonnage Calculation:

$$T = \frac{ER * X * \left(86{,}400 \frac{\text{seconds}}{\text{day}}\right) * \left(2.205 * 10^{-9} \frac{\text{micrograms}}{\text{pound}}\right)}{\left(2{,}000 \frac{\text{pounds}}{\text{ton}}\right)}$$

5.2 Preliminary Permit Calculation Reporting Procedures

The emission calculations are to be submitted in the RAP as part of the pump test and/or the pilot test results.

5.3 Post-Implementation Permit Calculation Procedures for Reporting

On-going tonnage calculations (in tons per year) are to be performed in order to demonstrate that the system is being operated in such a manner that the emissions are not exceeding the permitting thresholds. The data is to be collected during the time intervals outlined in Section 4.4. However, treated effluent water from an AS is also to be collected at a frequency to comply with the system NPDES permit or municipality requirements (for sanitary sewer discharge). For each month, calculate the amount of pollutant emitted using calculations such as those provided above to determine a 12-month rolling average. For these calculations, assume that the system will operate during the next interval at the concentration and flow rate determined during the most recent sampling event as shown below. If the DWEE Petroleum Remediation Section Air Emissions Calculation Workbook is used, the emission rates for the AS and VE are calculated for one sampling event on the ***Emission Rate*** worksheet. The corresponding risk calculations for that sampling event are automatically conducted and displayed on the ***Risk Evaluation*** worksheet. The user then transfers the emission rates and risk values from the ***Emission*** **Rate** and ***Risk Evaluation*** worksheets to the ***Emission Totals*** worksheet for that sampling event. For each subsequent sampling event, the user then transfers new emission rate and risk values to a new row on the ***Emission Totals*** worksheet. The user can then enter the start date and end date for the appropriate rolling 12-month average period in the "Averaging Period" cells of the ***Emission Totals*** worksheet to get the mass removed and average cancer risk for that period. If the user enters a 12-month period, the mass removed (displayed in pounds) can be converted to tons for the tpy value for reporting. The PTE calculations on the ***Emission Totals*** worksheet use the maximum value for estimating emissions from pilot test data.

Month 1 (collected at least 7 days and at most 30 days after system startup): represents the emissions concentrations for days 0 through 30 of the operation.

Month 2 (collected approximately 30 days after Month 1 sampling event): represents the emissions concentrations for days 30 through 60 of the operation, and so on through Month 5.

Month 6 (collected approximately 180 days after Month 1 sampling event): represents the emissions concentrations for day 180 through day 269 of operation.

Month 9 (collected approximately 270 days after Month 1 sampling event): represents the emissions concentrations for day 270 through day 365 days of operation.

Year 1 (collected approximately 365 days after Month 1 sampling event): represents the emissions concentrations for the first 6 months of the second year of operation, and so forth.

As long as the tons of pollutants emitted do not exceed the respective permitting criteria, the system may be operated as approved by the Department. Unless otherwise stated in the RAP or directed by the PRS PM, the sampling frequency may be reduced to semi-annual after one year if:

- Free product is not present nor has it been present for a period of one year;
- Sampling and analyses were performed as outlined in Sections 4.2, 4.3, and 4.4. Effluent sampling associated with the AS is to also be conducted as specified by the system NPDES permit or municipality requirements (for sanitary sewer discharge);
- Air monitoring reports were submitted with the appropriate information during the time frames described in SECTION 7; and
- The tons of pollutants emitted did not exceed 85 percent of the permitting thresholds, and the emissions did not exceed 85 percent of 1 x 10^{-5} for the cumulative cancer risk for a period of at least one year.

5.4 Cessation of Air Emissions Sampling

If it is determined from two consecutive years of air monitoring data that the criteria above were achieved and there is nothing to indicate that contamination levels are increasing, a written request with supporting discussion and documentation is to be submitted to the PRS PM for considering the cessation of air emission sampling. The request is to be submitted as a brief written discussion supporting the discontinuation of sampling, which can be submitted with the air monitoring report due at the end of two years.

5.5 Control Equipment

If simple operational techniques are not sufficient in reducing emissions to the permitting thresholds, an emission control device might have to be installed. Such control devices can be categorized as “destructive” [e.g., catalytic oxidizers (CO), thermal oxidizers (TO), regenerative thermal oxidizers (RTO)], and “non-destructive” [e.g., granulated carbon canisters (GACs)].

Some vendors of destructive control devices claim destruction efficiencies of 98 to 99.9 percent as long as the equipment is installed and maintained according to their instructions. Although vendors might claim greater destruction efficiencies, a default destruction efficiency of no more than 98 percent is allowed for calculating allowable emission pollutant tonnage for both permitting and risk thresholds. Otherwise, the vendor’s control efficiency data is to be used for efficiencies of less than 98 percent. A copy of the vendor’s expected destruction efficiency pertinent to the device used is to be submitted with the RAP. VOC and HAPs samples are still to be collected upstream of the destructive control device for laboratory analysis in order to ascertain when the control device can be removed (see Section 4.4 for sampling frequencies).

Efficiencies for non-destructive control devices (e.g., GAC systems) vary considerably with moisture content in the air stream, temperature, contaminant concentration fluctuations, and the capture materials used within the device. Consequently, where non-destructive control equipment is used, emission samples for laboratory analysis are to be collected upstream and downstream of the device. In addition to calculating the total tonnage emitted, the total pollutant mass removed can be estimated using mass balance equations as well as determining when the use of the control device can be discontinued.

The RP may request the PRS PM for approval to cease operation of the emission control equipment using the same criteria listed in Section 5.4. The request is to be submitted as described in Section 5.4. The physical removal of a control device is to be coordinated with the PRS PM.

SECTION 6 RISK ASSESSMENT

6.1 Introduction

It is stated in §81-1504, "The department shall have and may exercise the following powers and duties: (32) To consider the risk to human health and safety and to the environment in evaluating and approving plans for remedial action…." As previously stated in Section 2.3, AS and SVE/VE systems used in the remediation of petroleum release sites, have the potential to emit carcinogenic contaminants into the atmosphere at concentrations that pose a risk to human health. This section provides guidelines for the assessment of excess cancer risks that these emissions might pose. This information is used to facilitate remediation system modifications (e.g., emission control devices, adjustments of pumping rate, modification of stack height, etc.), if necessary, in order to ensure the protection of public health. Carcinogens present at a petroleum release site are identified as specified in Section 4.1.

The most common carcinogens that are likely to be present in petroleum releases that have occurred in recent years are benzene, ethylbenzene, and naphthalene.

Other carcinogens used as gasoline additives in the past are: 1,2-dibromoethane (EDB) and 1,2-dichloroethane (1,2-DCA).

Common carcinogens that might have been released to the environment from other sources include: carbon tetrachloride, methylene chloride, vinyl chloride, tetrachloroethylene (PCE), trichloroethylene (TCE) among others.

Guidelines in this section will focus on these common carcinogens, but all contaminants identified in the extracted fluid (water and/or soil gas) are to be considered when preparing the RAP. The PRS PM may desire assessment of these additional contaminants. The list of the HAPs found in Appendix B identifies other chemicals considered carcinogens.

This section provides one method for performing a cancer risk assessment which is summarized in Appendix A. Use of these procedures and the DWEE Petroleum Remediation Section Air Emissions Calculation Workbook available on the DWEE website will facilitate more effective Departmental review of this information. If these procedures are not used, the proposed alternative methods and procedures are to be provided in the RAP (detailed in writing) in order that DWEE personnel may determine if they are applicable and valid.

6.2 Data Collection and Sample Analysis Procedures

When gathering information for calculating the risk values for the construction permit (Section 4), analytical data is initially collected at the same time the pump test and/or pilot test is performed. When gathering information for calculating the risk values for an operating system, analytical data is collected at the times specified in SECTION 4.

In order to assess potential risks to public health from these emissions, the emitted air concentrations for each carcinogenic contaminant are to be determined using an air dispersion model, such as the SCREEN3 air dispersion model. The DWEE Petroleum Remediation Section Air Emissions Calculation Workbook that is located on the DWEE website makes use of a

SCREEN3 database in computing risk levels. It is recommended that the RP/consultant make use of this tool in calculating site risk which is discussed in more detail in Section 6.5 below. If another model is used, it is to be presented and discussed in the RAP.

6.3 Pre-system Implementation Assessment

The risk assessment data is to be collected at the same time as the permitting emission data (i.e., during a pump and/or pilot test) in order to assist with the development of the RAP prior to remediation system design. The following are data elements needed to determine the risk.

AS System Data Needs

- The designed system influent flow (pumping) rate into the stripper. Commonly, this is not the ground water extraction rate as an AS is often cycled;
- AS batch treatment period per hour;
- Treatment building dimensions;
- The maximum estimated influent concentration for each carcinogen present, based on ground water analysis;
- The minimum effluent concentration for each carcinogen present (note: if an effluent sample has not been collected, use the NPDES discharge permit level where applicable, or estimate using the system design efficiency if an NPDES discharge permit level is not available);
- Height of exhaust stack (above ground level);
- Exhaust diameter;
- Exhaust flow rate;
- System start date;
- Estimated operating days for the life of the system (planned system run time);
- Distance to nearest building (including offsite) in each direction from the discharge stack; and
- Approximate dimensions of nearest building in each direction from the discharge stack.

SVE/VE System Data Needs

- The designed system exhaust air flow rate;
- The maximum concentration for each carcinogen present in the exhaust air stream from each emission point;
- Height of exhaust stack (above ground level);
- Treatment building dimensions;
- Exhaust diameter;
- System start date;
- Estimated operating days for the life of the system (planned system run time);
- Distance to nearest building (including offsite) in each direction from the discharge stack; and
- Approximate dimensions of nearest building in each direction from the discharge stack.

Data Gathering Methods:

- The sampling and analysis methods for water and air are discussed in Sections 4.2 and 4.3.

If the proposed remediation system uses more than one remediation technology (e.g., AS coupled with SVE/VE) that will emit pollutants to the atmosphere, then the risk emission calculations for each system are to be derived individually and the sum of the results calculated to determine the total risk posed by the pollutant(s) emitted. In addition, the calculation is to be completed for each pollutant and summed to obtain the cumulative risk.

6.4 Post-system Implementation

Since the risk assessment is based on a chronic exposure to carcinogens, the post-system implementation (operating) assessment is to be performed to determine the average concentration of each carcinogen present for each emission point (as is performed when determining potential exceedance of the permitting threshold quantities). The assessments for each emission point at a site are then summed to determine the total risk for the site. One or more of the modifications mentioned in Section 3.3 and 5.5 is to be implemented if the total cumulative risk exceeds $1x10^{-5}$ for the summation of the individual carcinogens.

The data elements discussed below are to be collected at the appropriate intervals discussed in Section 4.4.

AS Systems Data Needs

- The average influent concentration entering the AS for each carcinogen detected at the site;
- The maximum effluent concentration exiting the AS for each carcinogen detected at the site (Note: the maximum effluent concentration may be calculated using the design efficiency of the AS model used by the remedial system);
- The total influent pumping rate (L/sec) for the AS; and
- Review for potential receptor changes (new construction or removal of homes) on nearby properties on an annual basis. Changed conditions necessitate updating the risk calculations.

SVE/VE Systems Data Needs

- The concentration of each carcinogen in the air being extracted by the system;
- The volumetric flow rate at the point where the carcinogen sample is collected; and
- Review for potential receptor changes (new construction or removal of homes) on nearby properties on an annual basis. Changed conditions necessitate updating the risk calculations.

Data Gathering Methods

- Water and air samples are to be analyzed by methods discussed in Sections 4.2 and 4.3; and
- Airflow rate is to be measured using the procedures discussed in Section 4.6.

If a non-destructive control device (e.g., granular activated carbon) has been installed, then the system data needs are to be collected and documented:

- Upstream of the emission control device; and
- Downstream of the emission control device.

Additional questions regarding air analysis methods approval should be directed to the Air Quality Compliance Section. Questions regarding water analysis methods approval should be directed to the PRS.

6.5 Determining the Air Dispersion Factors Using SCREEN3

The EPA SCREEN3 model is used in this assessment for determining the maximum ground-level concentration of a contaminant at a specified distance from the emission source. The model also simulates the effects of buildings upon dispersion of the contaminant plume as well as meteorological effects of fumigation, etc. The consultant/RP is encouraged to use DWEE PRS's Air Emissions Calculation Workbook, which will perform all these calculations that incorporates SCREEN3 modeling into risk assessment calculations for common scenarios. If the remedial system has unique operational features outside of most remediation systems, the Emission Rate Worksheet will direct the RP/consultant to "Re-check values or contact DWEE PRS." In these cases, the consultant will discuss with the PRS PM proposed design parameter modifications to ensure they are appropriate for the site. DWEE may also direct the consultant/RP to modify inputs to allow for use of the Workbook. Providing the proposed design parameters are appropriate for the site, DWEE may request the RP/consultant to use the SCREEN3 model to determine the 1-hour maximum air concentration to be used in the risk analyses.

With a set exhaust rate of 1 gram per second in the modeling, the Screen3 model 1-hour maximum air concentration serves as a dispersion factor in the calculations. In accordance with EPA protocol (EPA-454/R-92-019), the 1-hour maximum dispersion factor is converted to an annual average dispersion factor by the Average Annual EPA multiplying factor of 0.08.

The inputs into the SCREEN3 model that are built into DWEE's Emission Rate Worksheet are summarized in Table 3. Note that Table 3 uses the metric system in order to be standardized with the SCREEN3 model, but the DWEE Petroleum Remediation Section Air Emissions Calculation Workbook inputs are in US units for the benefit of the RP/Consultant (conversions are available in Appendix C). RP/Consultant inputs to the spreadsheet are bolded.

Table 3. SCREEN 3 Model Inputs

Parameter	Inputs or Ranges of Inputs
Source Type	Point
Terrain Options	Flat
Fumigation	Inversion Break-up
Rural/Urban	Urban
Meteorology	All Stab. & WS
Ambient Temperature (K)	293.15
Mixing Heights	Regulatory
Anemometer Height (m)	10
Emission Rate (g/s)	1
Average Annual EPA Multiplying Factor	0.08
Stack Height (m)	***3, 6, 9, 12 (10, 20, 30, 39 ft)***
Stack Diameter(1) (m)	***0.05, 0.10, 0.15, 0.20 (2, 4, 6, 8 inches)***
Exhaust Velocity (m/s)	0.91, 5.49, 10.06, 14.63, 19.2, 23.77
Exhaust Flow Rate (m^3/s)	***Variable (CFM)***
Exhaust Temperature(2) (K)	293.15
Building Height at roof peak(3) (m)	***3, 5, 6, 8, 9, 12 (10, 16, 20, 26, 30, 39 ft)***
Building Width perpendicular to wind direction(4) (m)	***3, 6, 9, 23 (10, 20, 30, 75 ft)***
Building Length parallel to wind direction(4) (m)	***3, 6, 9, 23 (10, 20, 30, 75 ft)***

Note 1: The largest stack diameter allowed in the Emission Rate worksheet is 8 inches (0.20 meters) in diameter. If the exhaust stack diameter is larger than 8 inches, then the RP/consultant enters an 8-inch stack diameter as a default. A notation is to be made to the DWEE PRS with RAP submittal.

Note 2: Exhaust temperature does not significantly affect the model results for the expected range of parameters, so a default value equivalent to the ambient temperature is used.

Note 3: Building dimensions apply to both the remediation system and adjacent buildings. If the offsite building exceeds 39 feet in height, then the RP/consultant is to contact the DWEE PRS for direction. A notation is to be made to DWEE with RAP submittal.

Note 4: If the building length or width dimensions exceed 75 feet, then the RP/consultant will use 75 feet as a default. A notation is to be made to the DWEE with RAP submittal.

6.6 Exposure Assessment

Exposure is defined as contact between a human and a chemical contaminant in the environment. The amount of contact is dependent on several factors including the chemical concentration and the frequency and duration of exposure. As such, an exposure assessment is an estimation of the magnitude, frequency, duration, and route of exposure.

To assess potential excess cancer risks at petroleum remediation sites, it is assumed that the receptor (human individual) is exposed to site contaminants 24 hours per day, 365 days per year, for a period of 5 years. If the system will operate for a longer or shorter period, then the 5-year parameter will need to be adjusted accordingly. (Note: Continuous operation of the system is assumed, and parameters other than the Exposure Duration are not adjusted.)

6.7 Toxicity Assessment

The purpose of the toxicity assessment is to weigh available evidence regarding the potential for contaminants to cause adverse effects in exposed individuals and to provide an estimate of the relationship between the extent of exposure and the likelihood of these adverse effects occurring. For purposes of this assessment, cancer is the adverse effect that is assessed by determining the excess cancer risk that is estimated to be associated with the exposure to site contaminants.

The excess cancer risk resulting from exposure to a contaminant is described as the probability of an individual developing cancer in his/her lifetime (70 years) as a result of exposure to a carcinogen. The term " excess" is used to refer to the risk above the lifetime risk of developing cancer in the United States of one in two men and one in three women for all types of cancer (American Cancer Society, *Cancer Facts and Figures 2009*).

Toxicity data for the contaminants discussed in Section 6.1 are obtained from the EPA Regional Screening Levels Table. The toxicity values will be updated at a frequency deemed appropriate by the Department and a revised version of the Air Emissions Calculations Workbook will be posted on the DWEE website.

6.8 Risk Characterization

Risk characterization combines the results of the exposure and toxicity assessments to present an estimate of the excess carcinogenic risk associated with the exposure to site contaminants. To calculate the excess carcinogenic risk, the combined cancer risks are to be evaluated. If the excess cumulative cancer risk for the summation of individual risks exceeds $1x10^{-5}$, then modifications (e.g., raising stack height, reducing the stack diameter, installation of a control device, etc.) to the system design are to be made and the risk recalculated.

6.9 Risk Calculation - AS Systems

The equations use only four variables: the influent flow (pumping) rate (Q), the influent carcinogen concentration (C_i), the effluent carcinogen concentration (C_e), and the modeled average annual dispersion factor (C_a). (Note: C_a is developed through running the SCREEN3 model, which has been automated in the DWEE Petroleum Remediation Section Air Emissions Calculation Workbook.) All other parameters used are either derived from these variables or are constants. For comparability purposes, the same method is to be used for both the influent and effluent carcinogen analysis. It is very important to represent the data in the units outlined in this document, and for convenience and consistency, it is recommended that the DWEE Petroleum Remediation Section Air Emissions Calculation Workbook available on the DWEE website be used.

For a single AS emitting pollutants to the atmosphere, a risk assessment for each carcinogen emitted is derived. The risks for all carcinogens are then summed to provide the total cancer risk for that AS. The total cancer risk is not to be greater than 1 x 10^{-5} when multiple carcinogens are present.

If more than one AS is used in the remediation system, then the individual and total cancer risks for all AS systems are totaled to provide the respective cancer risk for the site. Should SVE/VE be used in addition to AS, then the sum of risk assessments (see Section 6.4) for all SVE/VE emission points (derived for each carcinogen emitted and totaled) is added to that calculated for the AS system(s). The following equation is an example of solving for the total risk from one AS where only benzene is the carcinogen.

Parameters used:

R_{as} = Cancer risk for the AS
R_{tot} = Total site cancer risk
C_a = Modeled average annual dispersion factor from SCREEN3 model (ug/m^3) (g/sec)$^{-1}$
C_i = Air stripper influent concentration of benzene (g/L)
C_e = Air stripper effluent concentration of benzene (g/L)
IUR = Inhalation unit risk factor for benzene (ug/m^3)$^{-1}$
Q = Groundwater flow rate of full-scale system (L/sec)
X = Proposed duration of system operation (days)
25,550 = Continuous days of system operation in 70 years

ER Calculation:

$$\mathrm{ER} = \mathrm{Q} * (\mathrm{C_i} - \mathrm{C_e})$$

R_{as} Calculation:

$$R_{\mathrm{as}} = (ER)(C_a)(\mathrm{IUR})\left(\frac{x}{25{,}550}\right)$$

R_{tot} Calculation (if necessary):

$$\mathrm{R_{tot}} = \mathrm{R_{as}} + \mathrm{R_{sve}}$$

6.10 Risk Calculation - SVE/VE Systems

The equations use only two system variables: the system exhaust airflow rate (Q) and the carcinogen concentration in the exhaust air stream (C_b). The risk calculation also makes use of the modeled average annual dispersion factor (C_a). (Note: C_a is developed through running the SREEN3 model, which has been automated in the DWEE Petroleum Remediation Section Air Emissions Calculation Workbook.) All other parameters used are either derived from these variables or are constants. It is very important to represent the data in the units outlined in this document and, for convenience and consistency; it is recommended that the DWEE Petroleum Remediation Section Air Emissions Calculation Workbook, available on the DWEE website, be used.

For a single SVE/VE emitting pollutants to the atmosphere, a risk assessment for each carcinogen emitted is derived. The risks for all carcinogens are then summed to provide the total cancer risk for that SVE/VE. The total cancer risk is not to be greater than 1 x 10^{-5} for the total carcinogens present.

If more than one SVE/VE is used in the remediation system, then the total cancer risks for all SVE/VE systems are summed to provide the respective cancer risk for the site. Should an AS be used in addition to SVE/VE, then the sum of risk assessments (see Section 6.4) for all AS emission points (derived for each carcinogen emitted and totaled) is added to that calculated for the SVE/VE system(s). The following equation is an example of solving for the total risk from one SVE/VE where benzene is the only carcinogen.

Parameters to be used:

ER = Pollutant emission rate (g/sec)
R_{sve} = Cancer risk for the SVE/VE emissions
R_{tot} = Total site cancer risk
Q = Exhaust air flow rate for full scale system (L/sec)
C_a = Modeled average annual dispersion factor from SCREEN3 model $(\text{ug/m}^3)\ (\text{g/sec})^{-1}$
IUR = Inhalation unit risk factor for benzene $(\text{ug/m}^3)^{-1}$
X = Proposed duration of system operation (days)
25,550 = Continuous days of system operation in 70 years

Pre-system Implementation

- C_b = Maximum benzene concentration of the exhaust system (g/L)

Post-system Implementation

- C_b = Average benzene concentration of the exhaust system (g/L) with the startup results excluded

ER Calculation: $ER = Q * C_b$

R_{sve} Calculation:

$$R_{sve} = (ER)(C_a)(IUR)\left(\frac{X}{25{,}550}\right)$$

R_{tot} Calculation (If necessary): $R_{tot} = R_{as} + R_{sve}$

6.11 Risk Assessment Procedures

The following procedures are to be used to determine the risk at the site. For sites that incorporate more than one type of remediation system (e.g., AS, SVE/VE), the risk for all systems is to be summed on both an individual and total carcinogen basis.

Pre-system Installation

When conducting the initial cancer risk assessment, the greatest cancer risk value calculated is used employing the aforementioned procedures. If R_{tot} is greater than $1\text{x}10^{-5}$, the RP/consultant should be prepared to operate or modify the system design in such a manner that the risk factor will not be exceeded (e.g., reducing operating times or flow rates, or installing control equipment).

If the R_{tot} is less than or equal to $1x10^{-5}$ prior to system installation, then the remediation system may be installed and operated in accordance with the approved RAP.

Post-system Installation

Subsequent cancer risk assessments are to be reevaluated after every sampling event outlined in Section 4.4 of this document. Since this assessment is based on chronic exposure to a carcinogen, individual cancer risks are to be summed for every emission point on site (i.e., that is every AS and/or SVE/VE) and then the individual risks summed to obtain the cumulative risk (total risk). The total risk can then be averaged by dividing the sum of the total risks by the number of sampling events (excluding the startup results). If multiple carcinogens are present, then the individual risk is to be calculated for each carcinogen and summed to obtain the cumulative risk. If the cumulative average total risk is greater than $1x10^{-5}$ for carcinogens emanating from all emission points, then modifications may be needed.

The RP/consultant is encouraged to use the DWEE Petroleum Remediation Section Air Emissions Calculation Workbook to evaluate the ongoing risk as a result of remediation activities. With each new sampling event, the RP/consultant should update the ***Emission Rate*** worksheet, which automatically calculates the risk in the ***Risk Evaluation*** worksheet. The data results of the ***Emission Rate*** worksheet and the ***Risk Evaluation*** worksheet are then entered into the ***Emission Totals*** worksheet which will compute the combined excess lifetime cancer risk for a user-defined averaging period.

As long as the R_{tot} is less than or equal to $1x10^{-5}$, the system may be operated, as approved by DWEE. If not otherwise directed by the PRS PM, the sampling frequency may be reduced to semi-annual if the following criteria are met:

- The sampling and analysis were performed as outlined in Sections 4.2 and 4.3;
- Air monitoring reports were submitted with the appropriate information and during the time frames described in SECTION 7;
- Free product is not present nor was it present for a period of one year; and
- Emissions did not exceed 85 percent of the combined excess lifetime cancer risk of 1×10^{-5} for the total carcinogens present for a period of at least one year.

If it is determined from two consecutive years of air monitoring data that the criteria above were achieved and there is nothing to indicate that contamination levels are increasing, the RP or consultant is to submit a written request with supporting discussion and documentation to the PRS PM for considering the cessation of air emission sampling.

6.12 Control Equipment

See Section 5.5 for guidance pertaining to emission control devices.

SECTION 7 REPORTING PROCEDURES

A summary of the permitting and excess cancer risk data and calculations is to be included as part of the RAP. The RP/consultant is encouraged to use the DWEE Petroleum Remediation Section Air Emissions Calculation Workbook and submit the ***Emission Rate*** and ***Risk Evaluation*** worksheets with the RAP.

The RP/consultant is also encouraged to use the DWEE Petroleum Remediation Section Air Emissions Calculation Workbook to evaluate the ongoing risk and total emissions. The Worksheets are to be submitted as part of monitoring report submittals.

If it is determined through sampling that the emission of contaminants from an operating remediation system will exceed the Construction and Operating Permit threshold levels (Section 3.3) and/or the allowable excess cancer risk values (SECTION 6), the PRS PM is to be contacted by the close of the next working day.

7.1 Air Emissions Monitoring Reports

Air Emissions Monitoring Reports can be submitted in a combined format with any other report (e.g., ground water monitoring) due near the same time. The Air Emissions Monitoring Reports are to include: narrative, calculations, DWEE Petroleum Remediation Section Air Emissions Calculation Workbook, analytical summary tables, laboratory analytical reports, chromatograms, and chain-of-custody forms, and submitted per the following schedule, unless otherwise directed:

- First Air Emissions Monitoring Report – submitted on or before the last working day of the **7th month** following system startup. The report is to include the emissions sampling results collected 7 days after startup of the system through 6 months of operation. The startup emissions sample results collected 7 days after startup are also to be included in the report, but not used in the calculations.

- Second Air Monitoring Report – submitted on before the last working day of the **13th month** following system startup. The report is to include the emissions sampling results collected after 9 and 12 months of system operation following system startup in addition to that information submitted in the first report.

- Third Air Emissions Monitoring Report – submitted on or before the last working day of the **19th month** following system startup. The report is to include the emissions sampling results collected after 18 months of system operation following system startup in addition to information submitted in the previous reports.

- Fourth Air Emissions Monitoring Report – submitted on or before the last working day of the **25th month** following system startup. The report is to include the emissions sampling results collected after 24 months of system operation following system startup in addition to information submitted in the previous reports.

- Air emissions sampling events and monitoring report submittals are to continue every 6 months unless otherwise directed or the criteria discussed in Sections 5.3 and 5.4 are met.

If the emissions from an operating system exceed 85 percent of the permitting and/or risk exposure thresholds at any time, contact the PRS PM to discuss if more frequent sampling is necessary.

The emissions for the permitting tonnages are to be equal to or less than the permitting thresholds over a period of time equal to one year. When determining the emissions for the first year, the most current sampling results (in tons) are added to the results of the previous months to provide the total emission tonnages.

$$T_{tot} = SE_1 + SE_2 + SE_3 + SE_4 + SE_5 + SE_6 + SE_6 + SE_6 + SE_9 + SE_9 + SE_9 + SE_{12}$$

T_{tot} = twelve-month total tonnage
SE_n = sampling event concentrations (in tons) for month "n" (NOTE: SE_6 sample results (in tons) are substituted for those in months 7 and 8; and SE_9 sample results (in tons) for those in months 10 and 11, unless otherwise directed.)

As permitting emission sampling continues beyond the first twelve-month period, the most current sampling result (in tons) is added to those of the previous eleven months to provide a rolling twelve-month total tonnage.

$$T_{rtot} = SE_2 + SE_3 + SE_4 + SE_5 + SE_6 + SE_6 + SE_6 + SE_9 + SE_9 + SE_9 + SE_{12} + SE_{12}$$

T_{rtot} = rolling twelve-month total tonnage
SE_n = sampling event concentrations (tons) for month "n" (NOTE: no more than 12 months of results are ever summed; SE_{12} sample results (in tons) are substituted for those in months 13, 14, 15, 16 and 17; and SE_{18} results (in tons) for those in months 19, 20, 21, 22, and 23, unless otherwise directed.)

The emissions for the average total cancer risk levels at a site are to be equal to or less than $1x10^{-5}$ for the total number of carcinogens for a period of time equal to one year. When determining the risk for the first year, the cumulative total risk values for each month are summed and then divided by the number of months that have passed since operation has started in order to provide the most current average cumulative risk.

$$C_{ave} = \frac{(SE_1 + SE_2 + SE_3 + SE_4 + SE_5 + SE_6 + SE_6 + SE_6 + SE_9 + SE_9 + SE_9 + SE_{12})}{N_{SE}}$$

C_{ave} = twelve-month average total risk
SE_n = sampling event total risk for month "n" (NOTE: SE_6 results are substituted for those in months 7 and 8; and SE_9 results for those in months 10 and 11, unless otherwise directed.)
N_{SE} = the number of months (not to exceed 12)

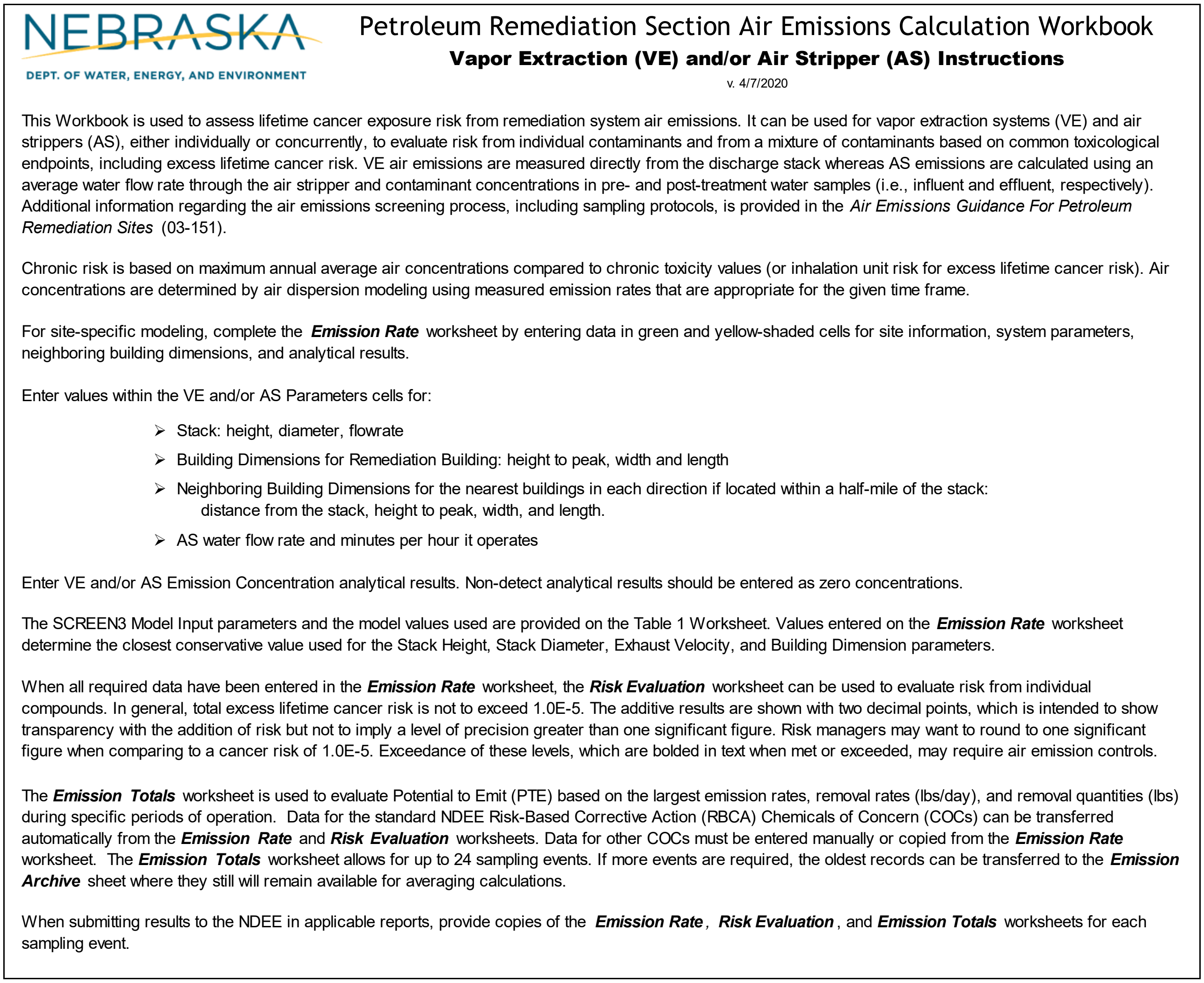
As emission sampling continues beyond the first twelve-month period, the total risk from the most current sampling results are averaged with the results of the previous eleven months.

$$C_{rave} = \frac{(SE_2 + SE_3 + SE_4 + SE_5 + SE_6 + SE_6 + SE_6 + SE_9 + SE_9 + SE_9 + SE_{12} + SE_{12})}{12}$$

C_{rave} = twelve-month rolling average total risk
SE_n = sampling event total risk for month "n" (NOTE: SE_{12} results are substituted for the risk in months 13, 14, 15, 16 and 17 and SE_{18} results for the risk in months 19, 20, 21, 22, and 23, unless otherwise directed.)

Example worksheets from the DWEE Petroleum Remediation Section Air Emissions Calculation Workbook are provided on the following pages. The Workbook is available in Excel format for download from the Department's website at:
https://dee.nebraska.gov/forms/publications-grants-forms/03-151

INSTRUCTION WORKSHEET



NEBRASKA
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Petroleum Remediation Section Air Emissions Calculation Workbook

Vapor Extraction (VE) and/or Air Stripper (AS) Instructions

v. 4/7/2020

This Workbook is used to assess lifetime cancer exposure risk from remediation system air emissions. It can be used for vapor extraction systems (VE) and air strippers (AS), either individually or concurrently, to evaluate risk from individual contaminants and from a mixture of contaminants based on common toxicological endpoints, including excess lifetime cancer risk. VE air emissions are measured directly from the discharge stack whereas AS emissions are calculated using an average water flow rate through the air stripper and contaminant concentrations in pre- and post-treatment water samples (i.e., influent and effluent, respectively). Additional information regarding the air emissions screening process, including sampling protocols, is provided in the *Air Emissions Guidance For Petroleum Remediation Sites* (03-151).

Chronic risk is based on maximum annual average air concentrations compared to chronic toxicity values (or inhalation unit risk for excess lifetime cancer risk). Air concentrations are determined by air dispersion modeling using measured emission rates that are appropriate for the given time frame.

For site-specific modeling, complete the ***Emission Rate*** worksheet by entering data in green and yellow-shaded cells for site information, system parameters, neighboring building dimensions, and analytical results.

Enter values within the VE and/or AS Parameters cells for:

- Stack: height, diameter, flowrate
- Building Dimensions for Remediation Building: height to peak, width and length
- Neighboring Building Dimensions for the nearest buildings in each direction if located within a half-mile of the stack: distance from the stack, height to peak, width, and length.
- AS water flow rate and minutes per hour it operates

Enter VE and/or AS Emission Concentration analytical results. Non-detect analytical results should be entered as zero concentrations.

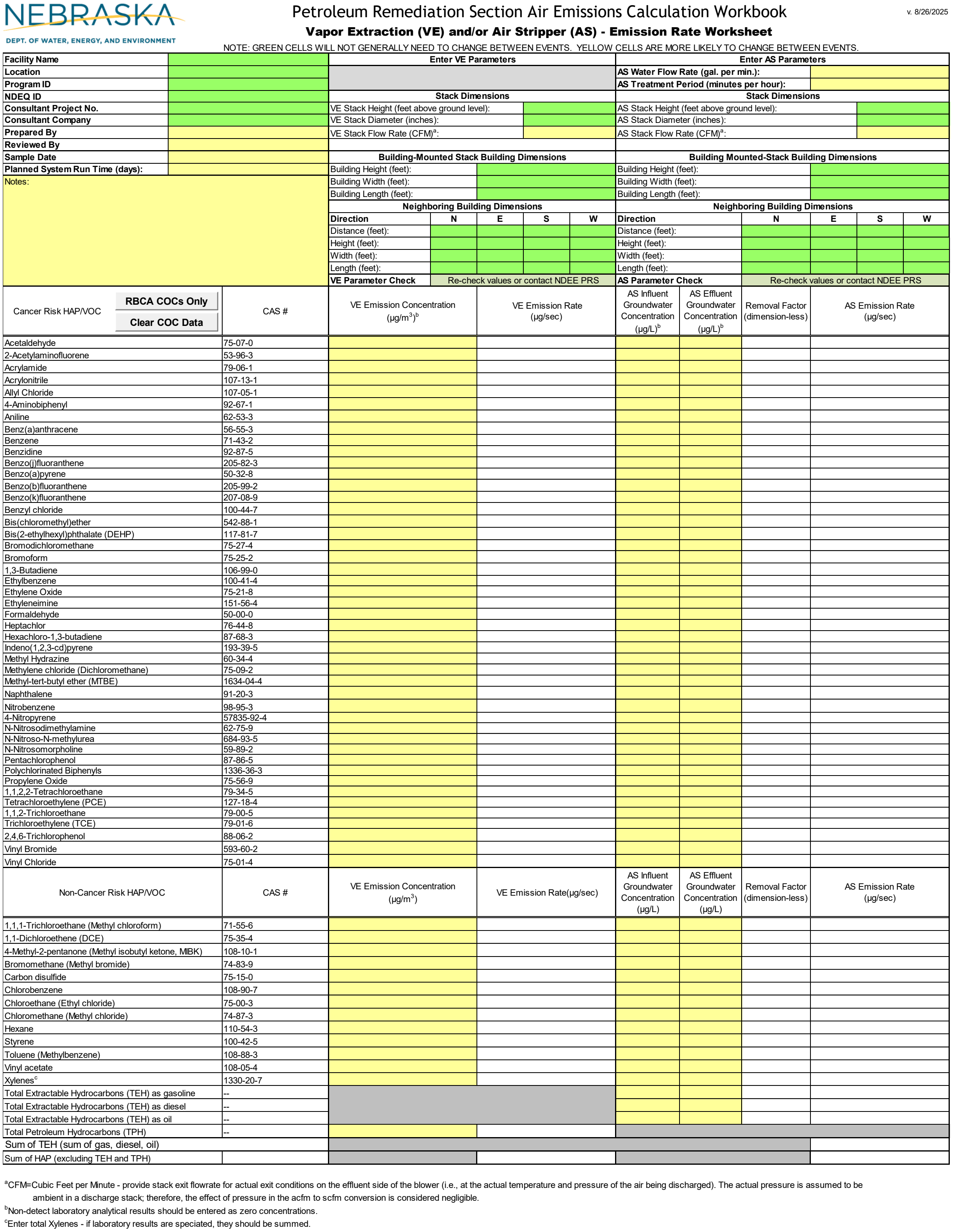
The SCREEN3 Model Input parameters and the model values used are provided on the Table 1 Worksheet. Values entered on the ***Emission Rate*** worksheet determine the closest conservative value used for the Stack Height, Stack Diameter, Exhaust Velocity, and Building Dimension parameters.

When all required data have been entered in the ***Emission Rate*** worksheet, the ***Risk Evaluation*** worksheet can be used to evaluate risk from individual compounds. In general, total excess lifetime cancer risk is not to exceed 1.0E-5. The additive results are shown with two decimal points, which is intended to show transparency with the addition of risk but not to imply a level of precision greater than one significant figure. Risk managers may want to round to one significant figure when comparing to a cancer risk of 1.0E-5. Exceedance of these levels, which are bolded in text when met or exceeded, may require air emission controls.

The ***Emission Totals*** worksheet is used to evaluate Potential to Emit (PTE) based on the largest emission rates, removal rates (lbs/day), and removal quantities (lbs) during specific periods of operation. Data for the standard NDEE Risk-Based Corrective Action (RBCA) Chemicals of Concern (COCs) can be transferred automatically from the ***Emission Rate*** and ***Risk Evaluation*** worksheets. Data for other COCs must be entered manually or copied from the ***Emission Rate*** worksheet. The ***Emission Totals*** worksheet allows for up to 24 sampling events. If more events are required, the oldest records can be transferred to the ***Emission Archive*** sheet where they still will remain available for averaging calculations.

When submitting results to the NDEE in applicable reports, provide copies of the ***Emission Rate***, ***Risk Evaluation***, and ***Emission Totals*** worksheets for each sampling event.

EMISSION RATE WORKSHEET EXAMPLE



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Petroleum Remediation Section Air Emissions Calculation Workbook

v. 8/26/2025

Vapor Extraction (VE) and/or Air Stripper (AS) - Emission Rate Worksheet

NOTE: GREEN CELLS WILL NOT GENERALLY NEED TO CHANGE BETWEEN EVENTS. YELLOW CELLS ARE MORE LIKELY TO CHANGE BETWEEN EVENTS.

Facility Name	
Location	
Program ID	
NDEQ ID	
Consultant Project No.	
Consultant Company	
Prepared By	
Reviewed By	
Sample Date	
Planned System Run Time (days):	
Notes:	

Enter VE Parameters				
Stack Dimensions				
VE Stack Height (feet above ground level):				
VE Stack Diameter (inches):				
VE Stack Flow Rate (CFM)[a]:				
Building-Mounted Stack Building Dimensions				
Building Height (feet):				
Building Width (feet):				
Building Length (feet):				
Neighboring Building Dimensions				
Direction	**N**	**E**	**S**	**W**
Distance (feet):				
Height (feet):				
Width (feet):				
Length (feet):				
VE Parameter Check	Re-check values or contact NDEE PRS			

Enter AS Parameters				
AS Water Flow Rate (gal. per min.):				
AS Treatment Period (minutes per hour):				
Stack Dimensions				
AS Stack Height (feet above ground level):				
AS Stack Diameter (inches):				
AS Stack Flow Rate (CFM)[a]:				
Building Mounted-Stack Building Dimensions				
Building Height (feet):				
Building Width (feet):				
Building Length (feet):				
Neighboring Building Dimensions				
Direction	**N**	**E**	**S**	**W**
Distance (feet):				
Height (feet):				
Width (feet):				
Length (feet):				
AS Parameter Check	Re-check values or contact NDEE PRS			

Cancer Risk HAP/VOC **RBCA COCs Only** **Clear COC Data**	CAS #	VE Emission Concentration (µg/m^3)[b]	VE Emission Rate (µg/sec)	AS Influent Groundwater Concentration (µg/L)[b]	AS Effluent Groundwater Concentration (µg/L)[b]	Removal Factor (dimension-less)	AS Emission Rate (µg/sec)
Acetaldehyde	75-07-0						
2-Acetylaminofluorene	53-96-3						
Acrylamide	79-06-1						
Acrylonitrile	107-13-1						
Allyl Chloride	107-05-1						
4-Aminobiphenyl	92-67-1						
Aniline	62-53-3						
Benz(a)anthracene	56-55-3						
Benzene	71-43-2						
Benzidine	92-87-5						
Benzo(j)fluoranthene	205-82-3						
Benzo(a)pyrene	50-32-8						
Benzo(b)fluoranthene	205-99-2						
Benzo(k)fluoranthene	207-08-9						
Benzyl chloride	100-44-7						
Bis(chloromethyl)ether	542-88-1						
Bis(2-ethylhexyl)phthalate (DEHP)	117-81-7						
Bromodichloromethane	75-27-4						
Bromoform	75-25-2						
1,3-Butadiene	106-99-0						
Ethylbenzene	100-41-4						
Ethylene Oxide	75-21-8						
Ethyleneimine	151-56-4						
Formaldehyde	50-00-0						
Heptachlor	76-44-8						
Hexachloro-1,3-butadiene	87-68-3						
Indeno(1,2,3-cd)pyrene	193-39-5						
Methyl Hydrazine	60-34-4						
Methylene chloride (Dichloromethane)	75-09-2						
Methyl-tert-butyl ether (MTBE)	1634-04-4						
Naphthalene	91-20-3						
Nitrobenzene	98-95-3						
4-Nitropyrene	57835-92-4						
N-Nitrosodimethylamine	62-75-9						
N-Nitroso-N-methylurea	684-93-5						
N-Nitrosomorpholine	59-89-2						
Pentachlorophenol	87-86-5						
Polychlorinated Biphenyls	1336-36-3						
Propylene Oxide	75-56-9						
1,1,2,2-Tetrachloroethane	79-34-5						
Tetrachloroethylene (PCE)	127-18-4						
1,1,2-Trichloroethane	79-00-5						
Trichloroethylene (TCE)	79-01-6						
2,4,6-Trichlorophenol	88-06-2						
Vinyl Bromide	593-60-2						
Vinyl Chloride	75-01-4						

Non-Cancer Risk HAP/VOC	CAS #	VE Emission Concentration (µg/m^3)	VE Emission Rate(µg/sec)	AS Influent Groundwater Concentration (µg/L)	AS Effluent Groundwater Concentration (µg/L)	Removal Factor (dimension-less)	AS Emission Rate (µg/sec)
1,1,1-Trichloroethane (Methyl chloroform)	71-55-6						
1,1-Dichloroethene (DCE)	75-35-4						
4-Methyl-2-pentanone (Methyl isobutyl ketone, MIBK)	108-10-1						
Bromomethane (Methyl bromide)	74-83-9						
Carbon disulfide	75-15-0						
Chlorobenzene	108-90-7						
Chloroethane (Ethyl chloride)	75-00-3						
Chloromethane (Methyl chloride)	74-87-3						
Hexane	110-54-3						
Styrene	100-42-5						
Toluene (Methylbenzene)	108-88-3						
Vinyl acetate	108-05-4						
Xylenes[c]	1330-20-7						
Total Extractable Hydrocarbons (TEH) as gasoline	--						
Total Extractable Hydrocarbons (TEH) as diesel	--						
Total Extractable Hydrocarbons (TEH) as oil	--						
Total Petroleum Hydrocarbons (TPH)	--						
Sum of TEH (sum of gas, diesel, oil)							
Sum of HAP (excluding TEH and TPH)							

[a] CFM=Cubic Feet per Minute - provide stack exit flowrate for actual exit conditions on the effluent side of the blower (i.e., at the actual temperature and pressure of the air being discharged). The actual pressure is assumed to be ambient in a discharge stack; therefore, the effect of pressure in the acfm to scfm conversion is considered negligible.

[b] Non-detect laboratory analytical results should be entered as zero concentrations.

[c] Enter total Xylenes - if laboratory results are speciated, they should be summed.

Note: Some rows of chemicals were removed from the example for clarity.

RISK EVALUATION WORKSHEET EXAMPLE

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Petroleum Remediation Section Air Emissions Calculation Workbook

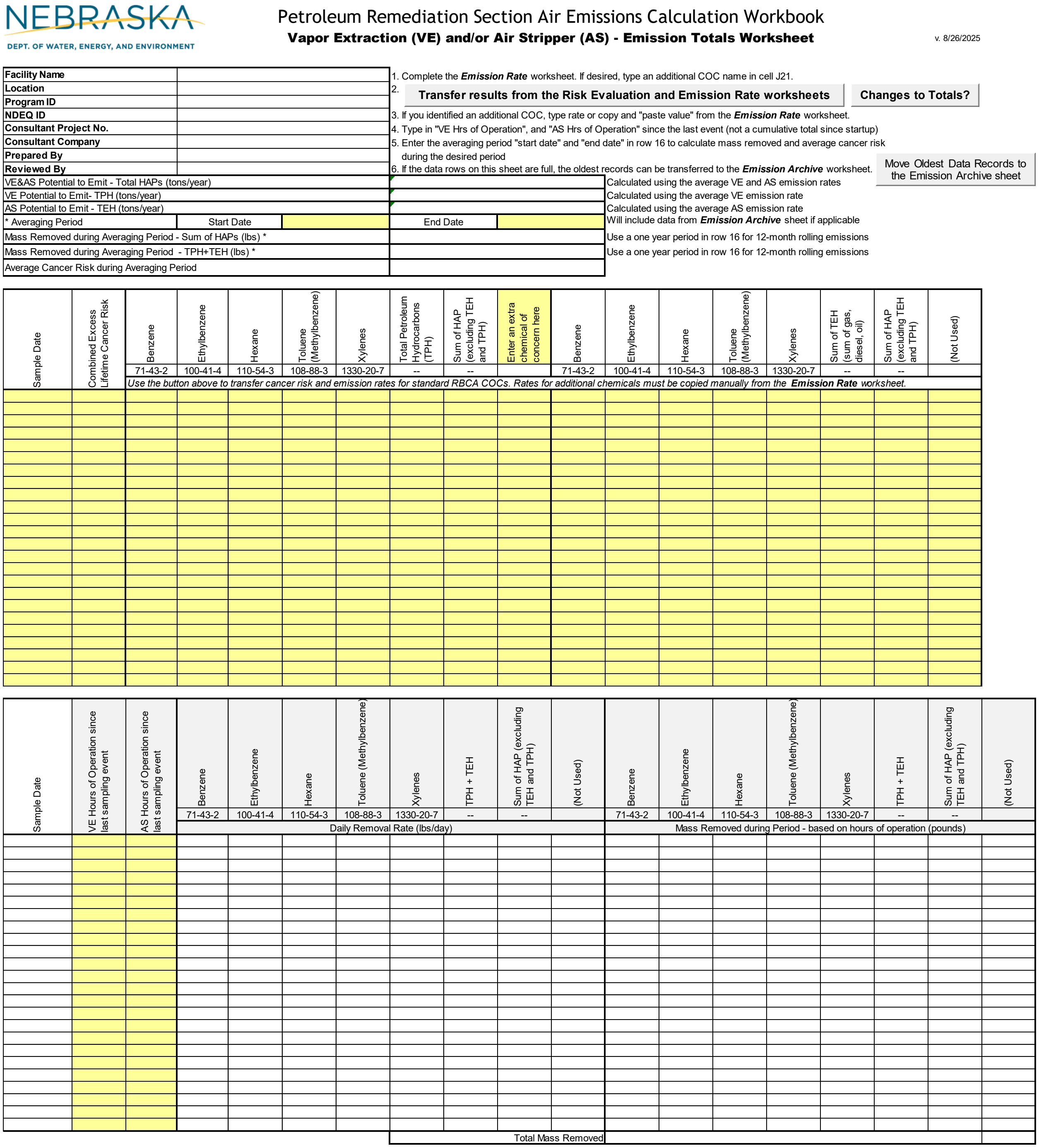
Vapor Extraction (VE) and/or Air Stripper (AS) - Risk Evaluation Worksheet

v. 8/26/2025

Facility Name	
Location	
Program ID	
NDEQ ID	
Consultant Project No.	
Consultant Company	
Prepared By	
Reviewed By	

Chemical Name	CAS #	Excess Lifetime Cancer Risk	Chemical Name	CAS #	Excess Lifetime Cancer Risk
Acetaldehyde	75-07-0		1,2-Dichloroethane (DCA)	107-06-2	
2-Acetylaminofluorene	53-96-3		1,2-Dichloropropane	78-87-5	
Acrylamide	79-06-1		1,3-dichloropropene	542-75-6	
Acrylonitrile	107-13-1		Dimethyl Aminoazobenzene	60-11-7	
Allyl Chloride	107-05-1		7,12-Dimethylbenz(a)anthracene	57-97-6	
4-Aminobiphenyl	92-67-1		2,4-Dinitrotoluene	121-14-2	
Aniline	62-53-3		1,4-dioxane	123-91-1	
Benz(a)anthracene	56-55-3		1,2-Dipheynalhydrazine	122-66-7	
Benzene	71-43-2		Epichlorohydrin	106-89-8	
Benzidine	92-87-5		Ethylbenzene	100-41-4	
Benzo(j)fluoranthene	205-82-3		Ethylene Oxide	75-21-8	
Benzo(a)pyrene	50-32-8		Ethyleneimine	151-56-4	
Benzo(b)fluoranthene	205-99-2		Formaldehyde	50-00-0	
Benzo(k)fluoranthene	207-08-9		Heptachlor	76-44-8	
Benzyl chloride	100-44-7		Hexachloro-1,3-butadiene	87-68-3	
Bis(chloromethyl)ether	542-88-1		Indeno(1,2,3-cd)pyrene	193-39-5	
Bis(2-ethylhexyl)phthalate (DEHP)	117-81-7		Methyl Hydrazine	60-34-4	
Bromodichloromethane	75-27-4		Methylene chloride (Dichloromethane)	75-09-2	
Bromoform	75-25-2		Methyl-tert-butyl ether (MTBE)	1634-04-4	
1,3-Butadiene	106-99-0		Naphthalene	91-20-3	
Carbon tetrachloride	56-23-5		Nitrobenzene	98-95-3	
Chlorobenzilate	510-15-6		4-Nitropyrene	57835-92-4	
2-Chloro-1,3-butadiene (Chloroprene)	126-99-8		N-Nitrosodimethylamine	62-75-9	
Chloroform	67-66-3		N-Nitroso-N-methylurea	684-93-5	
Chloromethyl Methyl Ether	107-30-2		N-Nitrosomorpholine	59-89-2	
Chrysene	218-01-9		Pentachlorophenol	87-86-5	
Dibenz(a,h)anthracene	53-70-3		Polychlorinated Biphenyls	1336-36-3	
Dibenzo(a,e)pyrene	192-65-4		Propylene Oxide	75-56-9	
1,2-Dibromo-3-choloropropate	96-12-8		1,1,2,2-Tetrachloroethane	79-34-5	
1,2-Dibromoethane (Ethylene dibromide, EDB)	106-93-4		Tetrachloroethylene (PCE)	127-18-4	
1,4-Dichlorobenzene	106-46-7		1,1,2-Trichloroethane	79-00-5	
3,3'-Dichlorobenzidine	91-94-1		Trichloroethylene (TCE)	79-01-6	
1,1-Dichloro-2,2-bis(p-chlorophenol)ethylene) (DDE)	72-55-9		2,4,6-Trichlorophenol	88-06-2	
1,1-Dichloroethane	75-34-3		Vinyl Bromide	593-60-2	
			Vinyl Chloride	75-01-4	
				Combined Excess Lifetime Cancer Risk:	**Contact NDEE**

EMISSION TOTALS WORKSHEET EXAMPLE



NEBRASKA
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Petroleum Remediation Section Air Emissions Calculation Workbook
Vapor Extraction (VE) and/or Air Stripper (AS) - Emission Totals Worksheet
v. 8/26/2025

Facility Name	
Location	
Program ID	
NDEQ ID	
Consultant Project No.	
Consultant Company	
Prepared By	
Reviewed By	

1. Complete the ***Emission Rate*** worksheet. If desired, type an additional COC name in cell J21.
2. **Transfer results from the Risk Evaluation and Emission Rate worksheets** **Changes to Totals?**
3. If you identified an additional COC, type rate or copy and "paste value" from the ***Emission Rate*** worksheet.
4. Type in "VE Hrs of Operation", and "AS Hrs of Operation" since the last event (not a cumulative total since startup)
5. Enter the averaging period "start date" and "end date" in row 16 to calculate mass removed and average cancer risk during the desired period
6. If the data rows on this sheet are full, the oldest records can be transferred to the ***Emission Archive*** worksheet.

Move Oldest Data Records to the Emission Archive sheet

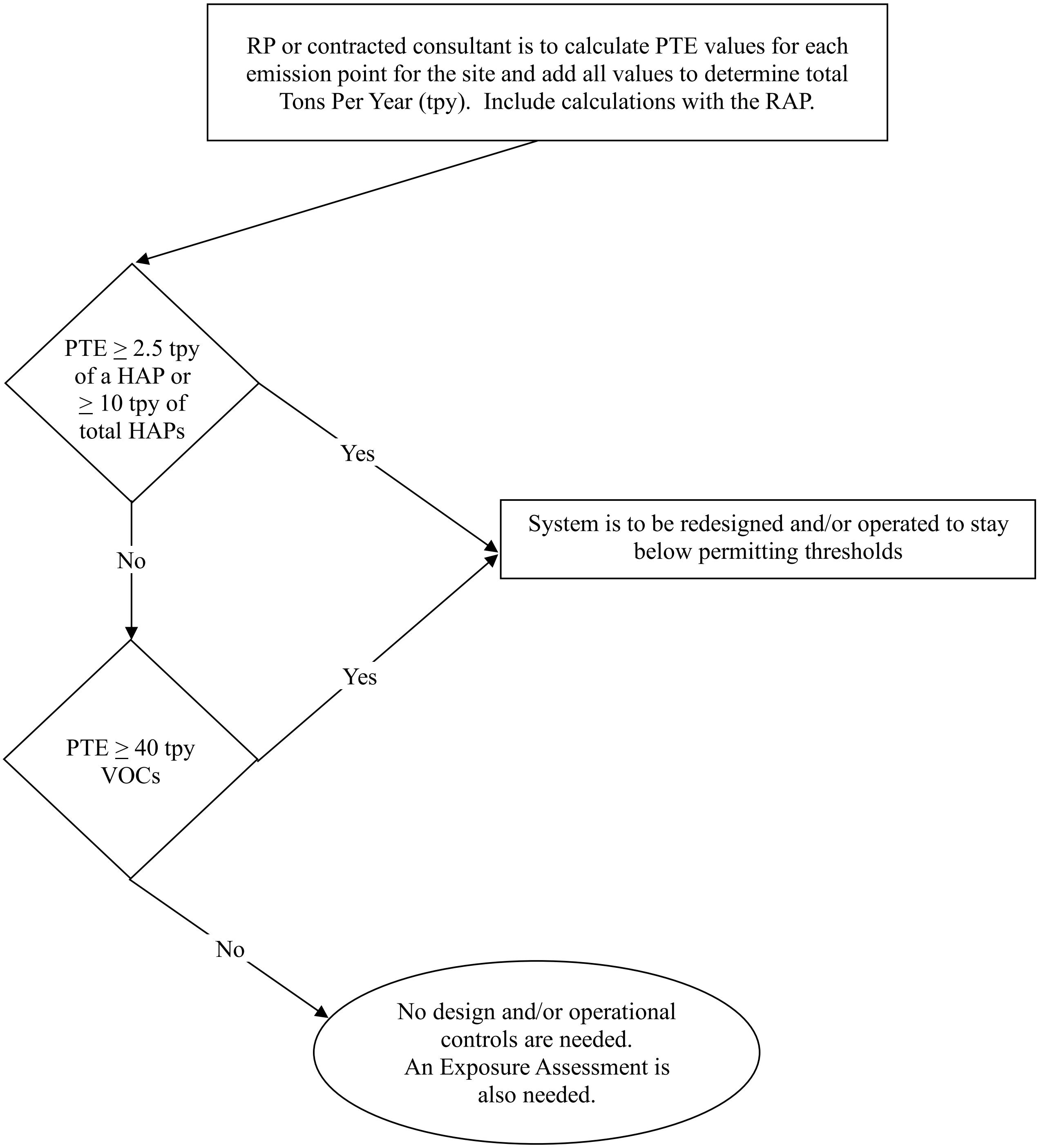
VE&AS Potential to Emit - Total HAPs (tons/year)				Calculated using the average VE and AS emission rates
VE Potential to Emit- TPH (tons/year)				Calculated using the average VE emission rate
AS Potential to Emit - TEH (tons/year)				Calculated using the average AS emission rate
* Averaging Period	Start Date		End Date	Will include data from ***Emission Archive*** sheet if applicable
Mass Removed during Averaging Period - Sum of HAPs (lbs) *				Use a one year period in row 16 for 12-month rolling emissions
Mass Removed during Averaging Period - TPH+TEH (lbs) *				Use a one year period in row 16 for 12-month rolling emissions
Average Cancer Risk during Averaging Period				

Sample Date	Combined Excess Lifetime Cancer Risk	Benzene	Ethylbenzene	Hexane	Toluene (Methylbenzene)	Xylenes	Total Petroleum Hydrocarbons (TPH)	Sum of HAP (excluding TEH and TPH)	Enter an extra chemical of concern here	Benzene	Ethylbenzene	Hexane	Toluene (Methylbenzene)	Xylenes	Sum of TEH (sum of gas, diesel, oil)	Sum of HAP (excluding TEH and TPH)	(Not Used)
		71-43-2	100-41-4	110-54-3	108-88-3	1330-20-7	--	--		71-43-2	100-41-4	110-54-3	108-88-3	1330-20-7	--	--	
		Use the button above to transfer cancer risk and emission rates for standard RBCA COCs. Rates for additional chemicals must be copied manually from the ***Emission Rate*** *worksheet.*															

Sample Date	VE Hours of Operation since last sampling event	AS Hours of Operation since last sampling event	Benzene	Ethylbenzene	Hexane	Toluene (Methylbenzene)	Xylenes	TPH + TEH	Sum of HAP (excluding TEH and TPH)	(Not Used)	Benzene	Ethylbenzene	Hexane	Toluene (Methylbenzene)	Xylenes	TPH + TEH	Sum of HAP (excluding TEH and TPH)	(Not Used)
			71-43-2	100-41-4	110-54-3	108-88-3	1330-20-7	--	--		71-43-2	100-41-4	110-54-3	108-88-3	1330-20-7	--	--	
			Daily Removal Rate (lbs/day)								Mass Removed during Period - based on hours of operation (pounds)							
									Total Mass Removed									

DWEE Air Emissions Guidance For Petroleum Remediation Sites Evaluation Flow Chart

(See Page 1 for Definitions of Acronyms)



RP or contracted consultant is to calculate PTE values for each emission point for the site and add all values to determine total Tons Per Year (tpy). Include calculations with the RAP.

System is to be redesigned and/or operated to stay below permitting thresholds

No design and/or operational controls are needed. An Exposure Assessment is also needed.

DWEE Air Emissions Guidance For Petroleum Remediation Sites Evaluation Flow Chart, Continued

Permitting Calculations

If the proposed remediation system uses more than one remediation technology (e.g., AS and SVE/VE) that emits pollutants (VOCs/HAPs) to the atmosphere, then the permitting calculations for emissions from each system are to be derived individually and the sum of the results calculated to determine the total tonnage of pollutant(s) being emitted. In addition, the calculation is to be completed for each pollutant and combination of pollutants.

Permitting Calculations for all VOCs/HAPs from all AS Systems

+

Permitting Calculations for all VOCs/HAPs from all SVE/VE(s)

=

Total Emissions Tonnage for the Site (Total Tonnage is to be below or equal to the Construction & Operation Permit Thresholds)

Calculating Construction/Operating Permit Tonnages

The emissions for the permitting tonnages (T_{tot}) are to be equal to or less than the permitting thresholds for a period of time equal to one year. When determining the emissions for the first year, the most current sampling results (in tons) are added to those of the previous months to provide the total tonnage.

When permitting emission sampling continues for more than a twelve-month period, then the most current sampling result (in tons) is added to the results of the previous eleven months to provide a rolling twelve-month total tonnage (T_{rtot}).

Totaling the first twelve months permitting tonnage:

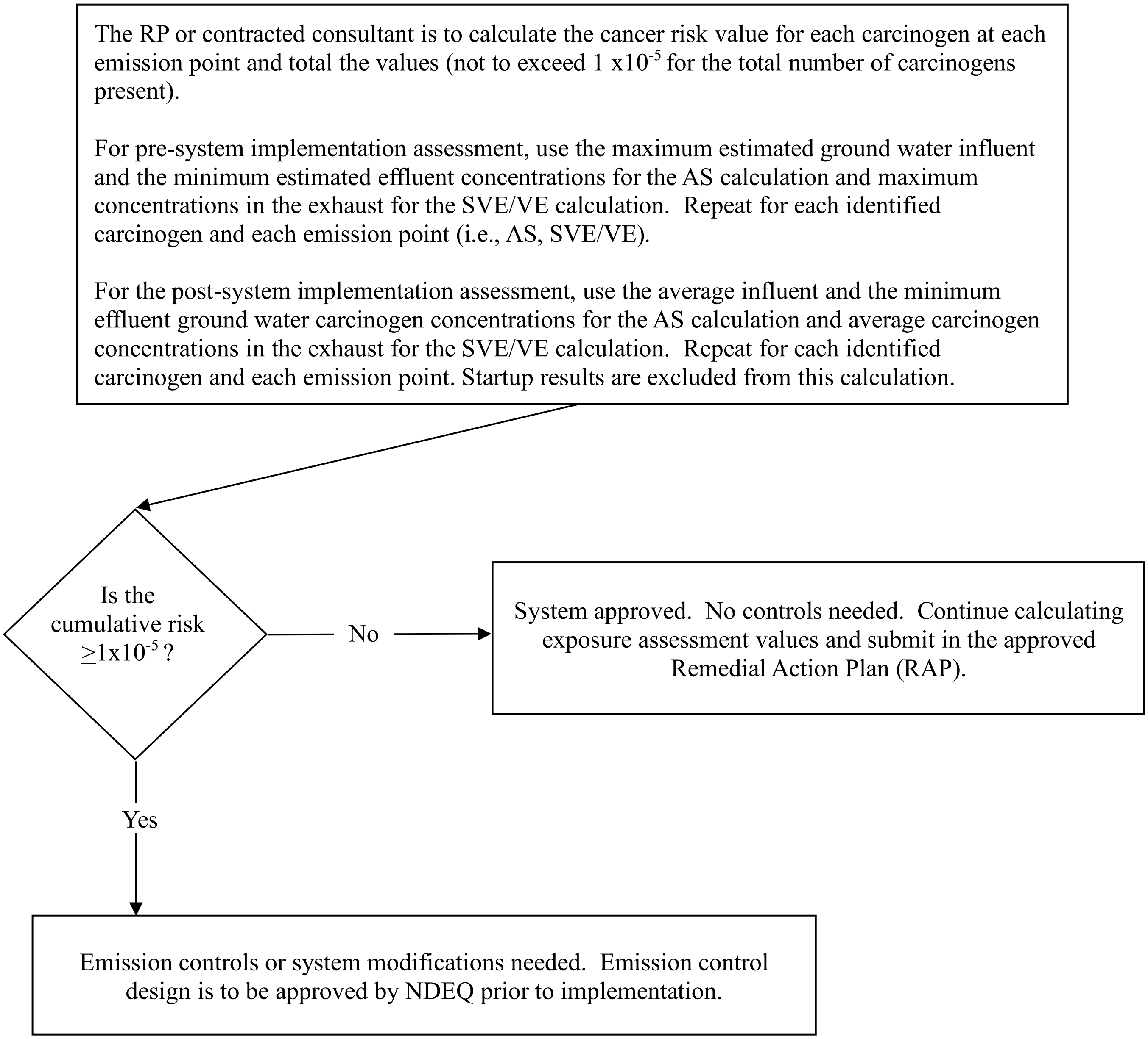
$$T_{tot} = SE_1 + SE_2 + SE_3 + SE_4 + SE_5 + SE_6 + SE_6 + SE_6 + SE_9 + SE_9 + SE_9 + SE_{12}$$

Totaling the second through thirteenth month exposure assessment (rolling twelve months):

$$T_{rtot} = SE_2 + SE_3 + SE_4 + SE_5 + SE_6 + SE_6 + SE_6 + SE_9 + SE_9 + SE_9 + SE_{12} + SE_{12}$$

(NOTE: SE_6 tonnages are substituted for the tonnages in months 7 and 8 and SE_9 tonnages for the tonnages in months 10 and 11. SE_{12} tonnages are substituted for the tonnages in months 13, 14, 15, 16 and 17 and SE_{18} tonnages for the tonnages in months 19, 20, 21, 22, and 23, unless otherwise directed.)

DWEE Air Emissions Guidance For Petroleum Remediation Sites Exposure Assessment Flow Chart



DWEE Air Emissions Guidance for Exposure Assessment at Petroleum Remediation Sites, Continued

Exposure Assessment

The total cancer risk for the site is based on the initial and ongoing Exposure Assessments. The RP or contracted consultant is to calculate the cancer risk for each carcinogen at each emissions point at the site (i.e., each AS emission point and each SVE/VE emission point) and then add the subtotals to provide the total cancer risk for the site.

AS Cancer Risk Assessment Calculations for Each Carcinogen

+

SVE/VE Cancer Risk Assessment Calculations for Each Carcinogen

=

Total Cancer Risk for the Site

Ongoing Exposure Assessment

For the first year, determine the average total carcinogen risk (C_{ave}) by adding the cumulative risk values for each sampling event (SE) and then dividing by the number of months (T_{SE}) since beginning system operation. When emission sampling continues for more than twelve months, then add the most current results with the results of the previous eleven months and divide by 12 to provide the twelve-month rolling average total risk (C_{rave}).

For first twelve months exposure assessment:

$$C_{ave} = \frac{\left(SE_1 + SE_2 + SE_3 + SE_4 + SE_5 + SE_6 + SE_6 + SE_6 + SE_9 + SE_9 + SE_9 + SE_{12}\right)}{T_{SE}}$$

For second through thirteenth month exposure assessment:

$$C_{rave} = \frac{\left(SE_2 + SE_3 + SE_4 + SE_5 + SE_6 + SE_6 + SE_6 + SE_9 + SE_9 + SE_9 + SE_{12} + SE_{12}\right)}{12}$$

(NOTE: SE_6 results are substituted for those in months 7 and 8 and SE_9 results for those in months 10 and 11. SE_{12} results are substituted for those in months 13, 14, 15, 16 and 17 and SE_{18} results for those in months 19, 20, 21, 22, and 23, unless otherwise directed.)

Hazardous Air Pollutant List
Alphabetical By Chemical Name

CAS Number(1)	Chemical Name	Identified in the Following Petroleum Products(2)	Laboratory Analysis(3)		Carcinogen Group(4)	Modeled Concentration(5)	Molecular Weight(6)
			Water	Air			
75-07-0	Acetaldehyde	Weathered Gasoline	8315	TO-15	2B		44.05
60-35-5	Acetamide	NA	NA	NA	2B		59.07
75-05-8	Acetonitrile	NA	8260	TO-15	NA		41.1
98-86-2	Acetophenone	NA	8270	TO-15	NA		120
53-96-3	2-Acetylaminofluorene	NA	8270	NA	NA		223.3
107-02-8	Acrolein	NA	8260 (8315, 1624)	TO-15	NA		56.06
79-06-1	Acrylamide	NA	NA	TO-15	2A		71.1
79-10-7	Acrylic acid	NA	NA	TO-15	NA		72.1
107-13-1	Acrylonitrile	NA	8260 (1624)	TO-15	2B		53.06
107-05-1	Allyl chloride	NA	8260	TO-15	NA		76.5
92-67-1	4-Aminobiphenyl	NA	8270	NA	1		169.2
62-53-3	Aniline	NA	8270	TO-15	NA		93.1
90-04-0	o-Anisidine	NA	8270	NA	2B		123.2
NA	Antimony Compounds	NA	NA	NA	NA		NA
NA	Arsenic Compounds	Used Oil	NA	NA	NA		NA
1332-21-4	Asbestos	NA	NA	NA	1		NA
71-43-2	Benzene	Gasoline, Weathered Gasoline, JP-4	8260 (1624, 602, 624)	TO-15	1	343.49	78.1
92-87-5	Benzidine	NA	8270	NA	1		184.3
106-51-4	p-Benzoquinone	NA	8270	NA	NA		108.1
98-07-7	Benzotrichloride	NA	NA	NA	2A		195.47
100-44-7	Benzyl chloride	NA	8260	TO-15	2A		126.6

Hazardous Air Pollutant List
Alphabetical By Chemical Name

CAS Number(1)	Chemical Name	Identified in the Following Petroleum Products(2)	Laboratory Analysis(3)		Carcinogen Group(4)	Modeled Concentration(5)	Molecular Weight(6)
			Water	Air			
NA	Beryllium Compounds	NA	NA	NA	NA		NA
58-89-9	BHC (Lindane)	NA	8270	NA	NA		290.8
92-52-4	Biphenyl	NA	NA	NA	NA		154.21
542-88-1	Bis (chloromethyl) ether	NA	NA	TO-15	1		114.96
111-44-4	Bis(2-chloroethyl) ether	NA	8270	TO-15	NA		143.01
117-81-7	Bis(2-ethylhexyl) phthalate	NA	8270	NA	NA		390.56
75-25-2	Bromoform	NA	8260 (1624, 624)	TO-15	NA		252.8
74-83-9	Bromomethane	NA	8260 (1624, 624)	TO-15	NA		95
106-99-0	1,3-Butadiene	NA	NA	TO-15	2A		54.09
78-93-3	2-Butanone	NA	8260 (1624)	TO-15	NA		72.1
NA	Cadmium compounds	Used Oil	NA	NA	1		NA
156-62-7	Calcium cyanamide	NA	NA	NA	NA		NA
133-06-2	Captan	NA	8270	NA	NA		300.6
63-25-2	Carbaryl	NA	8270	NA	NA		201.2
75-15-0	Carbon disulfide	NA	8260	TO-15	NA		76.14
56-23-5	Carbon tetrachloride	NA	8260 (1624, 624)	TO-15	2B		153.8
463-58-1	Carbonyl sulfide	NA	NA	TO-15	NA		60.07
120-80-9	Catechol	NA	NA	TO-15	2B		110.1
133-90-4	Chloramben	NA	NA	NA	NA		206.03
57-74-9	Chlordane (NOS)	NA	8270	NA	2B		409.78
7782-50-5	Chlorine	NA	NA	NA	NA		70.91

Hazardous Air Pollutant List
Alphabetical By Chemical Name

CAS Number(1)	Chemical Name	Identified in the Following Petroleum Products(2)	Laboratory Analysis(3)		Carcinogen Group(4)	Modeled Concentration(5)	Molecular Weight(6)
			Water	Air			
79-11-8	Chloroacetic acid	NA	NA	TO-15	NA		94.5
532-27-4	2-Chloroacetophenone	NA	NA	NA	NA		154.6
108-90-7	Chlorobenzene	NA	8260 (1624, 602, 624)	TO-15	NA		112.6
510-15-6	Chlorobenzilate	NA	8270	NA	NA		325.19
75-00-3	Chloroethane	NA	8260 (1624, 624)	TO-15	NA		64.51
67-66-3	Chloroform	NA	8260 (624)	TO-15	2B		119.38
74-87-3	Chloromethane	NA	8260 (1624, 624)	TO-15	NA		50.5
107-30-2	Chloromethyl methyl ether	NA	NA	TO-15	1		80.51
126-99-8	Chloroprene	NA	8260	TO-15	2B		88.5
NA	Chromium Compounds	Used Oil	NA	NA	NA		NA
NA	Cobalt Compounds	NA	NA	NA	2B		NA
NA	Coke Oven Emissions	NA	NA	NA	NA		NA
1319-77-3	Cresols/Cresylic acid (isomers and mixture)	NA	NA	TO-15	NA		108.2
NA	Cyanide Compounds	NA	NA	NA	NA		NA
94-75-7	2,4-D salts esters(2,4-Dichlorophenoxyacetic acid)	NA	NA	NA	NA		NA
95-80-7	2,4-Diaminotoluene	NA	8270	NA	2B		122
334-88-3	Diazomethane	NA	NA	TO-15	NA		42.1
132-64-9	Dibenzofuran	NA	8270	NA	NA		168.19
96-12-8	1,2-Dibromo-3-chloropropane	NA	8011, 8260 (8270)	TO-15	2B		236.4
106-93-4	1,2-Dibromoethane	Fuel Additive	8011, 8260	TO-15	2A		187.86

Hazardous Air Pollutant List
Alphabetical By Chemical Name

CAS Number[1]	Chemical Name	Identified in the Following Petroleum Products[2]	Laboratory Analysis[3]		Carcinogen Group[4]	Modeled Concentration[5]	Molecular Weight[6]
			Water	Air			
106-46-7	1,4-Dichlorobenzene	NA	8260 (8270, 602, 624)	TO-15	2B		147
91-94-1	3,3’-Dichlorobenzidine	NA	8270	NA	2B		253.1
107-06-2	1,2-Dichloroethane	Fuel Additive	8260 (1624, 624)	TO-15	2B		99
75-34-3	1,1-Dichloroethane	NA	8260 (1624), 624	TO-15	NA		99
75-35-4	1,1-Dichloroethene	NA	8260 (1624, 624)	TO-15	NA		99
78-87-5	1,2-Dichloropropane	NA	8260 (1624, 624)	TO-15	NA		112
542-75-6	1,3-Dichloropropene	NA	NA	TO-15	2B		111
62-73-7	Dichlorovos	NA	8270	NA	2B		221
111-42-2	Diethanolamine	NA	NA	NA	NA		105.2
64-67-5	Diethyl sulfate	NA	8270	TO-15	2A		154.18
119-90-4	3,3’-Dimethoxybenzidine	NA	8270	NA	2B		244.29
79-44-7	Dimethyl carbamoyl chloride	NA	NA	TO-15	2A		107.6
68-12-2	Dimethyl formamide	NA	NA	TO-15	NA		73.1
57-14-7	1,1-Dimethyl hydrazine	NA	NA	TO-15	2B		60.1
131-11-3	Dimethyl phthalate	NA	8270	NA	NA		194.2
77-78-1	Dimethyl Sulfate	NA	NA	TO-15	2A		126.1
60-11-7	Dimethylaminoazobenzene	NA	8270	NA	2B		225.3
121-69-7	N,N-Dimethylaniline	NA	NA	TO-15	NA		121.2
119-93-7	3,3’-Dimethylbenzidine	NA	8270	NA	2B		212.29
84-74-2	Di-n-butyl phthalate	NA	8270	NA	NA		278.35
534-52-1	4,6-Dinitro-2-methylphenol	NA	8270	NA	NA		198.13

Hazardous Air Pollutant List
Alphabetical By Chemical Name

CAS Number[1]	Chemical Name	Identified in the Following Petroleum Products[2]	Laboratory Analysis[3]		Carcinogen Group[4]	Modeled Concentration[5]	Molecular Weight[6]
			Water	Air			
51-28-5	2,4-Dinitrophenol	NA	8270	NA	NA		184
121-14-2	2,4-Dinitrotoluene	NA	8270	NA	2B		182.2
123-91-1	1,4-Dioxane	NA	8260 (1624)	TO-15	2B		88.1
122-66-7	1,2-Diphenylhydrazine	NA	8270	NA	NA		184.24
106-89-8	Epichlorohydrin	NA	8260	TO-15	2A		92.53
106-88-7	1,2-Epoxybutane	NA	NA	TO-15	2B		72.12
140-88-5	Ethyl acrylate	NA	NA	TO-15	2B		100.1
51-79-6	Ethyl carbamate	NA	8270	TO-15	2B		89.09
100-41-4	Ethyl benzene	Gasoline, Weathered Gasoline, JP-4, Fuel Oil Number 2	8260 (1624, 602, 624)	TO-15	2B		106.2
107-21-1	Ethylene glycol	NA	NA	NA	NA		62.1
151-56-4	Ethylene imine (Aziridine)	NA	NA	TO-15	2B		43.07
75-21-8	Ethylene oxide	NA	8260	TO-15	1		44.05
96-45-7	Ethylene thiourea	NA	NA	NA	NA		102.2
NA	Fine Mineral Fibers	NA	NA	NA	NA		NA
50-00-0	Formaldehyde	Weathered Gasoline	8315	TO-15	1		30.03
NA	Glycol Ethers	NA	NA	NA	NA		NA
76-44-8	Heptachlor	NA	8270	NA	2B		373.4
118-74-1	Hexachlorobenzene	NA	8270	NA	2B		284.78
87-68-3	Hexachlorobutadiene	NA	8260 (8270)	TO-15	NA		260.7
77-47-4	Hexachlorocyclopentadiene	NA	8270	NA	NA		272.8

Hazardous Air Pollutant List
Alphabetical By Chemical Name

CAS Number[1]	Chemical Name	Identified in the Following Petroleum Products[2]	Laboratory Analysis[3]		Carcinogen Group[4]	Modeled Concentration[5]	Molecular Weight[6]
			Water	Air			
67-72-1	Hexachloroethane	NA	8260 (8270)	TO-15	2B		236.7
822-06-0	Hexamethylene,-l,6-diisocyanate	NA	NA	NA	NA		168.2
680-31-9	Hexamethylphosphoramide	NA	8270	NA	2B		179.2
110-54-3	Hexane	Gasoline, Weathered Gasoline, JP-4	NA	TO-15	NA		86.2
302-01-2	Hydrazine	NA	NA	NA	2B		32.05
7647-01-0	Hydrochloric acid	NA	NA	NA	NA		36.46
7664-39-3	Hydrogen fluoride	NA	NA	NA	NA		20.01
123-31-9	Hydroquinone	NA	8270	NA	NA		110.1
74-88-4	Iodomethane	NA	8260	TO-15	NA		141.94
78-59-1	Isophorone	NA	8270	TO-15	NA		138.2
98-82-8	Isopropylbenzene	NA	8260	TO-15	NA		120.19
NA	Lead Compounds	Used Oil	NA	NA	2A		NA
108-31-6	Maleic anhydride	NA	8270	NA	NA		98.06
NA	Manganese Compounds	NA	NA	NA	NA		NA
NA	Mercury Compounds	NA	NA	NA	NA		NA
67-56-1	Methanol	Fuel Additive	8260	TO-15	NA		32.1
72-43-5	Methoxychlor	NA	8270	NA	NA		345.7
624-83-9	Methyl isocyanate	NA	NA	TO-15	NA		57.05
80-62-6	Methyl methacrylate	NA	8260	TO-15	NA		100.12
1634-04-4	Methyl tert-butyl ether	Fuel Additive	NA	TO-15	NA		88.15
108-10-1	4-Methyl-2-pentanone	NA	8260	TO-15	NA		100

Hazardous Air Pollutant List
Alphabetical By Chemical Name

CAS Number[(1)]	Chemical Name	Identified in the Following Petroleum Products[(2)]	Laboratory Analysis[(3)]		Carcinogen Group[(4)]	Modeled Concentration[(5)]	Molecular Weight[(6)]
			Water	Air			
75-09-2	Methylene chloride	NA	8260 (1624, 624)	TO-15	2B		84.9
101-68-8	Methylene diphenyl diisocyanate	NA	NA	NA	NA		250
101-14-4	4,4’-Methylenebis (2-chloroaniline)	NA	8270	NA	2A		267.2
101-77-9	.4,4’-Methylenedianiline	NA	NA	NA	2B		198.3
60-34-4	Methylhydrazine	NA	NA	TO-15	NA		46.1
106-44-5	4-Methylphenol	NA	8270	NA	NA		108.2
108-39-4	3-Methylphenol	NA	8270	NA	NA		108.2
95-48-7	2-Methylphenol	Fuel Oil Number 2	8270	TO-15	NA		108.2
91-20-3	Naphthalene	Gasoline, Weathered Gasoline, Fuel Oil Number 2	8260 (8270)	NA	2B		128.2
NA	Nickel compounds	NA	NA	NA	1		NA
98-95-3	Nitrobenzene	NA	8260 (8270)	TO-15	2B		123.1
92-93-3	4-Nitrobiphenyl	NA	8270	NA	NA		199.2
100-02-7	4-Nitrophenol	NA	8270	NA	NA		184
79-46-9	2-Nitropropane	NA	8260	TO-15	2B		89.1
684-93-5	N-Nitroso-N-methylurea	NA	NA	TO-15	2A		103.1
62-75-9	N-Nitrosodimethylamine	NA	8270	TO-15	2A		74.1
59-89-2	N-Nitrosomorpholine	NA	8270	TO-15	2B		NA
56-38-2	Parathion	NA	8270	NA	NA		291.3
82-68-8	Pentachloronitrobenzene	NA	8270	NA	NA		295.34
87-86-5	Pentachlorophenol	NA	8270	NA	NA		266.4

Hazardous Air Pollutant List
Alphabetical By Chemical Name

CAS Number[(1)]	Chemical Name	Identified in the Following Petroleum Products[(2)]	Laboratory Analysis[(3)]		Carcinogen Group[(4)]	Modeled Concentration[(5)]	Molecular Weight[(6)]
			Water	Air			
108-95-2	Phenol	Fuel Oil Number 2	8270	TO-15	NA		94.1
106-50-3	1,4-Phenylenediamine	NA	8270	NA	NA		108.2
75-44-5	Phosgene	NA	NA	TO-15	NA		98.92
7803-51-2	Phosphine	NA	NA	NA	NA		34
7723-14-0	Phosphorous	NA	NA	NA	NA		124
85-44-9	Phthalic anhydride	NA	8270	NA	NA		148.12
1336-36-3	Polychlorinated biphenyls (Aroclors)	NA	NA	NA	2A		NA
NA	Polycyclic Organic Matter (POM)	NA	NA	NA	NA		NA
123-38-6	Propanal	NA	8315	TO-15	NA		58
1120-71-4	1,3-Propane sultone	NA	NA	TO-15	2B		122.2
57-57-8	b-Propiolactone	NA	8260	TO-15	2B		72.1
114-26-1	Propoxur (Baygone)	NA	NA	NA	NA		209.3
115-07-1	Propylene	NA	NA	NA	NA		42.08
75-56-9	Propylene oxide	NA	NA	TO-15	2B		58.08
75-55-8	1,2-Propylenimine (2-Methyl aziridine)	NA	NA	TO-15	2B		57.1
91-22-5	Quinoline	Fuel Oil Number 2	NA	NA	NA		129.16
NA	Radionuclides (including Radon)	NA	NA	NA	NA		NA
NA	Selenium Compounds	NA	NA	NA	NA		NA
100-42-5	Styrene	NA	8260	TO-15	2B		104.2
96-09-3	Styrene oxide	NA	NA	TO-15	2A		120.2
1746-01-6	2,3,7,8-Tetrachlorodibenzo-p-dioxin	NA	NA	NA	1		321.96

Hazardous Air Pollutant List
Alphabetical By Chemical Name

CAS Number(1)	Chemical Name	Identified in the Following Petroleum Products(2)	Laboratory Analysis(3)		Carcinogen Group(4)	Modeled Concentration(5)	Molecular Weight(6)
			Water	Air			
79-34-5	1,1,2,2-Tetrachloroethane	NA	8260 (1624, 624)	TO-15	NA		167.9
127-18-4	Tetrachloroethene (Perc)	NA	8260 (1624, 624)	TO-15	2A		165.8
7550-45-0	Titanium tetrachloride	NA	NA	NA	NA		189.69
108-88-3	Toluene	Gasoline, Weathered Gasoline, JP-4	8260 (1624, 602, 624)	TO-15	NA		92.1
584-84-9	Toluene diisocyanate	NA	8270	NA	NA		174.16
95-53-4	o-Toluidine	NA	8260 (8270)	NA	2A		107.2
8001-35-2	Toxaphene	NA	8270	NA	2B		413.8
120-82-1	1,2,4-Trichlorobenzene	NA	8260 (8270)	TO-15	NA		181.4
71-55-6	1,1,1-Trichloroethane (1,1,1-TCA)	NA	8260 (1624, 624)	TO-15	NA		133.4
79-00-5	1,1,2-Trichloroethane	NA	8260 (1624, 624)	TO-15	NA		133.4
79-01-6	Trichloroethene (TCE)	NA	8260 (1624, 624)	TO-15	2A		133.4
88-06-2	2,4,6-Trichlorophenol	NA	8270	NA	NA		197.46
95-95-4	2,4,5-Trichlorophenol	NA	8270	NA	NA		197.46
121-44-8	Triethylamine	NA	NA	TO-15	NA		101.2
1582-09-8	Trifluralin	NA	8270	NA	NA		335.28
540-84-1	2,2,4-Trimethylpentane	Gasoline, Weathered Gasoline	NA	TO-15	NA		114.23
108-05-4	Vinyl acetate	NA	8260	TO-15	2B		86.09
593-60-2	Vinyl bromide (bromoethene)	NA	NA	TO-15	2A		107
75-01-4	Vinyl chloride	NA	8260 (1624, 624)	TO-15	1		62.05
95-47-6	o-Xylene	Weathered Gasoline	8260	TO-15	NA		106.2
106-42-3	p-Xylene	Gasoline, Weathered Gasoline	8260	TO-15	NA		106.2

Hazardous Air Pollutant List
Alphabetical By Chemical Name

CAS Number[1]	Chemical Name	Identified in the Following Petroleum Products[2]	Laboratory Analysis[3]		Carcinogen Group[4]	Modeled Concentration[5]	Molecular Weight[6]
			Water	Air			
108-38-3	m-Xylene	Gasoline, Weathered Gasoline, JP-4, Fuel Oil Number 2	8260	TO-15	NA		106.2
1330-20-7	Xylenes (isomers and mixture)	NA	NA	TO-15	NA		106.2

(1) CAS stands for Chemical Abstract Service
(2) Petroleum products information from: February 2004 NDEQ RBCA at Petroleum Release Sites; Spring 1990 GWMR; June 1995 Journal of the Air and Waste Management Association, and EPA Oil Specification Standards
(3) The latest version of EPA Method 8260 is the preferred analysis method for identifying the pollutants present in the ground water. Alternate analysis methods listed in parentheses should be used only after consultation with the PRS PM or if needed in order to meet the requirements of an NPDES discharge permit.
8011: EPA Method 8011: 1,2-Dibromoethane And 1,2-Dibromo-3-Chloropropane By Microextraction And Gas Chromatography
8270: EPA Method 8270: Semivolatile Organic Compounds By GC/MS
8315: EPA Method 8315: Determination of Carbonyl Compounds by High Performance Liquid Chromatography (HPLC)
602: EPA Method 602 Purgeable Aromatics
624: EPA Method 624: Purgeables
162: EPA Method 1624 Revision B: Volatile Organic Compounds by Isotope Dilution GC/MS
TO-3: EPA Method TO-3: Method for the Determination of Volatile Organic Compounds in Ambient Air Using Cryogenic Pre-Concentration Techniques and Gas Chromatography With Flame Ionization and Electron Capture Detection
TO-15: EPA Compendium Method TO-15: Determination of VOCs in Air Collected in Specially-Prepared Canisters and Analyzed by GC/MS
(4) Carcinogen Group is based on the International Agency for Research on Cancer website (http://www-cie.iarc.fr/), July 2005:
1 stands for Group 1: The agent (mixture) is carcinogenic to humans. The exposure circumstance entails exposures that are carcinogenic to humans.
2A stands for Group 2A: The agent (mixture) is probably carcinogenic to humans. The exposure circumstance entails exposures that are probably carcinogenic to humans.
2B stands for Group 2B: The agent (mixture) is possibly carcinogenic to humans. The exposure circumstance entails exposures that are possibly carcinogenic to humans.
NA stands for not applicable (i.e., not listed as a group 1, 2A or 2B agent)
(5) Modeled Concentration is the Modeled Average Annual Ambient Chemical Concentration provided by DWEE. Units are in (milligrams per meter cubed) per (gram per second)
(6) Molecular Weight is in grams per gram-mole or pounds per pound-mole

Unit Conversion Table

To convert from:	To:	Multiply by:
Concentration of a Chemical in Air		
mg/m^3	ppb	24,450/{molecular weight of chemical (g/gmole)}
	ppm	24.45/{molecular weight of chemical (g/gmole)}
	ug/m^3	1,000
ppb	mg/m^3	molecular weight of chemical (g/gmole)/24,450
	ppm	0.001
	ug/m^3	molecular weight of chemical (g/gmole)/24.45
ppm	mg/m^3	molecular weight of chemical (g/gmole)/24.45
	ppb	1,000
	ug/m^3	1,000*molecular weight of chemical (g/gmole)/24.45
ug/m^3	mg/m^3	0.001
	ppb	24.45/{molecular weight of chemical (g/gmole)}
	ppm	0.02445/{molecular weight of chemical (g/gmole)}
Concentration of a Chemical in a Liquid		
mg/l	ppb	1,000/{Liquid specific gravity or density (g/ml)}
	ppm	1/{Liquid specific gravity or density (g/ml)}
	ug/l	1,000
ppb	mg/l	{Liquid specific gravity or density (g/ml)} / 1,000
	ppm	0.001
	ug/l	Liquid specific gravity or density (g/ml)
ppm	mg/l	Liquid specific gravity or density (g/ml)
	ppb	1,000
	ug/l	1,000 * liquid specific gravity or density (g/ml)
ug/l	mg/l	0.001
	ppm	1/{1,000*[Liquid specific gravity or density (g/ml)]}
	ppb	1/{Liquid specific gravity or density (g/ml)}

density of water is 1 gram per milliliter
g/gmole = grams per gram mole
g/ml = grams per milliliter
mg/l = milligrams per liter
mg/m^3 = milligrams per cubic meter
molecular weights for Hazardous Air Pollutants are included in Appendix B
ppm = parts per million
ppb = parts per billion
specific gravity = density of a liquid divided by the density of water (1 for water)
ug/l = micrograms per liter
ug/m^3 = micrograms per cubic meter

Unit Conversion Table

To convert from:	To:	Multiply by:
Flow (Including conversions to velocity)		
cfm	ft/min	1/{3.14*(radius of pipe in feet)^2}
	ft/sec	1/{188*(radius of pipe in feet)^2}
	gpm	7.48
	l/min	28.3
	m/sec	1/{618*(radius of pipe in feet)^2}
gpm	cfm	0.134
	ft/min	1/{23.5*(radius of pipe in feet)^2}
	ft/sec	1/{1,410*(radius of pipe in feet)^2}
	l/min	3.785
	m/sec	1/{4,626*(radius of pipe in feet)^2}
Time		
hr	min	60
	sec	3,600
	years	1.14*10^{-4} or 1/8,760
min	hr	0.0167 or 1/60
	sec	60
	years	1.90*10^{-6} or 1/525,600
sec	hr	2.78*10^{-4} or 1/3600
	min	0.0167 or 1/60
	years	3.17*10^{-8} or 1/31,536,000
years	hr	8,760
	min	525,600
	sec	31,536,000

cfm = cubic feet per minute
ft/min = feet per minute
ft/sec = feet per second
gpm = gallons per minute
hr = hours
l/min = liters per minute
min = minutes
m/s = meters per second
sec = seconds

Unit Conversion Table

To convert from:	To:	Multiply by:
Velocity (including conversion to flow)		
ft/min	cfm	3.14*(radius of pipe in feet)^2
	ft/sec	0.0167 or 1/60
	gpm	23.5*(radius of pipe in feet)^2
	m/sec	$5.08*10^{-3}$
ft/sec	cfm	188*(radius of pipe in feet)^2
	ft/min	60
	gpm	1,409*(radius of pipe in feet)^2
	m/sec	0.3048
m/sec	cfm	197*(radius of pipe in feet)^2
	ft/min	197
	ft/sec	3.28
	gpm	1,473*(radius of pipe in feet)^2
Weight		
g	kg	0.001 or 1/1,000
	lb	0.0022 or 2.2/1,000
	mg	1,000
	tons	$1.1*10^{-6}$ or 2.2/2,000,000
	ug	1,000,000
kg	g	1,000
	lb	2.2
	mg	1,000,000
	tons	0.0011 or 2.2/2,000
	ug	$1*10^9$
lbs	g	455 or 1,000/2.2
	kg	0.455 or 1/2.2
	mg	455,000 or 1,000,000/2.2
	tons	$5*10^{-4}$ or 1/2,000
	ug	$4.55*10^8$

cfm = cubic feet per minute
ft/min = feet per minute
ft/sec = feet per second
g = grams
gpm = gallons per minute
kg = kilograms
lb = pounds
l/min = liters per minute
mg = milligrams
m/s = meters per second
ug = micrograms

Unit Conversion Table

To convert from:	To:	Multiply by:
Weight		
mg	g	0.001 or 1/1,000
	kg	$1*10^{-6}$
	lb	$2.2*10^{-6}$
	tons	$1.1*10^{-9}$
	ug	1,000
tons	g	909,000
	kg	909
	lb	2,000
	mg	$9.09*10^{8}$
	ug	$9.09*10^{11}$
ug	g	$1*10^{-6}$
	kg	$1*10^{-9}$
	lb	$2.2*10^{-9}$
	mg	0.001
	tons	$1.1*10^{-12}$

g = grams
kg = kilograms
lb = pounds
mg = milligrams
ug = micrograms

Sample Calculation for a Concentration of a Chemical in Water

A part per million (ppm) concentration of a chemical in water is coincidentally equivalent to a milligram of chemical per liter of water since the density of water is equal to one gram per milliliter. The ppm and ppb concentrations are by weight unless noted otherwise (i.e., with a subscript "v": ppm_v).

The following is a sample calculation for converting parts per million to milligrams per liter:

$$1\,\text{ppm} = \frac{1\,\text{part chemical}}{1\,\text{million parts water}} = \frac{1\,\text{gram chemical}}{1{,}000{,}000\,\text{grams water}} = \frac{(1\,\text{gram chemical}) * \left(\dfrac{1000\,\text{milligrams}}{1\,\text{gram}}\right)}{(1{,}000{,}000\,\text{grams water}) / \left(\dfrac{1\,\text{gram water}}{1\,\text{milliliter water}}\right)} =$$

$$\frac{1{,}000\,\text{milligrams chemical}}{1{,}000{,}000\,\text{milliliters water}} = \frac{1{,}000\,\text{milligrams chemical}}{(1{,}000{,}000\,\text{milliliters water}) * \left(\dfrac{1\,\text{liter}}{1{,}000\,\text{milliliters}}\right)} = \frac{1\,\text{milligram chemical}}{1\,\text{liter water}} = 1\,\frac{\text{mg}}{\text{L}}$$

Sample Calculation for a Concentration of a Chemical in Air

A ppm or ppb chemical concentration in air is typically by volume, not by weight (i.e., unless the units are presented with a subscript "w": ppm_w). Therefore, converting ppm and ppb concentrations in air to a weight per unit volume concentration (e.g., mg/m^3 or ug/m^3) requires a conversion of the chemical volume to a chemical weight.

A ppm concentration in air may be written as follows:

$$C_{\text{ppm}} = X = \frac{X\,\text{parts chemical}}{1\,\text{million parts air}} = \frac{X\,\text{liters chemical}}{1{,}000{,}000\,\text{liters air}} = \frac{\left(\dfrac{X\,\text{liters chemical}}{1{,}000{,}000\,\text{liters air}}\right)}{1\,\text{ppm}}$$

The volume occupied by a liter (i.e., or other volume unit) of the chemical is calculated using the Ideal Gas Law, which assumes the chemical is present at low concentrations and at low pressure (i.e., limited interactions between the chemical and air approaches ideal conditions).

$$P * V = n * R * T$$

Where:

P = Pressure
V = Volume of chemical
n = Number of moles of the chemical
R = Ideal gas law constant
T = Absolute Temperature

The units may vary (i.e., as long as the appropriate ideal gas law constant is used so that the units cancel), but the temperature is to be in Rankine or Kelvin (i.e., absolute temperature).

The Ideal Gas Law equation may be manipulated so that the equation can be solved for the number of moles of the chemical:

$$P * V = n * R * T \Rightarrow n = \frac{P * V}{R * T}$$

Multiplying the number of moles of a chemical by the molecular weight of the chemical yields a formula for the weight of the chemical based on the volume occupied by the chemical:

$$w = MW * n = MW * \frac{P * V}{R * T}$$

Where:

W = weight of chemical in grams
MW = molecular weight of chemical in grams per gram mole

Molecular weights for Hazardous Air Pollutants are included in Appendix B. Chemical groups, such as total petroleum hydrocarbons as gasoline, do not have a single molecular weight, but an average molecular weight may be used.

Substituting the variables with the following:

- A pressure of one atmosphere,
- An unknown volume of chemical X (i.e., X would be the concentration of the chemical in ppm),

- The Ideal Gas Law constant (0.08205 for the units used), and
- A temperature of 293.15 Kelvin (i.e., 20 degrees Celsius or 68 degrees Fahrenheit; used to represent typical conditions).

The substitution yields:

$$W = \left(\text{MW}\frac{\text{grams chemical}}{\text{gram moles chemical}}\right) * \frac{(1\text{ atmosphere}) * (\text{X liters of chemical})}{\left(0.08205\ \frac{\text{atmospheres} * \text{liters}}{\text{gram moles Kelvin}}\right) * (293.15\text{ Kelvin})}$$

$$= \frac{\left(\text{MW}\ \frac{\text{grams chemical}}{\text{gram moles chemical}}\right)}{\left(24.05\frac{\text{liters of chemical}}{\text{gram moles chemical}}\right)} * (\text{X liters of chemical})$$

If the molecular weight (MW) divided by 24.45 is multiplied by the formula for the concentration in parts per million, the following equation results:

$$\text{C}_{\text{ppm}} * \frac{\left(\text{MW}\ \frac{\text{grams chemical}}{\text{gram moles chemical}}\right)}{\left(24.45\frac{\text{liters of chemical}}{\text{gram moles chemical}}\right)} = \frac{\left(\frac{\text{X liters of chemical}}{1{,}000{,}000\text{ liters air}}\right)}{1\text{ ppm}} * \frac{\left(\text{MW}\ \frac{\text{grams chemical}}{\text{gram moles chemical}}\right)}{\left(24.45\frac{\text{liters of chemical}}{\text{gram moles chemical}}\right)}$$

Simplifying this equation yields:

$$\text{C}_{\text{ppm}} * \frac{\left(\text{MW}\ \frac{\text{grams chemical}}{\text{gram moles chemical}}\right)}{\left(24.45\frac{\text{liters of chemical}}{\text{gram moles chemical}}\right)} = \frac{\text{X} * \text{MW grams chemical}}{24{,}450{,}000\text{ liters air} * \text{ppm}}$$

Converting the units to milligrams per cubic meter yields:

$$C_{\text{ppm}} * \frac{\left(\text{MW}\,\dfrac{\text{grams chemical}}{\text{gram moles chemical}}\right)}{\left(24.45\,\dfrac{\text{liters of chemical}}{\text{gram moles chemical}}\right)} = \frac{\text{X} * \text{MW grams chemical}}{24{,}450{,}000\ \text{liters air} * \text{ppm}} \frac{\left(\dfrac{1{,}000\ \text{milligrams}}{1\ \text{gram}}\right)}{\left(\dfrac{1\ \text{cubic meter}}{1{,}000\ \text{liters}}\right)} = \frac{\text{X} * \text{MW milligrams chemical}}{24.45\ \text{cubic meters air} * \text{ppm}}$$

$$C_{\text{ppm}} * \frac{\left(\text{MW}\,\dfrac{\text{grams chemical}}{\text{gram moles chemical}}\right)}{\left(24.45\,\dfrac{\text{liters of chemical}}{\text{gram moles chemical}}\right)} = \frac{\text{X} * \text{MW milligrams chemical}}{24.45\ \text{cubic meters air} * \text{ppm}} = C_{\frac{\text{mg}}{\text{m}^3}}$$

An example conversion for a Tedlar bag sample:

- Concentration of benzene = 0.3 parts per million
- Molecular weight of benzene (from Appendix B) = 78.1 grams per gram-mole

Therefore, the concentration of benzene in milligrams per cubic meter of air is:

$$C_{\frac{\text{mg}}{\text{m}^3}} = C_{\text{ppm}} * \frac{\left(\text{MW}\,\dfrac{\text{milligrams chemical}}{\text{gram moles chemical}}\right)}{\left(24.45\,\dfrac{\text{cubic meters air}}{\text{gram moles chemical}}\right)} = 0.3\ \text{ppm} * \frac{\left(78.1\,\dfrac{\text{milligrams chemical}}{\text{gram moles chemical}}\right)}{\left(24.45\,\dfrac{\text{cubic meters air}}{\text{gram moles chemical}}\right)} = 0.958\,\frac{\text{milligrams}}{\text{cubic meter}}$$